2024 Soils and Land Use

STUDY RESOURCES

2024 NCF-ENVIROTHON
NEW YORK

Soils and Land Use

Table of Contents

NCF-Envirothon 2024 New York

Soils and Land Use Study Resources

Key Topic #1: General Physical Properties of Soil and Soil Formation

1. Describe the five soil forming factors, and how they influence soil properties.
2. Identify and describe soil characteristics (such as texture, structure, and color).
3. Identify and understand physical features of soil profiles and use this information to interpret soil properties and limitations.
4. Identify the different particle sizes in a soil (sand, silt, and clay) and describe how their proportions influence soil properties.
5. Describe how different soil attributes (mineral composition, organic matter, particle size, etcetera) affect the properties of a soil.

Study Resources

Resource Title	Source	Located on
Urban Soils Primer: Chapter 2: Basic Soil Properties	*USDA NRCS, Scheyer, J.M., and Hipple, K.W., 2005*	page 4-13
The Color of Soil	*USDA, Natural Resources Conservation Service, 2023*	page 14-18
Urban Soils Primer-Glossary	*USDA NRCS, Scheyer, J.M., and Hipple K.W., 2005*	page 19-22
Determining Soil Texture by Feel	*Ritchey, McGrath, Gehring, NRCS AGR-217 UK, 2015*	page 23-25

Study Resources begin on the next page! ➡

Chapter 2: Basic Soil Properties

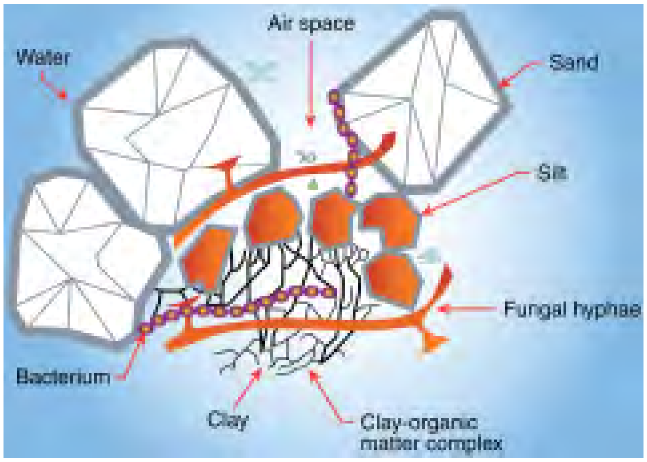


Figure 2.1

Soils in an urban area may share some properties with soils in forests, pastures, cotton fields, or even other urban areas. There are large differences in soils as they naturally occur in forests, farmed fields, and grazing land areas, and these differences are changed when an area is converted to an urban area. Soil scientists have developed conventions and language to communicate among themselves. It is important that we share scientific information with everyone, not just other scientists and professionals. Soil properties, such as soil texture and structure, particle-size distribution, soil reaction, and bulk density, help us to understand and predict how soils react and respond to different uses. Construction activities, compaction, and surface sealing dramatically change soil properties and can sometimes result in a reduced ability to perform the critical functions or activities of natural soil.

Topics in this chapter:

- **Soil variation**
- **Soil components**
- **Soil-forming processes**
- **Soil horizons**
- **Measuring and monitoring soil properties**

Soil Variation

What is soil and why is soil important to each of us? Traditionally, soil is defined as a dynamic natural body that is made up solids, liquids, and gases, occurs on the earth's surface, contains living matter, and supports or is capable of supporting plants. Bockheim (1974) defines urban soil as "soil material having a non-agricultural, man-made surface layer more than 50 cm (20 inches) thick that has been produced by mixing, filling, or by contamination of land surface in urban and suburban areas." In some important ways, soils of urban areas differ from soils of other areas.

Differences in urban soils have been observed and recorded by scientists, engineers, equipment operators, and construction workers for a long time. Even within urban areas, there is a multiplicity of soil conditions, ranging from "natural" soils that are relatively undisturbed to soils in which the natural materials have been mixed or truncated, to soils that formed in added materials, or fill, of varying thickness. Each of these areas, in turn, can be subject to different types of use and management, which can further affect their soil properties. Soils in urban areas can be divided into two general types: *natural* soils, which formed in material naturally deposited by water, wind, or ice or in material weathered from the underlying bedrock, and *anthropogenic* soils, which formed in human-deposited material, or fill (table 2.1). Anthropogenic soils are almost anywhere in the urban environment. The purpose of adding fill to an area may be to alleviate undesirable soil properties or to modify the urban landscape for specific activities.

Table 2.1: Examples of Fill Material in Urban Soils

- Natural soil materials that have been moved around by humans
- Construction debris
- Materials dredged from waterways
- Coal ash
- Municipal solid waste
- A combination of any or all of the above

Characteristics of soil in any urban area depend on many things. They depend on how deep the site has been excavated during construction and if new materials were brought in and mixed with the original soil materials. They depend on the properties of the original natural soil and the past uses of the site. Many times topsoil is removed from the site prior to construction and may or may not be returned to the site. After excavation, subsoil may be placed as fill over topsoil. Changing the order of the soil layers or mixing the topsoil and subsoil can alter soil properties. These variables make predicting soil behavior difficult in urban areas.

Soil Components

All soil is made up of air, water, numerous kinds of living and/or dead organisms (organic matter), and mineral matter (sand, silt, and clay). In the urban arena, it includes many manmade materials. The amount of each of these soil components varies from one place to another in the world or from one kind of soil to another. Soil components can vary dramatically within distances of only a few feet on the same landscape.

Soil composition can be dramatically changed by pedestrian or vehicular traffic, especially when the soil is wet. The soil components most easily changed are the amounts of soil air and water. Imagine the change in soil composition at construction sites after large trucks and heavy construction equipment drive over a soil and compact it. Imagine people walking and playing on wet soils in city parks and recreation areas or yards. Note the differences in percent of soil air and soil water in figures 2.2 and 2.3. Figure 2.2 illustrates the general composition of a natural soil. Figure 2.3 illustrates the general composition of a soil that has been compacted by heavy traffic. As soil particles are squeezed together, pores for air and water are reduced in size and number (figure 2.4). The reduced pore space changes the way a soil handles water intake and water movement throughout its layers, or horizons.

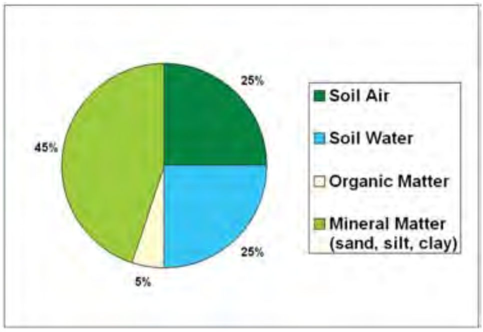


Figure 2.2: Composition of a natural soil, by weight.

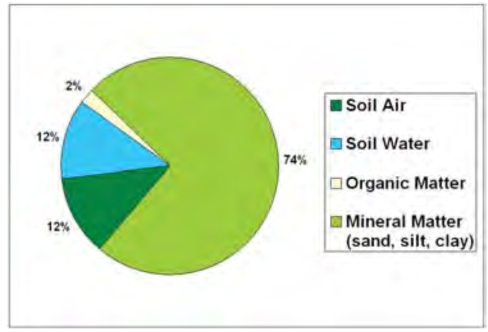


Figure 2.3: Composition of a compacted soil, by weight.

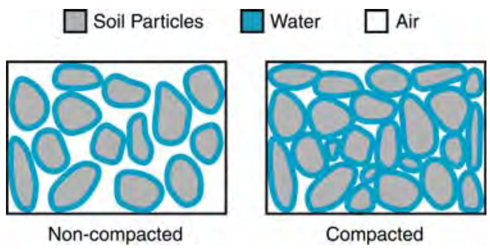


Figure 2.4: Soil pore space.

Soil-Forming Processes

Soils form through a group of processes no matter where they are located or what they are used for. All soils form because of four processes operating along with five basic soil-forming factors. The four processes that operate on soil material are additions, transformations, translocations, and losses (figure 2.5). We are able to map, classify, and interpret soil because a given set of environmental factors produces a predictable kind of soil.

The soil-forming factors are parent material, climate, living and dead organisms, time, and landscape position. When all soil-forming factors are similar, a similar soil is produced. If we change one or more of the soil-forming factors significantly, then a different soil is produced.

Additions to soil generally include organic matter, fertilizer, pollutants, and deposits of soil material. All of the additions change a soil and how it functions. In urban areas new soil material is sometimes added on top of an existing soil. If thick enough, the new layer or layers can change the way the soil develops. When a layer of concrete or asphalt is added to the top of a soil in areas where streets, parking lots, or driveways are built, additions to the soil are suddenly altered, restricted, or even stopped.

Transformations are changes that take place within a soil. In figure 2.5, transformations are illustrated by the letters x and y and the arrows that connect them. During transformation processes, material does not leave the soil but is simply changed from one form to another or from one compound to another. Micro-organisms and earthworms play an important role in soil transformations. Earthworms eat soil and plant materials and transform them into organic material that provides food for plants and other organisms. Chemical weathering changes parent material, such as rocks and sand grains, and creates new minerals and/or smaller particles. Rocks are transformed into sand grains, and sand grains are transformed into silt and clay particles over time. As iron particles change form, they change soil colors from gray to brown or to red and yellow. Applying too much fertilizer of certain kinds can transform a soil into one that is too acidic for plants to grow.

Translocations are movements of soil components from one place to another in the soil. Translocations can move materials from one soil layer to another and can even move the materials completely out of a soil. Water moves through a soil profile and carries clay particles, soluble salts, organic matter, and chemical compounds downward into the soil. Translocations can also be upward or horizontal. As soil dries and water evaporates from the soil surface, minerals and salts may move back toward the soil surface. In dry areas translocations are restricted because there is less water to carry compounds and materials deep into the soil. Compounds and minerals can move only as deep as water moves into a soil. Concentrations of soluble material generally are closer to the surface in dry areas than in other areas. Windthrow and the activity of animals (i.e., ants, termites, groundhogs, and worms) also can move soil components upward.

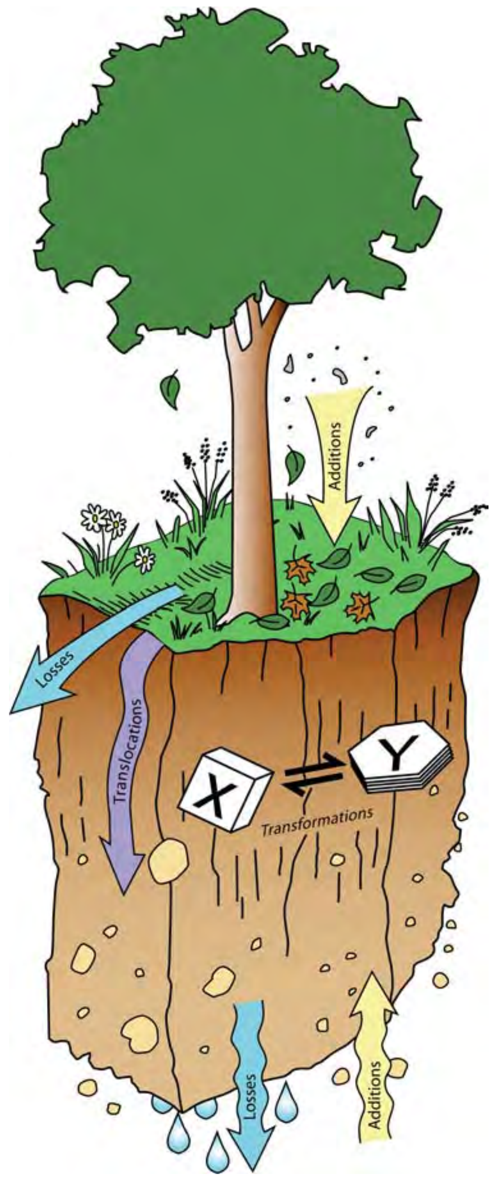


Figure 2.5: Soil-forming processes.

Losses occur when water moves material through and out of a soil profile. If enough water is available, soluble materials, such as sodium and calcium, are removed early in the process of soil formation. Lawn and garden fertilizers are relatively soluble and may be removed from a soil when too much water is applied. Ground-water pollution can occur if too much water is added to a soil that contains contaminates. Erosion by wind or water removes the soil particles and compounds needed for plant growth. Topsoil removed through water erosion in a given area can improve the soil in the area where the sediments are deposited.

Soil Horizons

Soils are made up of soil horizons, or layers, that form as the result of five soil-forming factors. The six major kinds of soil horizons are designated as O, A, E, B, C, and R (figure 2.6). All six of these horizons are not always evident in every soil profile.

For example, most agricultural soils do not have an O horizon because organic horizons are usually mixed with A horizons during tillage. Also, a soil has an R horizon only if bedrock is close to the surface.

O horizons are generally the uppermost layers and form on top of mineral horizons where they occur. They are formed by the accumulation of fresh and decaying plant parts, such as leaves, grass, needles, and twigs. O horizons are dark colored (mainly black or brown) because decomposing plant and animal materials produce humus. They are generally in forested or wet areas.

A horizons are below O horizons and are made up mostly of mineral material. They are characterized by the loss of iron, clay, and aluminum and the addition of organic matter by soil organisms. Hence, they are dark colored in most areas, except for extremely dry areas. A horizons are commonly referred to as topsoil.

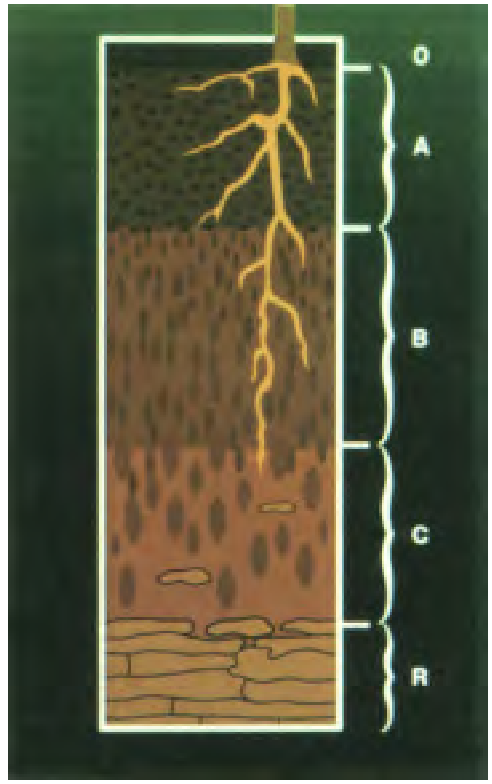


Figure 2.6:Natural soil profile with major horizons.

E horizon*s* are commonly in forested areas. The “E” stands for eluvial, which means that clay, iron, organic matter, and other minerals have been removed from this horizon. E horizons commonly appear white or lighter in color than the horizons above and below them.

B horizons are below A or E horizons and are characterized by the accumulation of iron, clay, aluminum, and other compounds. B horizons are commonly referred to as subsoil.

C horizons are below B horizons and are commonly referred to as the substratum. They are made up mainly of partially weathered or disintegrated parent material, but soft bedrock can also occur. Because C horizons are deeper in the profile, the effects of the soil-forming factors are less pronounced than the effects in the overlying A and B horizons.

R horizons are made up of bedrock. The bedrock can be far below or just a few inches below the surface.

Horizons in urban soils may not be fully related to the natural soil-forming factors but instead may be manmade layers formed by the deposition of dredge, fill, and/or mixed materials. Human artifacts, such as bricks, bottles, pieces of concrete, plastics, glass, pesticides, petroleum products, pollutants, garbage, and disposable diapers, are often components of urban soils. Manmade materials may be added to raise a landscape to a higher level, backfill ditches or foundation walls, or construct berms. In urban areas, human activity is often the predominant activity in making soil instead of the action of the natural agents of wind, water, ice, gravity, and heat.

Urban soils differ from natural soils because they have been altered to some degree. They have been excavated, compacted, disturbed, and mixed and may no longer possess their natural soil properties and features. Many highly disturbed soils in urban areas or on construction sites have not been in place long enough for soil-forming factors to significantly change them and to form soil horizons. In areas where

Figure 2.7: Urban soil profile.

fill materials have been in place for a considerable time (e.g., 50 years or so), the formation of A horizons and sometimes weakly expressed B horizons has been documented. Figures 2.7 and 2.8 show soil horizons in urban and natural soil profiles.

Measuring and Monitoring Soil Properties

Soil properties are measured at specific sites or sampled for laboratory analysis. The properties that can be described in the field include horizonation and layering, color, texture, structure, consistence, depth to bedrock, and drainage class. The properties that generally are measured in the laboratory include content of organic matter, particle-size distribution, clay mineralogy, reaction, exchangeable cations, and concentrations of contaminants. The soil characteristics that are estimated or calculated from the measured properties include engineering classification and erodibility.

Physical Soil Properties

Soil is a mixture of mineral matter, organic material, air, and water. The texture of a mineral soil is based on the amounts of sand, silt, and clay in the soil. Sand, silt, and clay are defined on the basis of the size of each individual soil particle. These size

Figure 2.8: Natural soil profile.

relationships can be demonstrated by imagining that a sand particle is the size of a basketball, a silt particle is the size of a baseball, and a clay is the size of an aspirin tablet (figure 2.9).

Soil texture and other soil properties vary significantly within short distances on urban or natural landscapes. This variation is caused by the movement and mixing of soil materials during construction activities or changes in any of the soil-forming

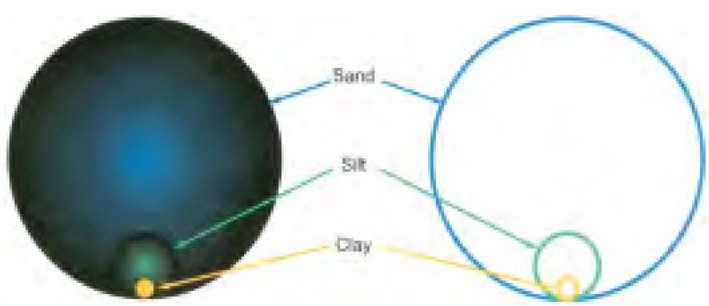


Figure 2.9: Relative sizes of sand, silt, and clay particles.

factors. The combinations of different textures may improve or limit the soil for a specific use.

Soil texture affects water and air movement through the soil as particles of different sizes pack together and thus determine the size and spacing of pores and channels. Sand particles have the largest pore spaces and allow water to drain through the pores most freely. Silt particles have smaller pore spaces, so water moves through them more slowly. Clay particles have very small pores, and so they tend to adsorb and hold more water. The mixture of particle sizes affects water, nutrient, and contaminant absorption. The specific type of mineral influences engineering properties, such as shrink-swell potential and excavation difficulty, especially in expanding clays (smectite), which behave like plastics.

The soil textural triangle (figure 2.10) can be used to determine soil texture from the relative amounts of particles of any two sizes. For example, a clay percentage of 15 with a silt percentage of 70 gives a soil texture of silt loam.

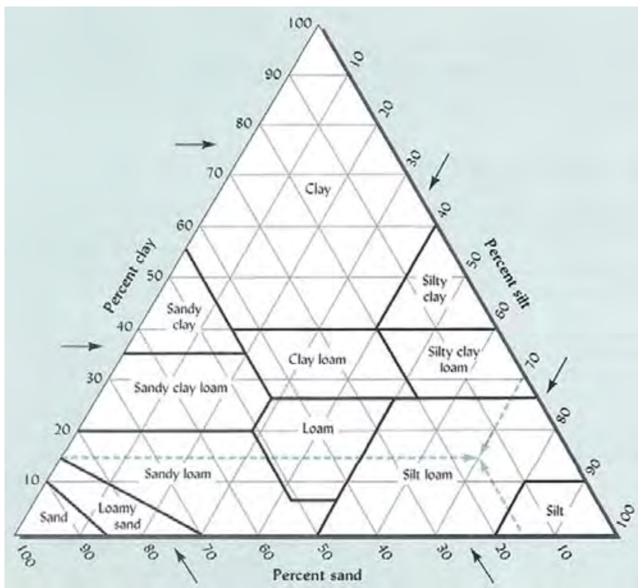


Figure 2.10: Soil textural triangle.

Measures of Water Movement

Water movement in urban soils is described in three ways (figure 2.11):

- infiltration into the soil surface, especially from rainfall
- percolation within the soil drain lines from septic systems, which is especially important in the soil below the drain line and above a restrictive layer
- permeability within the soil from the surface to a restrictive layer

Key terms in understanding water movement in soils are “restrictive layer” and “water table.” Restrictive layers have high density (high weight in a given volume of soil) and low porosity (limited space between particles), so that water cannot flow into or through them. Restrictive layers at the surface can cause surface sealing and limit

Figure 2.11: Comparison of descriptive terms for water movement in soils.

infiltration of water into the soil. Restrictive layers within the percolation zone reduce the drainage rate of fluids in septic drain lines and can cause septic systems to back up and fail. Compaction of soil materials can occur if heavy weight is on the surface when the soil is wet, resulting in dense restrictive layers below the surface.

A "perched" water table occurs when a restrictive layer anywhere in the soil limits waterflow deeper into the soil. Water drains down from the soil surface and builds up, or "perches," above the restrictive layer and above the expected water table depth. An "apparent" water table is fed from below by ground water, streamflow, or subsurface lateral flow as water moves across a restrictive layer below the soil surface.

Soil Color

Soil color differences in a profile reflect soil-forming processes and can be an indicator of soil wetness. These differences help to distinguish fill from natural soil. Important coloring agents in soil include parent (geologic) material, soil wetness, extent of leaching, content of organic matter, and the chemical form and content of iron.

Organic matter darkens the soil to a degree, depending on the content and the extent of decomposition. *Iron* gives soil a brown, yellow, or red color. Shades of blue or green may also appear, depending on iron amount, oxidation state, and hydration state. When soil is saturated, iron can become soluble and can be removed, leaving the soil with "mottled" brown and gray colors or completely gray colors, depending on the extent of the wetness.

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. Wetting and drying cycles are important in creating structure. Soil structure influences pore space and water movement in soils.

The principal forms of soil structure are—*granular* (roughly spherical)*; platy* (laminated); *angular or subangular blocky* (roughly cube shaped, with more-or-less flat surfaces); *prismatic* (vertical axis of aggregates longer than horizontal); and *columnar* (prisms with rounded tops). See figures 2.12 to 2.15.

Structureless soils are either *single grained* (each grain by itself, as in dune sand) or *massive* (the particles adhering without any regular cleavage, as in many hardpans).

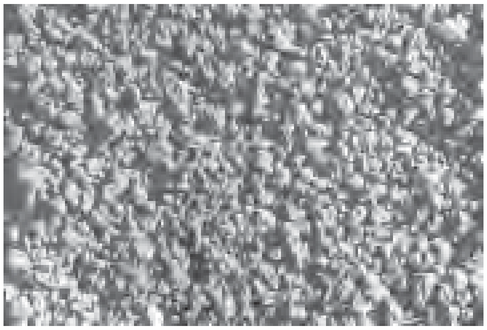


Figure 2.12: Granular structure.

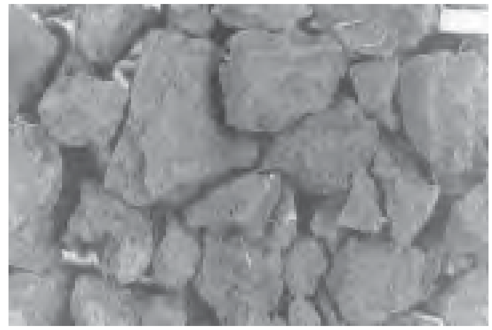


Figure 2.13: Blocky structure.

Figure 2.14: Prismatic structure.

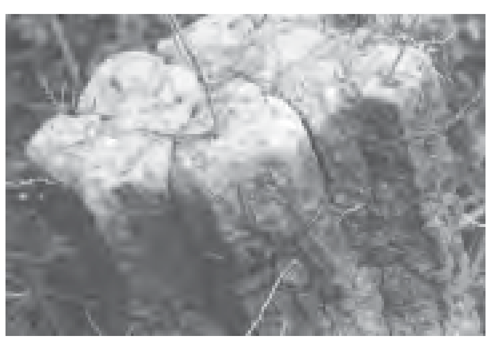
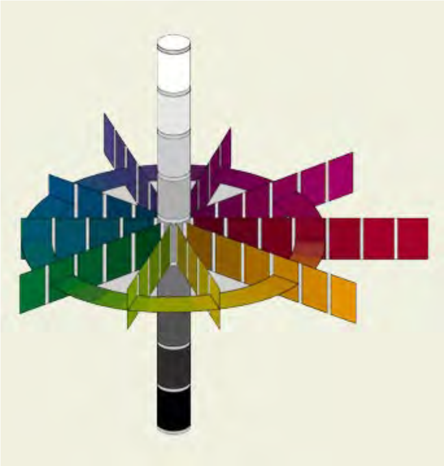


Figure 2.15: Columnar structure.

The Color of Soil



The first impression we have when looking at bare earth or soil is of color. Bright colors especially, catch our eye. Geographers are familiar with Red Desert soils in California, Arizona, and Nevada (Arizona State Soil); and Gray Desert soils in Idaho, Utah, and Nevada (Nevada State Soil). We have the White Sands in New Mexico, Green Sands along the Atlantic Coast, and Redbeds in Texas and Oklahoma (Oklahoma State Soil). The Red River between Oklahoma and Texas carries red sediment downstream, particularly in times of flood. The Yellow River (Hwang Ho) in China carries yellow sediment. Surface soils in the Great Plains and Corn Belt are darkened and enriched by organic matter.

Earth materials found in such locations as those mentioned above were used as coloring agents early in the development of most human cultures. As earth material was fashioned into utilitarian vessels, artistic colors inevitably were incorporated into them. Indigenous North American cultures used contrasting earth colors as body paints, and modern American culture uses colored earth in cosmetics and ceramics and as pigments for paints.

Munsell Color System

Red, brown, yellow, yellowish-red, grayish-brown, and pale red are all good descriptive colors of soil, but not very exact. Just as paint stores have pages of color chips, soil scientists use a book of color chips that follow the Munsell System of Color Notation (www.munsell.com). The Munsell System allows for direct comparison of soils anywhere in the world. The system has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity) that are arranged in books of color chips. Soil is held next to the chips to find a visual match and assigned the corresponding Munsell notation. For example, a brown soil may be noted as: hue value/chroma (10YR 5/3). With a soil color book with Munsell notations, a science student or teacher can visually connect soil colors with natural environments of the area, and students can learn to read and record the color, scientifically. Soil color by Munsell notation is one of many standard methods used to describe soils for soil survey. Munsell color notations can be used to define an archeological site or to make comparisons in a criminal investigation. Even carpet manufacturers use Munsell soil colors to match carpet colors to local soils so that the carpet will not show the dirt (soil) tracked into the house.

Soil Composition and Color

Soil color and other properties including texture, structure, and consistence are used to distinguish and identify soil horizons (layers) and to group soils according to the soil classification system called *Soil Taxonomy*. Color development and distribution of color within a soil profile are part of weathering. As rocks containing iron or manganese weather, the elements oxidize. Iron forms small crystals with a yellow or red color, organic matter decomposes into black humus, and manganese forms black mineral deposits. These pigments paint the soil (Michigan State Soil). Color is also affected by the environment: aerobic environments produce sweeping vistas of uniform or subtly changing color, and anaerobic (lacking oxygen), wet environments disrupt color flow with complex, often intriguing patterns and points of accent. With depth below the soil surface, colors usually become lighter, yellower, or redder.

Interpreting Soil Color

Color can be used as a clue to mineral content of a soil. Iron minerals, by far, provide the most and the greatest variety of pigments in earth and soil (see the following table).

Properties of Minerals

Mineral	Formula	Size	Munsell	Color
goethite	FeOOH	(1-2 µm)	10YR 8/6	yellow
goethite	FeOOH	(~0.2 µm)	7.5YR 5/6	strong brown
hematite	Fe_2O_3	(~0.4 µm)	5R 3/6	Red
hematite	Fe_2O_3	(~0.1 µm)	10R 4/8	Red
lepidocrocite	FeOOH	(~0.5 µm)	5YR 6/8	reddish-yellow
lepidocrocite	FeOOH	(~0.1 µm)	2.5YR 4/6	Red
ferrihydrite	$Fe(OH)_3$		2.5YR 3/6	dark red
glauconite	$K(Si_xAl_{4-x})(Al,Fe,Mg)O_{10}(OH)_2$		5Y 5/1	dark gray
iron sulfide	FeS		10YR 2/1	black
pyrite	FeS_2		10YR 2/1	black (metallic)

jarosite	$K Fe_3 (OH)_6 (SO_4)_2$		5Y 6/4	pale yellow
todorokite	MnO_4		10YR 2/1	black
humus			10YR 2/1	black
calcite	$CaCO_3$		10YR 8/2	white
dolomite	$CaMg (CO_3)_2$		10YR 8/2	white
gypsum	$CaSO_{4\times} 2H_2O$		10YR 8/3	very pale brown
quartz	SiO_2		10YR 6/1	light gray

Relatively large crystals of goethite give the ubiquitous yellow pigment of aerobic soils. Smaller goethite crystals produce shades of brown. Hematite (Greek for blood-like) adds rich red tints. Large hematite crystals give a purplish-red color to geologic sediments that, in a soil, may be inherited from the geologic parent material. In general, goethite soil colors occur more frequently in temperate climates, and hematite colors are more prevalent in hot deserts and tropical climates.

Color - or lack of color - can also tell us something about the environment. Anaerobic environments occur when a soil has a high water table or water settles above an impermeable layer. In many soils, the water table rises in the rainy season. When standing water covers soil, any oxygen in the water is used rapidly, and then the aerobic bacteria go dormant. Anaerobic bacteria use ferric iron (Fe^{3+}) in goethite and hematite as an electron acceptor in their metabolism. In the process, iron is reduced to colorless, water-soluble ferrous iron (Fe^{2+}), which is returned to the soil. Other anaerobic bacteria use Mn^{4+} as an electron acceptor, which is reduced to colorless, soluble Mn^{2+}. The loss of pigment leaves gray colors of the underlying mineral. If water stays high for long periods, the entire zone turns gray.

When the water table edges down in the dry season, oxygen reenters. Soluble iron oxidizes into characteristic orange colored mottles of lepidocrocite (same formula as goethite but different crystal structure) on cracks in the soil. If the soil aerates rapidly, bright red mottles of ferrihydrite form in pores and on cracks. Usually ferrihydrite is not stable and, in time, alters to lepidocrocite.

Along seacoasts, tide waters saturate soils twice daily, bringing soluble sulfate anions. Anaerobic bacteria use the sulfate as an electron acceptor and release sulfide (S^{2-}) which combines with ferrous iron to precipitate black iron sulfide. A little hydrochloric acid (HCl) dropped on this black pigment quickly produces a rotten egg odor of hydrogen sulfide (H_2S) gas. Soils that release H_2S gas are called sulfidic soils. With time, iron sulfide alters to pyrite (FeS_2) and imparts a metallic bluish color. If sulfidic soils are drained and aerated, they quickly become very acid (pH 2.5 to

3.5), and a distinctive pale yellow pigment of jarosite forms. This is the mark of an acid sulfate soil that is quite corrosive and grows few plants.

Galuconitic green sands form in shallow ocean water near a coast. They become part of soils that form after sea level drops. White colors of uncoated calcite, dolomite, and gypsum are common in geologic materials and soils in arid climates. A little carbonate dissolves in water, moves downward, and precipitates in soft white bodies or harder nodules. It also accumulates in root pores as lacy, dendritic (tree-branch) patterns.

Influence of Organic Matter on Soil Color

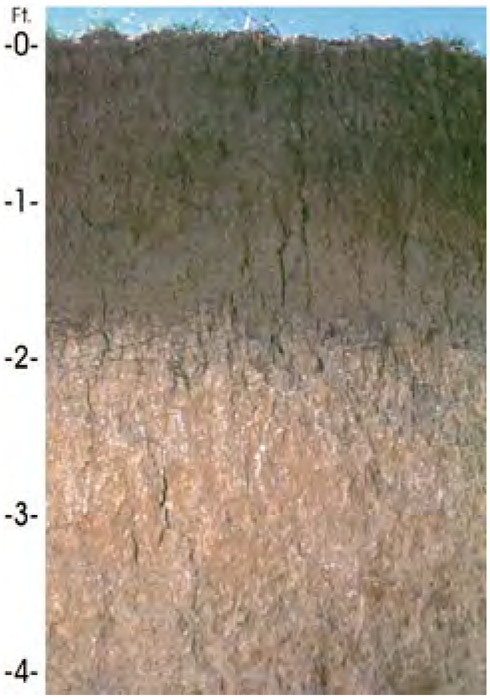
Soil has living organisms and dead organic matter, which decomposes into black humus. In grassland (prairie) soils the dark color permeates through the surface layers bringing with it nutrients and high fertility (Kansas State Soil). Deeper in the soil, the organic pigment coats surfaces of soil, making them darker than the color inside. Humus color decreases with depth and iron pigments become more apparent. In forested areas, organic matter (leaves, needles, pine cones, dead animals) accumulates on top of the soil. Water-soluble carbon moves down through the soil and scavenges bits of humus and iron that accumulate below in black, humic bands over reddish iron bands. Often, a white layer, mostly quartz occurs between organic matter on the surface where pigments were removed (Wisconsin State Soil).

Organic matter plays an indirect, but crucial role in the removal of iron and manganese pigments in wet soils. All bacteria, including those that reduce iron and manganese, must have a food source. Therefore, anaerobic bacteria thrive in concentrations of organic matter, particularly in dead roots. Here, concentrations of gray mottles develop.

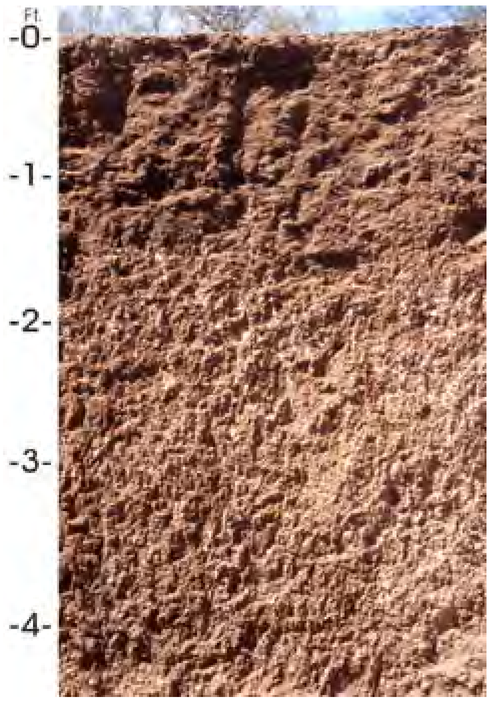
Soil color is a study of various chemical processes acting on soil. These processes include the weathering of geologic material, the chemistry of oxidation-reduction actions upon the various minerals of soil, especially iron and manganese, and the biochemistry of the decomposition of organic matter. Other aspects of Earth science such as climate, physical geography, and geology all influence the rates and conditions under which these chemical reactions occur.

Soil adds beauty to our landscapes. These colors blend with vegetation, sky, and water. For art students and others who may be interested in creating a natural look to their artwork, try to incorporate finely ground colored soils as pigments into your work.

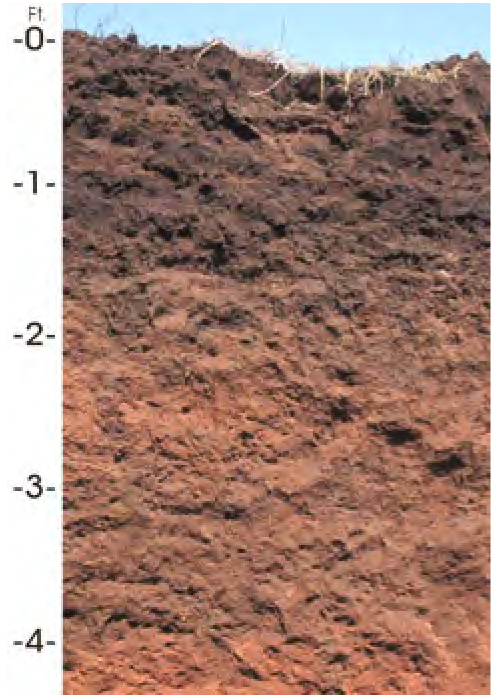
Arizona State Soil



Oklahoma State Soil

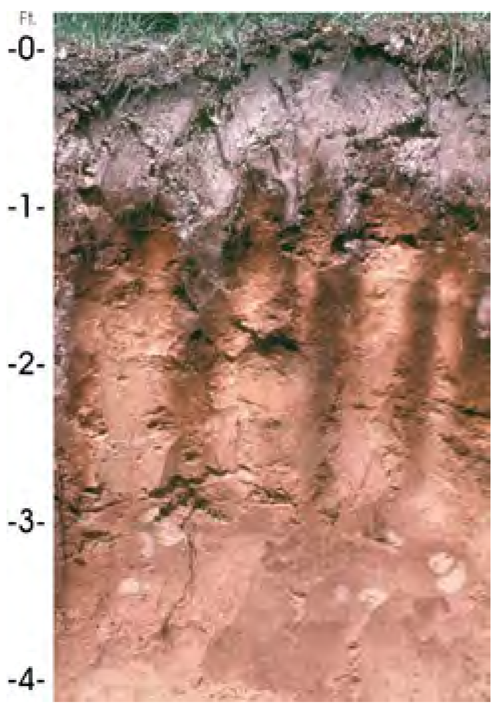


Kansas State Soil

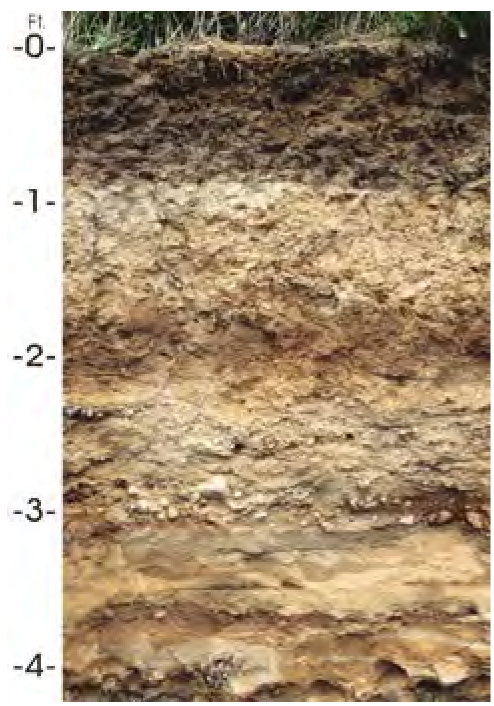


Nevada State Soil

Michigan State Soil



Wisconsin State Soil



Urban Soils Primer-Glossary

Aggregate, soil. Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging.

Bedrock. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Catena. A sequence, or "chain," of soils on a landscape that formed in similar kinds of parent material but have different characteristics as a result of differences in relief and drainage.

Cation. An ion carrying a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.

Cation-exchange capacity. The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value.

Clay. As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Compaction. Creation of dense soil layers when the soil is subject to the heavy weight of machinery or foot traffic, especially during wet periods.

Composting. Managing the decomposition of organic materials, such as leaves, grass, and garden waste.

Container gardens. Gardens planted in pots, concrete boxes, brick or stone basins, or other isolated rooting areas within paved areas.

Contaminated soil. A soil that has high concentrations of trace metals or organic waste that is toxic or a high risk to people or animals.

Drainage class (natural). Refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized—*excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained,* and *very poorly drained*.

Drainage, surface. Runoff, or surface flow of water, from an area.

Erosion. The wearing away of the land surface by water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion (geologic). Erosion caused by geologic processes acting over long geologic periods and resulting in the wearing away of mountains and the building up of such landscape features as flood plains and coastal plains. Synonym: natural erosion.

Erosion (accelerated). Erosion much more rapid than geologic erosion, mainly as a result of human or animal activities or of a catastrophe in nature, such as a fire, that exposes the surface.

Fertility, soil. The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable.

Gravel. Rounded or angular fragments of rock as much as 3 inches (2 millimeters to 7.6 centimeters) in diameter. An individual piece is a pebble.

Hard bedrock. Bedrock that cannot be excavated except by blasting or by the use of special equipment that is not commonly used in construction.

Heat islands. Small areas of artificially drained urban soils surrounded by tall buildings that change soil temperature and moisture patterns. May also refer to an entire city with an artificial microclimate.

Horizon, soil. A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. In the identification of soil horizons, an uppercase letter represents the major horizons. Numbers or lowercase letters that follow represent subdivisions of the major horizons. The major horizons of mineral soil are as follows:

O horizon.—An organic layer of fresh and decaying plant residue.

A horizon.—The mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material. Also, a plowed surface horizon, most of which was originally part of a B horizon.

E horizon.—The mineral horizon in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these.

B horizon.—The mineral horizon below an A horizon. The B horizon is in part a layer of transition from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics, such as (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) prismatic or blocky structure; (3) redder or browner colors than those in the A horizon; or (4) a combination of these.

C horizon.—The mineral horizon or layer, excluding indurated bedrock, that is little affected by soil-forming processes and does not have the properties typical of the overlying soil material. The material of a C horizon may be either like or unlike that in which the solum formed. If the material is known to differ from that in the solum, an Arabic numeral, commonly a 2, precedes the letter C.

Cr horizon.—Soft, consolidated bedrock beneath the soil.

R layer.—Consolidated bedrock beneath the soil. The bedrock commonly underlies a C horizon, but it can be directly below an A or a B horizon.

Humus. The well decomposed, more or less stable part of the organic matter in mineral soils.

Hydrologic soil groups. Refers to soils grouped according to their runoff potential. The soil properties that influence this potential are those that affect the minimum rate of water infiltration on a bare soil during periods after prolonged wetting when the soil is not frozen. These properties are depth to a seasonal high water table, the infiltration rate and permeability after prolonged wetting, and depth to a very slowly permeable layer. The slope and the kind of plant cover are not considered but are separate factors in predicting runoff.

Hydrologic unit or watershed. In urban areas, a catchment area with an outlet in or affecting a densely populated area.

Impervious soil. A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.

Infiltration. The downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is movement of water through soil layers or material.

Landslide. The rapid downhill movement of a mass of soil and loose rock, generally when wet or saturated. The speed and distance of movement, as well as the amount of soil and rock material, vary greatly.

Leaching. The removal of soluble material from soil or other material by percolating water.

Loam. Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles.

Low strength. The soil is not strong enough to support loads.

Nutrient, plant. Any element taken in by a plant essential to its growth. Plant nutrients are mainly nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, boron, and zinc obtained from the soil and carbon, hydrogen, and oxygen obtained from the air and water.

Organic matter. Plant and animal residue in the soil in various stages of decomposition.

Parent material. The unconsolidated organic and mineral material in which soil forms.

Percolation. The movement of water through the soil.

Permeability. The quality of the soil that enables water or air to move downward through the profile. The rate at which a saturated soil transmits water is accepted as a measure of this quality. In soil physics, the rate is referred to as "saturated hydraulic conductivity."

pH value. A numerical designation of acidity and alkalinity in soil. (See Reaction, soil.)

Pocket park. A relatively small area reserved for recreation or gardening and surrounded by streets or buildings.

Profile, soil. A vertical section of the soil extending through all its horizons and into the parent material.

Raised bed gardens. Gardens that are planted in boxes made of wood or other materials and have the rooting area above the ground surface. The boxes may be filled with composted materials mixed with uncontaminated soil.

Reaction, soil. A measure of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline.

Relief. The elevations or inequalities of a land surface, considered collectively.

Restrictive layer. A compact, dense layer in a soil that impedes the movement of water and the growth of roots.

Runoff. The precipitation discharged into stream channels from an area. The water that flows off the surface of the land without sinking into the soil is called surface runoff. Water that enters the soil before reaching surface streams is called ground-water runoff or seepage flow from ground water.

Sand. As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.

Sealed soil. Soil that is covered with buildings, pavement, asphalt, or other material. Water and air do not enter the soil from the surface.

Series, soil. A group of soils that have profiles that are almost alike, except for differences in texture of the surface layer. All the soils of a series have horizons that are similar in composition, thickness, and arrangement.

Shale. Sedimentary rock formed by the hardening of a clay deposit.

Shrink-swell potential. The potential for volume change in a soil with a loss or gain in moisture. Volume change occurs mainly because of the interaction of clay minerals with water and varies with the amount and type of clay minerals in the soil. The size of the load on the soil and the magnitude of the change in soil moisture content influence the amount of swelling of soils in place. Shrinking and swelling can damage roads, dams, building foundations, and other structures. It can also damage plant roots.

Silt. As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.

Sinkhole. A depression in the landscape where limestone has been dissolved or lava tubes have collapsed.

Slope. The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.

Soft bedrock. Bedrock that can be excavated with trenching machines, backhoes, small rippers, and other equipment commonly used in construction.

Soil-forming factors. Five factors responsible for the formation of the soil from the unconsolidated parent material. The factors are time, climate, parent material, living organisms (including humans), and relief.

Structure, soil. The arrangement of primary soil particles into compound particles or aggregates. The principal forms of soil structure are platy, prismatic, columnar, blocky, and granular. Structureless soils are either single grained or massive.

Texture, soil. The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are *sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay,* and *clay*. The sand, loamy sand, and sandy loam classes may be further divided by specifying “coarse,” “fine,” or “very fine.”

Topographic maps (USGS). Maps that show terrain, ridges, waterways, contours, elevations, and geographic locations. Also may show roads and buildings.

Trace elements. Chemical elements, for example, zinc, cobalt, manganese, copper, and iron, in soils in extremely small amounts. They are essential to plant growth.

COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY COLLEGE OF AGRICULTURE, FOOD AND ENVIRONMENT, LEXINGTON, KY, 40546

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UK University of Kentucky College of Agriculture, Food and Environment

Determining Soil Texture by Feel

Edwin Ritchey and Josh McGrath, Plant and Soil Sciences; and David Gehring, Natural Resource Conservation Services

What is soil texture?

Soil texture refers to the proportion of sand, silt, and clay in a soil. Texture influences almost every aspect of soil use, both in agricultural and engineering applications, and even how natural ecosystems function. Many scientists consider soil texture the most important soil property as it can influence soil/water relationships, gas exchange, and plant nutrition. Accurately determining soil texture in a lab requires time and money; therefore, it is often necessary to estimate soil texture in the field by feel, which can be very accurate if done correctly.

What gives soil its texture?

The three building blocks of soil—sand, silt, and clay—feel very different and lend different properties to a soil. Although the three types of soil particles are differentiated by their size (Table 1), which is a physical property, the relative amount of each of these components has a large influence on the physical, chemical, and biological properties of a soil. The pore spaces between soil particles are largely responsible for the amount of water a soil can hold. Finer soil textures have greater surface area, smaller soil pores, and slower water infiltration into the soil profile.

- **Sand** is the largest soil particle, measuring 0.05 to 2 mm in diameter, and can be seen by the naked eye. Sand feels gritty to the touch and holds very little water.
- **Silt** is the medium-sized component of soil, measuring 0.002 to 0.05 mm in diameter. Dry silt particles feel like flour or baby powder. When wet, silt will feel smooth. Silt only holds a moderate amount of water.
- **Clay** is the smallest particle in the soil, measuring less than 0.002 mm in diameter, and can only be seen with powerful microscopes. The largest clay particle is 25 times smaller than the largest silt particle and a thousand times smaller than the largest sand particle. Clay will feel sticky when wet and hard and brittle when dry. Clay can hold much more water than sand or silt. In most soils, clay content increases with depth.

Figure 1. USDA soil texture triangle showing twelve soil texture classes based on proportion of sand, silt, and clay particles. Coarse textured soils are tan, medium textured soils are green, fine textured soils are yellow.

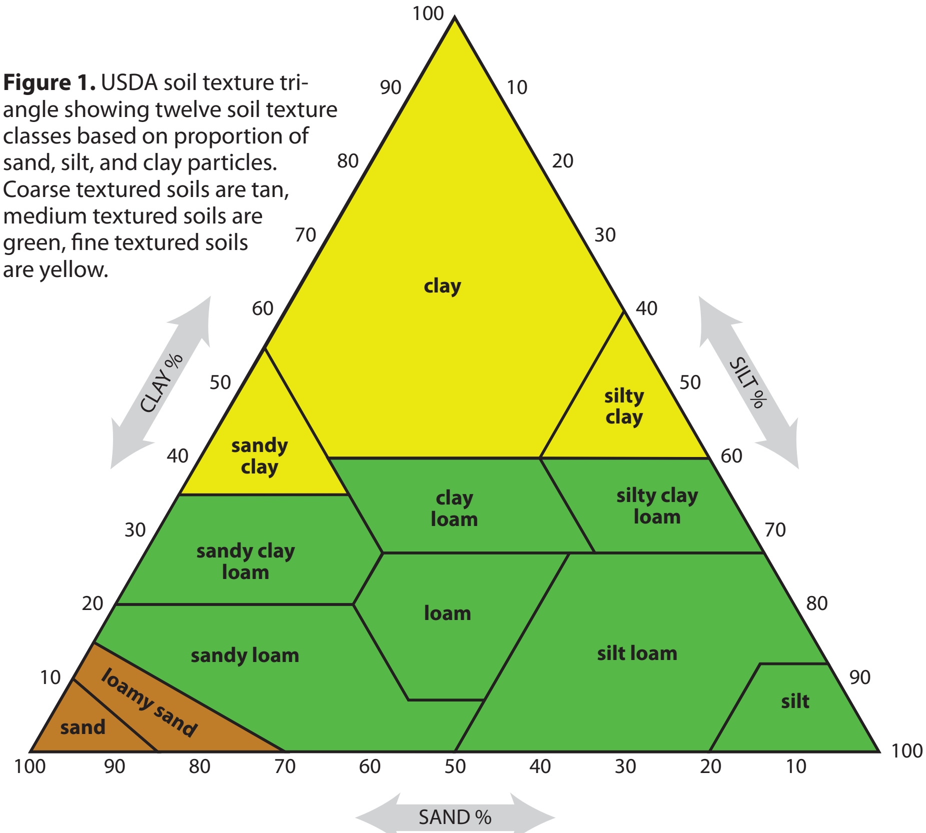


Table 1. Particle sizes for soil separates

Soil Separate	Diameter (mm)
Clay	<0.002
Silt	0.002 to 0.05
Sand	0.05 to 2.0
Very fine sand	0.05 to 0.10
Fine sand	0.10 to 0.25
Medium sand	0.25 to 0.5
Coarse sand	0.5 to 1.0
Very coarse sand	1.0 to 2.0

How are soil textures classified?

Soils are divided into three broad texture groups—coarse-textured soils, medium-textured soils, and fine-textured soils (Figure 1). A **coarse-textured** or sandy soil has 70 to 100 percent sand-sized particles. Because of the strong properties clay exhibits, a soil only needs to have 35 to 40 percent clay-sized particles to be considered **fine-textured** or clayey. Finally, the **medium-textured** soils or loams have a more even distribution between clay and sand particles.

The United States Department of Agriculture (USDA) soil texture triangle (Figure 1) is used to divide soils into 12 distinct classes based on their particle size distribution, or the relative amount of sand, silt, and clay in the soil. In the laboratory, we would first determine the relative amount of sand, silt, and clay particles in a soil sample as a percent of the sample's weight, follow the arrows from each side to where they intersect, and identify what texture class the soil belongs to. For example, if we determined that a soil had 30 percent sand, 40 percent silt, and 30 percent clay, it would be called a *clay loam.* However, we can also estimate soil texture by feel fairly accurately with practice.

Using soil texture in the field

Once the soil texture is determined in the field, general characteristics of a soil can be predicted with reasonable accuracy, which helps identify proper management practices to use. A coarse-textured soil would have low water holding capacity, high water infiltration rates, high potential for leaching, low nutrient retention, and should respond well to supplemental irrigation. In contrast, fine-textured soils will remain wet longer than medium- or coarse-textured soils, have slow water infiltration rates, high potential for denitrification, and high nutrient retention. The medium-texture soils, such as loams, silt loams, or clay loams, have a good balance of sand silt, and clay. Medium-textured soils generally are very productive soils that allow for sufficient water infiltration without excessive drainage and have good water holding capacity and nutrient retention. Most soils can be used to produce crops or forage, if managed properly. Accurate determination of the soil texture allows for proper management practices to be used to maximize the potential soil productivity.

References

Thien, S.J. 1979. A flow diagram for teaching texture by feel analysis. Journal of Agronomic Education. 8:54-55.

Photos by Edwin Ritchey

How do I estimate texture by feel?

Three simple steps along with the flow chart in Figure 2 will help you to determine soil texture by feel.

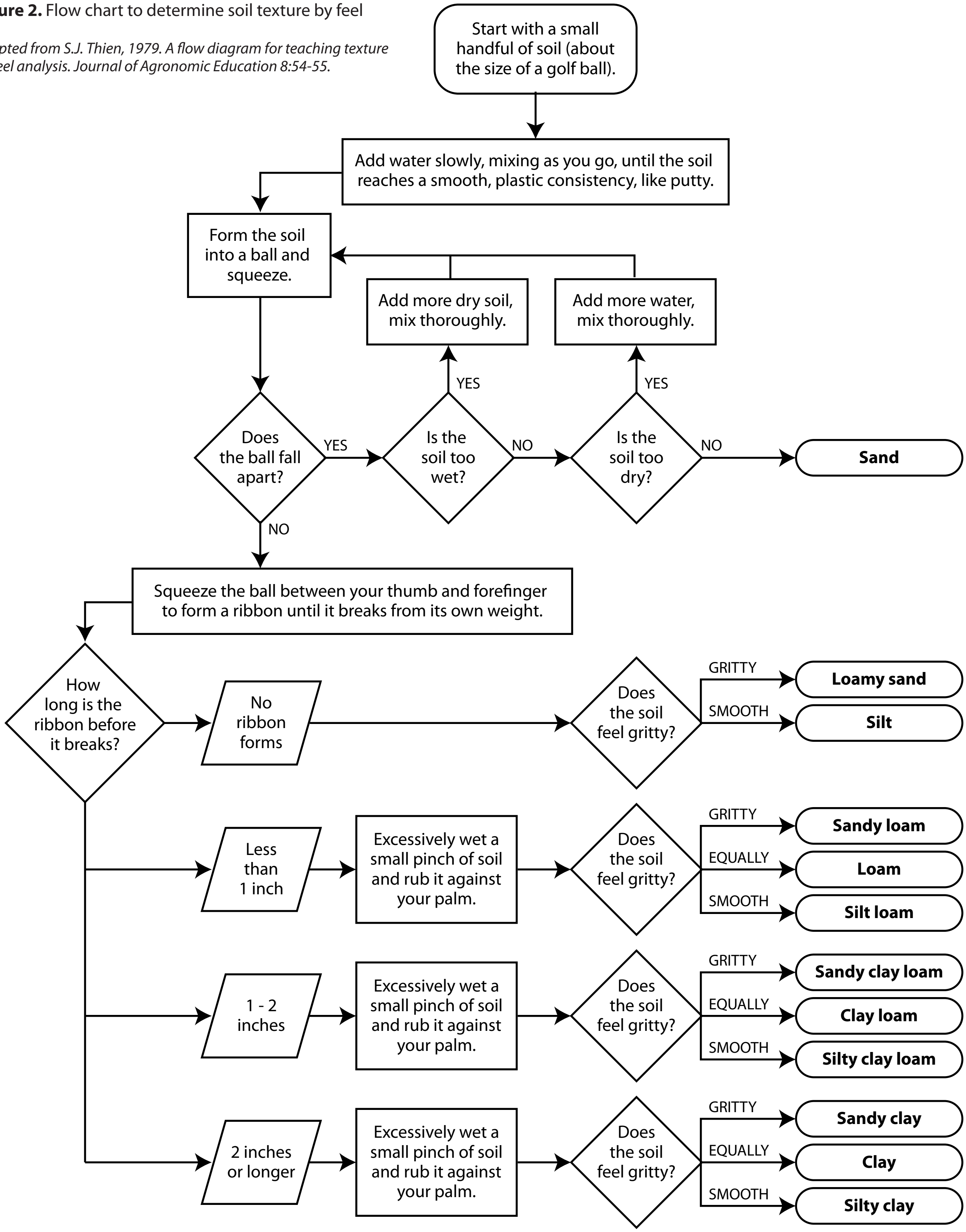
Step 1: Start with a small handful of soil, about the size of a golf ball, and slowly add water a drop at a time, mixing as you go, until you have a ball of soil that has the consistency of putty. Gently squeeze the ball to determine if it will stay together in a ball or fall apart.

Step 2: If the ball of soil stays intact, gently press the ball between your thumb and index finger, trying to work it out to form a ribbon. If you can form a ribbon, measure how long the ribbon is before it falls apart.

Step 3: After completing the ribbon test, add water to a pinch of soil in the palm of your hand until you have a muddy puddle. Rub the mud puddle against your palm and determine if it feels gritty, smooth, or equally gritty and smooth.

Figure 2. Flow chart to determine soil texture by feel

Adapted from S.J. Thien, 1979. A flow diagram for teaching texture by feel analysis. Journal of Agronomic Education 8:54-55.



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Soils and Land Use Study Resources

Key Topic #2: Soil Survey and Interpretations

6. Identify common management considerations, and strategies to address resource concerns within urban areas.

7. Interpret soil survey reports and apply the information to make decisions on suitable land uses and soil/land management.

8. Evaluate a soil profile for soil properties and characteristics, land use history, water table level, and management recommendations.

Study Resources

Resource Title	Source	Located on
Urban Soils Primer: Chapter 4: Soils Sustain Plant and Animal Diversity And productivity	*USDA NRCS, Scheyer, J.M., Hipple, K.W., 2005*	page 27-34
Web Soil Survey	*Joseph Foster, Dale Gates, Grey Albreth, Karl Czymnek And Quirine Ketterings, Cornell University Cooperative Extension, 2010*	page 35-36
Soil Survey Interpretations	*NRCS Soils Division Staff, 2017*	page 37-41

<u>Study Resources begin on the next page!</u> ➡

Chapter 4: Soils Sustain Plant and Animal Diversity and Productivity

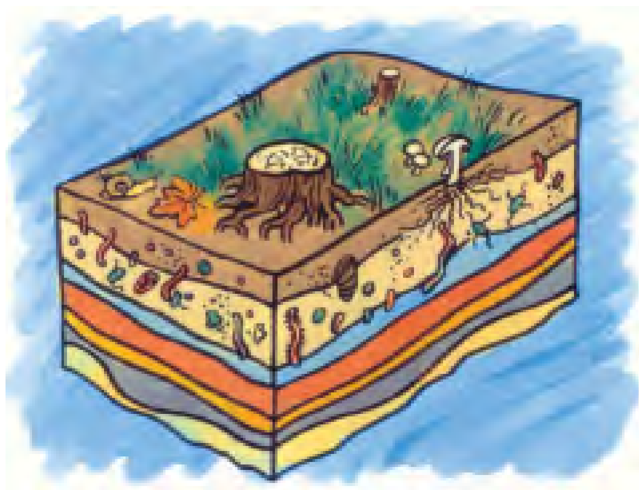


Figure 4.1

Whether they are in urban or natural areas, soils provide living space and supply air, water, and nutrients for micro-organisms, plants, animals, and humans. In most areas, soil properties determine which plants and animals can live in and on the soil. Urban soils that have been disturbed and mixed may no longer possess the natural characteristics needed to support life. Soil amendments may be required to reestablish plants. In many urban areas, the remaining soil materials must be modified before they can support plant and animal life.

Topics in this chapter:

- **Soil fertility and plant nutrition**
- **Soil acidity**
- **Soil organisms and biochemistry**
- **Soil as a filter and buffer for waste**
- **Identifying problem sites from historical records**
- **Identifying problem sites by visual clues**
- **Precautions for community gardens, playgrounds, and parks**
- **Historical tidbits on waste management**

Soil Fertility and Plant Nutrition

Management of urban soils for productive gardens requires a basic understanding of physical and chemical soil properties. Local sampling and testing can help gardeners to determine the suitability of urban soils for certain plants and the need for fertilizer, or plant food (table 4.1).

Table 4.1: Examples of the Factors That May Affect the Productivity of Urban Soil

- Little or no addition of organic matter
- Artifacts that disrupt water movement
- Elevated salt content
- Interrupted nutrient cycling and modified activity of micro-organisms
- High soil temperatures that increase the rate of chemical reactions
- Generally higher pH values resulting from additions of cement, plaster, and road salts
- Lateral (sideways) subsurface waterflow resulting from compacted layers

Meeting the nutritional needs of urban plants requires consideration of soil moisture and temperature as well as the chemicals and biological organisms needed to convert fertilizers into useful nutrients. Plant selection may vary according to the grower's nutritional needs, cultural traditions, soil conditions, and the space available. Plants common in different ethnic diets can be successfully grown in urban areas (figures 4.2 and 4.3). Attention must be paid to different plant tolerances for metals and to drainage, the growing season, and weed control.

Figure 4.2: Produce from a Vietnamese home garden.

Figure 4.3: Intensive Vietnamese home garden in an urban area.

Plant growth and nutrition are closely linked to soil properties. The ability of soil particles to hold and release nutrients for plants and micro-organisms to use is called the cation-exchange capacity (CEC). This capacity determines which nutrients stay in solution and are available for uptake by plant roots and which nutrients are moved through the soil and thus are not available for plant and microbe use. Cations in the soil are positively charged nutrients, such as nitrogen, sodium, calcium, and potassium. Different plants and microbes require different kinds and amounts of nutrients. Trace metals also are nutrients in the soil. They generally are used in very small amounts. Such trace metals as iron and manganese are necessary for plant growth. Also, they help plants to fight diseases. Metal mobility and potential toxicity in soil occur at the lower pH levels and depend on metal binding through cation exchange.

Various kinds of clay in the soil attract and hold cations onto negatively charged parts of their surfaces. Certain clays internally bind some chemicals very tightly. As a result, it is difficult for plants to obtain the necessary nutrients from the soil solution. In areas of these highly active clays, we often add lime (calcium carbonate) to reduce the acidity of the soils and facilitate release of the nutrients from the clays into soil solution.

Figure 4.4 Soil profile in a long-term garden.

Organic matter has many active sites that bind chemicals in a manner similar to the way clay particles bind the chemicals in the soil. Organic matter is often visible in a thick, dark surface layer, in which plants begin to grow and take up nutrients. Clays and other soil materials are mixed with the organic matter in each soil layer to form a chemical system. Intensive vegetable gardening over many years during which unused plant materials and organic waste are returned to the soil can produce a thick, dark surface layer of organic matter. The color of the resulting dark surface layer may contrast with the color of the underlying soil, as is shown in figure 4.4, which pictures a 100-year-old continuous vegetable garden.

Soil Acidity

An acid is a substance that has a positive charge and usually yields hydrogen ions when dissolved in water. Hydrogen ions are positively charged. The stronger the acid, the better it dissolves in water. The pH scale (1-14) is a common measure of soil reaction. The lower the number, the greater the acidity. The midpoint of the pH scale is neutral (7.0), a good level for the growth of most plants.

Changes in soil reaction, as measured by pH, have significant effects on metals in soil. Metal toxicity to plants and animals increases in strongly acid soils with a low pH (3.5). Metals in these soils are released from negative sites back into soil solution. At a higher pH (8.5), the metals often are sequestered in the soil. The term “sequestered” indicates that the positively charged metal ions are bound tightly to negatively charged sites in the soil. These sites may be on clays, mineral compounds, or organic matter, including the surfaces of some micro-organisms. These strong, tight bonds restrict the availability of metals for plant uptake and reduce the risk of animal consumption or human skin contact.

Soil Organisms and Biochemistry

Soil is made up of mineral particles and organic matter, the decomposed remains of living things. Bacteria, fungi, and other micro-organisms are largely responsible for breaking down dead plants and animals in the soil. Small organisms (microbes) have negatively charged sites where soil nutrients and metals can bind to form soil aggregates and compounds. Earthworms and larger animals eat and digest organic materials and minerals, transform them into soil aggregates, and deposit them as waste. Soil aggregates are loose groupings of many different soil components in a structure allowing water and air movement as well as biochemical reactions for energy production and nutrient cycling (figure 4.5).

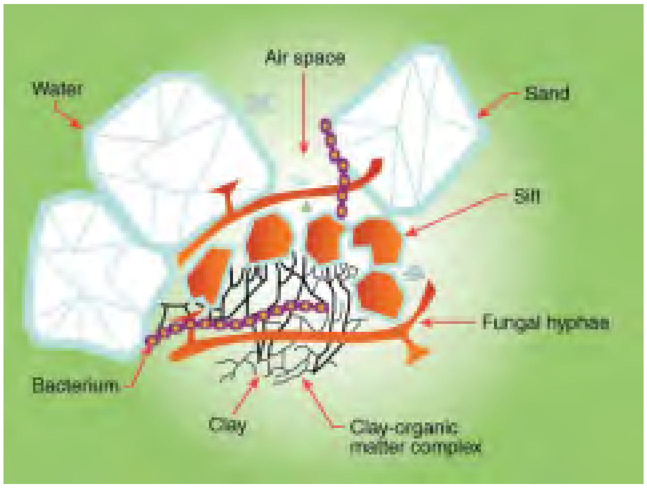


Figure 4.5 : Soil components at a microbial scale.

Soil as a Filter and Buffer for Waste

Managing compost and organic waste is important for plant nutrition and for the biological degradation and conversion of contaminants into inactive forms in the soil. Two key ways to manage waste are filtering and buffering. Waste is filtered when it flows through the soil and is slowly trapped and bound to soil particles. Soil buffering traps waste particles and transforms them into inactive forms.

Composting and using septic systems are examples of waste management in urban soils. Organic materials are needed to hold water and nutrients in the soil for plant growth. In urban parks and community gardens, as well as suburban home gardens and yards, composting can recycle most of the leaves and grass clippings (figure 4.6). This management alternative provides inexpensive soil conditioner that increases porosity and improves the rooting environment for plants.

The major considerations in applying yard and garden waste after composting are plant nutritional needs and the potential of the compost to contain weed seeds or contaminants. Existing resources from the Cooperative Extension Service provide guidelines for managing compost in a manner that maximizes the nutrient content and minimizes the transfer of diseases or contaminants. The same practices work for

Figure 4.6: Composting barrels or traditional fenced piles fit different management intensities in home gardens.

organic waste whether from urban or agricultural sources, and the economic benefits of recycling apply to both.

Understanding the role of soils in septic systems helps residents of small towns or remote housing developments to manage the return of some nutrients to the soil. The liquid septic effluent can provide nitrogen and phosphorus for use by the roots of lawn grasses. Lawn areas receiving liquid drainage from poorly designed or failing septic systems may appear darker green and have thicker grass than surrounding lawn areas. Lakes surrounded by intensive development using septic systems may have water-quality problems, such as algae blooms or high phosphorus levels, if the systems become overloaded.

Conversion of summer cottages to year-round homes may lead to septic system failure or excessive drainage of nutrient-rich septic effluent to lakes or streams. Upgrades, cleanouts, and enlargements of septic systems are needed to accommodate the amount of human waste produced and to make sure that the waste does not pollute surface water or the ground-water supply for wells. Soil properties affecting septic system design and installation include slope, depth to bedrock, permeability, depth to the water table, plasticity of the soil (possible expansion when the soil is wetted and then dried), soil texture and structure, and potential for corrosion of steel or concrete pipe.

Identifying Problem Sites From Historical Records

Metals in soils come from various sources. They may have been present in the geologic rock, or they may occur as atmospheric additions of copper, mercury, lead, and zinc. Metals also may have been deposited by past industrial activities, such as battery production, brass and steel manufacturing, mining, and many different processes involving nickel, cadmium, copper, and lead. Lead is especially evident near roadways because of automobile emissions before the availability of unleaded gasoline, and automobile demolition areas may contain a variety of metals that were commonly used in older cars. As lead paints and some window blinds and soldered pipes used in houses before 1978 wear out and deteriorate, they add lead to nearby soils.

Other ongoing sources of metals and organic waste material are landfills and dump areas that are poorly maintained or unregulated. Landfill materials eventually decompose and form a highly variable type of urban soil. The volunteer vegetation may be dominated by phragmites, as is shown in figure 4.7. These sites can be reclaimed for limited recreational or industrial use.

Figure 4.7: An older landfill with phragmites.

Areas affected by city fires may have concentrated metals buried in the soils. These concentrations are discovered only by referring to historical records or by digging into the soils (figure 4.8). Major fires may leave surface residue high in contaminants. A variety of plants may still grow well, but careful evaluation of each site is needed to determine the risk to human health.

Marine sediments may be dredged and used as fill in low-lying urban areas. Contaminants in the dredged material may be moved onto a site. Other problems with water movement and root resistance may result from compaction of a subsurface layer of very fine sand.

Figure 4.8: Soil profile with a buried layer of ash and refuse. This site was burned by a city fire.

Identifying Problem Sites by Visual Clues

Metal contamination on a site may be evidenced by plant growth, animal behavior, or paint flecks containing lead from older buildings. Many plants simply cannot grow where the level of certain metals is high. Other plants grow well in contaminated soil but fail to set seed or do not grow as well as expected. Absence of any plant growth is a warning sign that a site may be severely contaminated. Caution during sampling is needed.

Metals may be present at a site but not be a high risk for gardening or recreation, depending on the soil properties, drainage, and vegetation at the site. A human health risk from mosquitoes can occur not only in areas of standing water but also in any areas near homes or on city streets with stagnant water. Compaction is often the main problem causing water to pool on the surface without infiltrating into the soil. Mixing the soil when it is just a little moist can increase the porosity (air space between particles) and allow water to soak in. Other options are to divert the water away from low spots and to create channels for storm water to flow around the site or in specific streams or ditches across the site.

Precautions for Community Gardens, Playgrounds, and Parks

Outdoor recreation and gardening are popular activities on urban soils. The risk to human health varies among the sites used for these activities and even between the soils on the same site. A careful study of the area and consideration of key soil properties are needed (table 4.2)

Community and home gardens on contaminated soils may not be a health risk if the garden vegetables supply a very small proportion of the vegetables in the overall human diet. Caution is advised, however, when produce grown in contaminated soils is eaten. Often, the garden supplements the produce bought at grocery stores and for most of the year the nutritional needs of the growers are met elsewhere. Buying vegetables at farmer's markets or school fundraising gardens is another way to dilute the dietary intake of contaminated plants by any one person

Caution is needed in areas of bare ground or leaking water near past industrial sites, dumps, or older homes. Gloves should be worn during soil sampling. Dust from contaminated sites may be dangerous if inhaled by humans or animals. Extended skin contact or hand-to-mouth activities may allow metals to enter children's bodies and interfere with growth and mental development. Pets may collect contaminated dust or mud and carry it into the home.

Prolonged skin contact with contaminated gardens can endanger young children. Raised bed gardens built with a liner on the soil surface and carefully selected fill materials provide a relatively safe and productive alternative. For many residents of urban areas, a community garden is a desirable opportunity for physical exercise, visiting with neighbors, supplementing vegetables, and relaxation.

Table 4.2: Human Health Risks

potential health risks
- **dust inhaled**
- **soluble lead for plant intake**
- **mud puddles that attract children and increase skin contact**

soil chemical properties influencing relative risks
- **strongly bound and insoluble forms of contaminants**
- **prevalence of active clay surfaces for binding**
- **organic carbon in various active forms for binding**
- **other cations, electrical conductivity, pH, and salts**

soil physical properties influencing relative risk
- **drainage**
- **infiltration and permeability**
- **erosion potential for runoff and sediment loss**
- **particle sizes and water in soil pore space**

Web Soil Survey

Introduction

Soil is one of our most valuable resources and maintaining its productivity over time is essential for agricultural sustainability. Cataloging soils and their characteristics is critical for understanding management impacts and protecting the soil resource. Most counties in New York State have had a soil survey conducted and, depending on availability, hardcopies of some of the surveys can be obtained from the county Natural Resources Conservation Service (NRCS) office. In addition, NRCS maintains the Web Soil Survey (WSS) to provide online access to soils information. In this factsheet we provide general information on soil surveys and more specific details on access and use of the WSS.

How are Soil Surveys Made?

In each county, soil scientists traverse the landscape digging soil pits and taking soil samples to describe the many characteristics of the soil (i.e. color, texture, structure, soil chemical properties, etc.) over depth. This description is called a soil profile. After the profile is compared with others in the area, the area can be classified and named through a national system of soil taxonomy. The final step in generating a soil survey is to plot the soil classification on aerial photographs and generate useful soil survey data.

Benefits of the Web Soil Survey

The WSS always displays the most updated version of soil survey mapping and data, and it provides viewable and searchable maps. A user has the option to select only the area of interest, e.g. a specific farm or field, and get tailored soil maps, descriptions of the soils, and interpretations for the defined area.

How to Use the Web Soil Survey

Access and Field Selection

The Web Soil Survey can be accessed at: *http://websoilsurvey.nrcs.usda.gov/app/.* From the homepage, click the green "Start WSS" button. From the mapping page, an area of interest (AOI) must be selected to view the soils information. The AOI can be determined by street address, county and state, soil survey area, latitude and longitude, section, township and range, federal land boundaries, and hydrologic unit. One can also just click on the United States map and continue to zoom in to locate the farm or field of interest. As seen in Figure 1, there are two ways to define the AOI for soils information: (1) using rectangular areas; and (2) selection of irregularly shaped areas or polygons. Once the AOI is defined by the red outline (limited to 10,000 acres or less), the user can select tabs for the information of interest.

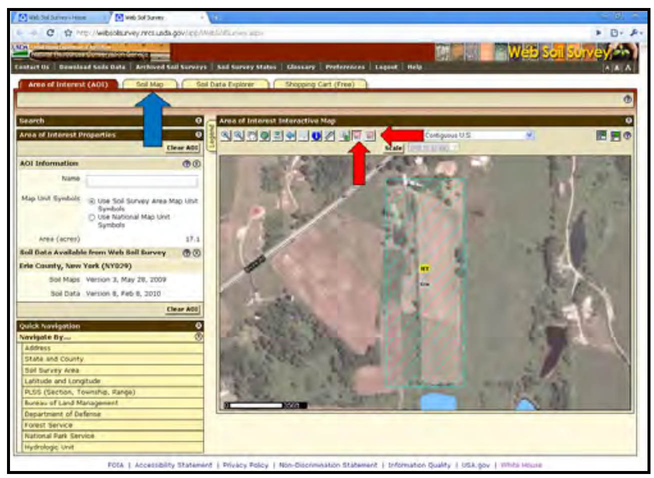


Figure 1: Screen illustrating selection of area of interest (red arrows) and soil map (blue arrow) leads to the soil maps and interpretations.

Soil Map

The "Soil Map" tab indicated by a blue arrow in Figure 1 allows the user to view the soil series as is shown in Figure 2. Map feature, such as roads, water, aerial photo background, topographic map background, special point features, etc., can be selected by clicking on the "Legend" tab at the upper left corner of the map. The table accompanying the map lists the soil series name(s) and the acres of each series mapped in the AOI. The user can click on the soil series name (highlighted in blue) within the table and a list of properties will appear that provides information about the texture, drainage, depth to limiting layer and other features of the soil. The three letters of the map soil symbol classify the soil. For example, the map unit symbol CeB denotes the soil name (Ce, Castile gravelly loam), and the last large letter is a slope range classification (B) which denotes a 3 to 8 percent slope in this example. A letter "C" (CeC) would have indicated the same soil type but with an 8 to 15 percent slope.

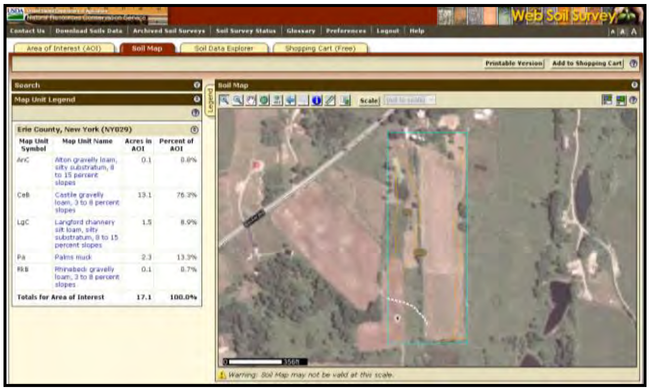


Figure 2: Screen illustrating soil map and the associated table of soil series.

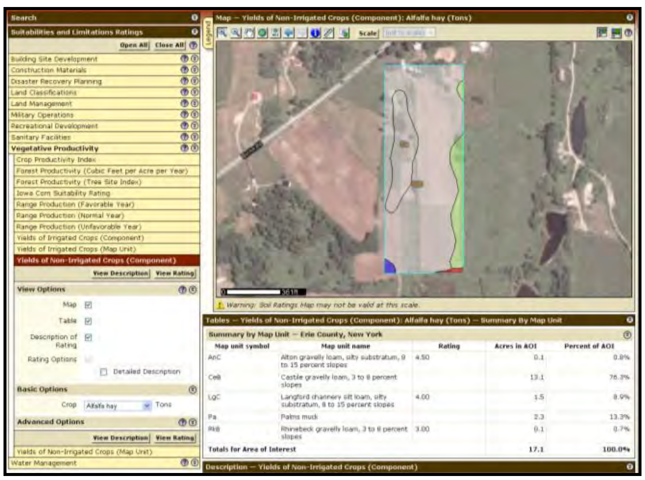


Figure 3: Illustration of soil suitability and limitations for alfalfa hay yields.

Soil Data Explorer

The "Soil Data Explorer" tab provides information about land use suitability and limitations (Figure 3). The first tab on the left, "Intro to Soils", shows definitions of soil terms that may be useful. For example, if the user wants to know what a soil horizon is, (s)he can check that box and a definition will appear. The second tab is titled "Suitabilities and Limitations for Use". For example, clicking on "Vegetative Productivity" and selecting "Yields of Non-Irrigated Crops", will give a user two options: (1) "View Description", and (2) "View Rating". The description provides a text-based overview of the properties and the "View Rating" provides a visual map with associated tables listing the soil names, ratings of yields, acres and percentages of area compared to the entire AOI (Figure 3). The "Soil Properties and Qualities" tab includes links to maps and tables of the specific physical, chemical, erosion, and water features of the soils in the AOI. The "Soil Reports" tab offers several summary reports of the information available on the other tabs. For example, in the "AOI Inventory" option, users can generate comprehensive soil series reports by selecting "Map Unit Description (Brief, Generated)" to view a broad range of information about soils in the AOI.

Printing

Each page can be printed by using the printable version feature. In "Soil Reports", check the boxes of desired items to be printed and a report will be compiled. Adding maps and data to the "Shopping Cart" will ensure they will be included in the "Custom Soil Resource Report".

In Summary

The WSS is an excellent resource for farmers and farm advisors; it helps users identify soil characteristics, as well as evaluate fields for production potential, management challenges, and environmental concerns.

Additional Resources:

- Natural Resources Conservation Service Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/) and bulletin (http://nrb.state.vt.us/lup/publications/wssbrochure.pdf).

For more information

Cornell University Cooperative Extension

Nutrient Management Spear Program
http://nmsp.cals.cornell.edu

Joseph Foster, Dale Gates (NRCS), Greg Albrecht (NYSDAM), Karl Czymmek, and Quirine Ketterings

2010

Soil Survey and Interpretations

Soil Survey—Definition and Description—*from Soil Division Staff, 2017.*
A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organized database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems. The information collected in a soil survey helps in the development of land use plans and can be used to evaluate and predict the effects of land use on the environment.

A soil map consists of many individual delineations showing the location and extent of different soils. The collection of all delineations that have the same symbol on the map (e.g., 34B) are a "map unit." Each map unit is named for one or more soils or nonsoil areas (e.g., Sharpsburg silt loam). Each kind of soil or nonsoil (e.g., Rock outcrop) making up the composition of a map unit is a map unit component. See chapter 4 for a full discussion of map units and their components.

The soils are natural three-dimensional bodies occupying a characteristic part of the landscape. Soil survey maps are therefore different from other maps that show just one or a few specific soil properties or other environmental information. The concept of soil survey as defined for the NCSS is related to, but does not include, maps showing the distribution of a single soil property (such as texture, slope, or depth) alone or in limited combinations; maps showing the distribution of soil qualities (such as productivity or erodibility); and maps of soil-forming factors (such as climate, topography, vegetation, or geologic material). A soil map from a soil survey, as defined here, delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its pedogenic history. The soils mapped by the NCSS are identified by names that serve as references to a national system of soil classification.

The geographic distribution of many individual soil properties or soil qualities can be extracted from soil maps and shown on separate maps for special purposes, such as showing predicted soil behavior for a particular use. Numerous interpretative maps can be derived from a soil map, and each of these maps would differ from the others according to its purpose. A map made for one specific interpretation rarely can serve a different purpose.

Maps that show one or more soil properties can be made directly from field observations without making a basic soil map. Such maps serve their specific purposes but have few other applications. Predictions of soil behavior can also be mapped directly; however, most of these interpretations will need to be changed with changes in land use and in the cultural and economic environment. For example, a map showing the productivity of crops on soils that are wet and undrained has little value after drainage systems have been installed. If the basic soil map is made accurately, and a wide array of soil property data is collected and stored in an organized database, interpretative maps can be revised as needed without additional fieldwork. In planning soil surveys, this point needs to be emphasized. In some cases, inventories are made for some narrow objective, perhaps at a cost lower than that of a soil survey. Generally, maps for these inventories quickly become obsolete. They cannot be revised without fieldwork because vital data are missing, facts are mixed with interpretations, or boundaries between significantly different soil units have been omitted.

The basic objective of soil surveys is the same for all kinds of land, but the number of map units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus, a soil survey is designed for the soils and the soil related problems of the area. Soil surveys increase general knowledge about soils and serve practical purposes. They provide soil information about specific geographic areas needed for regional or local land use plans. These plans include resource conservation for farms and ranches, development of reclamation projects, forest management, engineering projects, as well as other purposes.

USDA NRCS photo Web Soil Survey | Natural Resources Conservation Service (usda.gov)

Where to find Soil Survey information—*from USDA NRCS Soil Survey Staff*

The Web Soil Survey (WSS) provides soil survey maps and information through an online, interactive mapping tool. It is operated by the USDA Natural Resources Conservation Service (NRCS). The WSS is used by agricultural producers, conservationists, planners, engineering firms, government agencies, and others to explore properties, features, suitabilities, and limitations of soils and to view descriptions of ecological sites. Soil maps and associated data are available for more than 95 percent of the counties in the United States.

A user is able to select an area of interest through a variety of methods, including defining an area on a map, selecting an area from menus, searching on keywords, or importing a shapefile. The user can access a wide range of detailed information, including chemical properties, physical properties, erosion factors, water features, and ratings for building site development, sanitary facilities, and vegetative productivity. The resulting soil map and associated information can be printed, downloaded, or saved for download later.

Soil properties are measured or inferred from direct observations in the field or laboratory. Examples of soil properties are particle-size distribution, cation-exchange capacity, and salinity.

Soil qualities are behavior and performance attributes that are not directly measured. They are inferred from observations of dynamic conditions and from soil properties. Examples of soil qualities are corrosivity, natural drainage, frost action, and wind erodibility.

Soil properties and soil qualities are the criteria used in soil interpretations, as predictors of soil behavior, and for classification and mapping of soils.

Soil survey interpretations predict soil behavior for specified soil uses and under specified soil management practices. They can be used for establishing criteria for laws, programs, and regulations at local, State, and national levels. They assist the planning of broad categories of land use, such as cropland, rangeland, pastureland, forestland, or urban development. They are used to assist in preplanning and post planning activities for national emergencies. Soil survey interpretations also help plan specific management practices that are applied to soils, such as irrigation of cropland or equipment use. Soil interpretations provide users of soil survey information with predictions of soil behavior to help in the development of reasonable and effective alternatives for the use and management of soil, water, air, plant, and animal resources. Prediction of soil behavior results from the observation and record of soil responses to specific uses and management practices, such as seasonal wet soil moisture status and the resultant effect in a basement. Recorded observations validate predictive models. The models project the expected behavior of similar soils from the behavior of observed soils.

Soil interpretations use soil properties or qualities that directly influence a specified use or management of the soil. Soil properties and qualities that characterize the soil are criteria for interpretation models. These properties and qualities include site features, such as slope gradient; individual horizon features, such as particle size; and characteristics that pertain to soil as a whole, such as depth to a restrictive layer. Soil interpretation criteria may change with technology.

Laboratory and field measurements, models and inferences from soil properties, morphology, and geomorphic characteristics provide the values used for estimating soil properties. Sources of laboratory data commonly are the NSSC Kellogg Soil Survey Laboratory, agricultural experiment station laboratories, and State highway department testing laboratories. Pedon descriptions record field measurements, field observations, and descriptions of soil morphology. Develop lab sampling plans to fill data gaps. Changes to soil features in the database change soil interpretive results. Soil scientists prepare entries and change entries with interdisciplinary assistance of engineers, agronomists, foresters, biologists, resource conservationists, range conservationists, and others.

The farmland classification designates map units as prime farmland, farmland of statewide importance, farmland of local importance, or farmland of unique importance. Soil map units with components of prime farmland are classified as prime where 50 percent or more of the components in the map unit composition are prime; of statewide importance where less than 50 percent of the components in the map unit are prime but a combination of lands of prime or statewide importance is 50 percent or more of the map unit composition; of local importance where less than 50 percent of the components in the map unit are of prime or statewide importance but the total of land of prime, statewide, and/or local importance is 50 percent or more of the map unit composition.

All other soil map units are shown as not farmland unless they are designated as unique.

Prime farmland is defined as land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops and that Title 430 – National Soil Survey Handbook (430-622-NSSH, June 2020) 622-A.4 is available for these uses. It has the combination of soil properties, growing season, and moisture supply needed to produce sustained high yields of crops in an economic manner if it is treated and managed according to acceptable farming methods. In general, prime farmland has an adequate and dependable water supply from precipitation or irrigation, a favorable temperature and growing season, an acceptable level of acidity or alkalinity, an acceptable content of salt or sodium, and few or no rocks. Its soils are permeable to water and air. Prime farmland is not excessively eroded or saturated with water for long periods of time, and it either does not flood frequently during the growing season or is protected from flooding. Users of the lists of prime farmland map units should recognize that soil properties are only one of several criteria that are necessary.
Other considerations for prime farmland are the following:

(i) Land use.—Prime farmland is designated independently of current land use, but it cannot be areas of water or urban or built-up land. Map units that are complexes or associations containing components of urban land or other miscellaneous areas, as defined in the Soil Survey Manual as part of the map unit name (i.e., major components), cannot be designated as prime farmland. The soil survey memorandum of understanding determines the scale of mapping, and local land use interests should be considered in designing map units.

(ii) Flooding frequency.—Some map units may include both prime farmland and land not prime farmland because of variations in flooding frequency.

(iii) Irrigation.—Some map units have areas with a developed irrigation water supply that is dependable and of adequate quality while other areas do not have such a supply. In these map units, only the irrigated areas meet the prime farmland criteria.

(iv) Water table.—Most map units are drained but a few undrained areas are included. Only the drained areas meet the prime farmland criteria.

(v) Wind erodibility.—The product of I (soil erodibility) x C (climate factor) cannot exceed 60 to meet prime farmland criteria.

Unique farmland is land other than prime farmland that is used for the production of specific high-value food and fiber crops. It has the special combination of soil quality, location, growing season, and moisture supply needed to economically produce sustained high-quality and/or high yields of a specific crop when treated and managed according to acceptable farming methods. Examples of such crops are citrus, tree nuts, olives, cranberries, fruit, and vegetables. The specific characteristics of unique farmland are the following:

(i) It is used for a specific high-value food or fiber crop;
(ii) It has a moisture supply that is adequate for the specific crop (the supply is from stored moisture, precipitation, or a developed irrigation system); and
(iii) It combines favorable factors of soil quality, growing season, temperature, humidity, air drainage, elevation, aspect, or other conditions, such as nearness to market, that favor the growth of a specific food or fiber crop.

Significance.—Farmland classification identifies the location and extent of the most suitable land for producing food, feed, fiber, forage, and oilseed crops. The Natural Resources Conservation Service (NRCS) has national leadership for the management and maintenance of the resource base that supports the productive capacity of American agriculture. This management and maintenance includes identifying, locating, and determining the extent of the most suitable land for producing food, feed, fiber, forage, and oilseed crops. Prime farmland information is one of the four designations of farmland. An NRCS state conservationist can approve and have recorded in the field office technical guide (FOTG) a list of soil map units that meet soil information-based criteria, as determined by the appropriate State agency, for additional farmland of statewide importance.

NCF-Envirothon 2024 New York

Soils and Land Use Study Resources

Key Topic #3: Soil Ecology and Soil Health

9. Explain the importance of biological diversity and how it is important for soil health, environmental health, and human health.
10. Identify predominant types of organisms (flora and fauna) in a soil ecosystem and explain their roles and effects on soil properties (such as decomposition, nutrient cycling, impacts on soil color etcetera).
11. Describe common agricultural practices (including conventional till, no-till, cover crops, compost, irrigation, etcetera) and explain their effects on soil health.
12. Describe how soil properties can influence the plant communities found on a particular soil.
13. Describe the possible challenges for gardening in a historically urban setting and apply management practices to address these issues.

Study Resources

Resource Title	Source	Located on
Soil Biology and Land Management	*Soil Quality-Soil Biology Technical Note, NRCS, 2004*	page 43-60
Soil Contaminants and Best Practices for Healthy Gardens	*Hannah Shayler, Murray McBride, Ellen Harrison, Cornell Waste Management Institute, 2009*	page 61-63
Healthy Soils, Healthy Communities- Metals in Urban Garden Soils	*NYS Department of Health, Cornell University, Cornell University Cooperative Extension NYC, 2015*	page 64-72
Healthy, Productive Soils Checklist for Growers	*Natural Resources Conservation Service, 2013*	page 73-74
Soil Health in Field and Forage Crop Production	*Sjoerd W. Duiker, Joel C. Myers and Lisa C. Blazure, USDA-NRCS with Penn State University, 2017*	page 75-93

<u>Study Resources begin on the next page!</u> ➡

Soil Biology and Land Management

The goal of soil biology management

The goal of managing the soil biological community is to improve biological functions, including forming and stabilizing soil structure, cycling nutrients, controlling pests and disease, and degrading or detoxifying contaminants.

Research shows that management practices and disturbances impact soil biological functions because they can 1) enhance or degrade the microbial habitat, 2) add to or remove food resources, or 3) directly add or kill soil organisms. Although management practices are known to impact soil biology, there is limited knowledge to support the development of detailed management strategies. A particular practice may have the desired result in one situation but have little effect in another because biological communities respond to the interaction of multiple factors including food sources, physical habitat, moisture, and impacts of historical land use. Therefore, before a new product or practice is applied to a large parcel of land, it should be tested on a limited area and results should be monitored in comparison to an untreated plot.

Why should land managers understand soil biology?

Energy and the food web

Through agriculture, the sun's energy is converted into food, feed, and fiber. However, most of the solar energy captured by plants is not directly harvested when crops are gathered; instead, it feeds the belowground food web. Feeding the "underground livestock" is essential to productive forests, rangeland, and farmland. Figure 1 shows how energy is recycled repeatedly through belowground soil organisms. The soil food web is part of energy, nutrient, and water cycles. The energy cycle begins when the sun's energy is captured by the plant-based (aboveground) food web. Nutrient availability is governed by the detritus-based (belowground) food web. The water cycle is also influenced by the interaction of plants, soils, and soil organisms.

Functions of the soil food web

Nutrient cycling

In a healthy soil ecosystem, soil biota regulates the flow and storage of nutrients in many ways. For example, they decompose plant and animal residue, fix atmospheric nitrogen, transform nitrogen and other nutrients among various organic and inorganic forms, release plant available forms of nutrients, mobilize phosphorus, and form mycorrhizal (fungus-root) associations for nutrient exchange. Even applied fertilizers may pass through soil organisms before being utilized by crops.

Soil stability and erosion

Soil organisms play an important role in forming and stabilizing soil structure. In a healthy soil ecosystem, fungal filaments and exudates from microbes and earthworms help bind soil particles together into stable aggregates that improve water infiltration, and protect soil from erosion, crusting, and compaction. Macropores formed by earthworms and other burrowing creatures facilitate the movement of water into and through soil. Good soil structure enhances root development, which further improves the soil.

Water quality and quantity

By improving or stabilizing soil structure, soil organism dynamics help reduce runoff and improve the infiltration and filtering capacity of soil. In a healthy soil ecosystem, soil organisms reduce the impacts of pollution by buffering, detoxifying, and decomposing potential pollutants. Bacteria and other microbes are increasingly used for remediation of contaminated water and soil.

Plant health

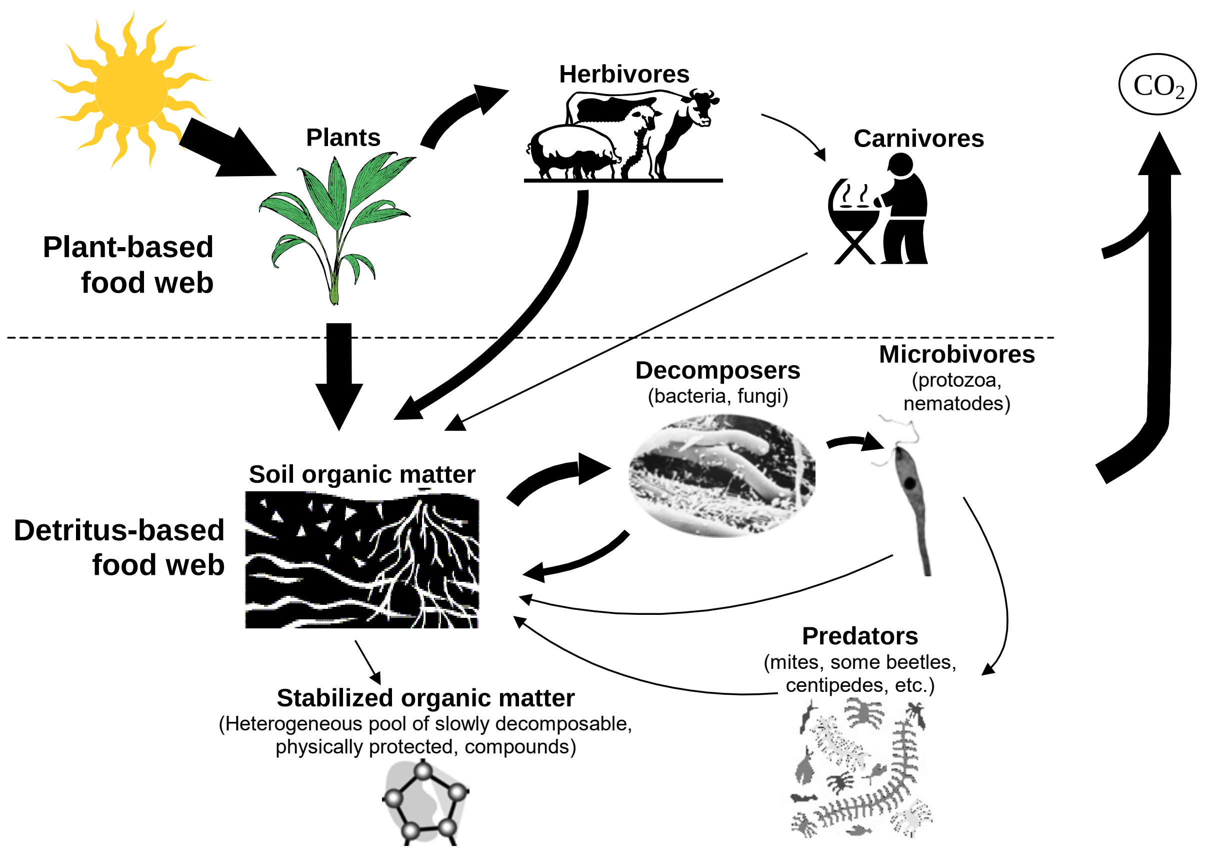
A relatively small number of soil organisms cause plant disease. A healthy soil ecosystem has a diverse soil food web that keeps pest organisms in check through competition and predation. Some soil organisms release compounds that enhance plant growth or reduce disease susceptibility. Plants may exude specific substances that attract beneficial organisms or repel harmful ones, especially when they are under stress, such as grazing.

For more information about what lives in the soil and how they function, see the "Soil Biology Primer" (Tugel and Lewandowski, 1999), and the soil biology glossary on the NRCS Soil Quality web site.

Complexity and function

Many soil biological functions emerge from the complex interactions of soil organisms and are not predictable by adding up the activity of individual soil organisms. How well the soil community performs each of these functions depends in part on the complexity of the biological community. Complexity is a factor of both the number of species and the different kinds or functions of species. Greater complexity may imply more diversity of functions and more redundancy of functions, and therefore more stability. For example, when multiple populations of microbes convert ammonium to nitrate, even if one population dies out, the function (nitrification) will continue to be performed. Functional redundancy is the underlying idea behind the "insurance hypothesis," which states that biodiversity insures ecosystems against declines in function.

Figure 1. The plant-based (aboveground) and detritus-based (belowground) food webs. Arrows represent energy flow (commonly measured in carbon units). Of the aboveground organic matter entering the pool of soil organic matter, 60%-80% of the carbon is eventually lost as CO_2. (Based on Chapin et al., 2002, Fig. 11.12.)



The underground community

Soil organisms can be grouped by size as shown in figure 2, or by functions as described below (Wardle, 2002; Coleman & Crossley, 1996).

Decomposers

Bacteria, actinomycetes (filamentous bacteria), and saprophytic fungi degrade plant and animal residue, organic compounds, and some pesticides. Bacteria generally, but not exclusively, degrade the more readily decomposed (lower C:N ratio) materials, compared to fungi, which can use more chemically complex materials. (See boxes on pages 7 and 8.) Bacteria often degrade what they can of a particular material; then fungi decompose the remainder.

Grazers and predators

Protozoa, mites, nematodes, and other organisms "graze" on bacteria or fungi; prey on other species of protozoa and nematodes; or both graze and prey. Grazers and predators release plant-available nutrients as they consume microbes. Often organisms specialize in one type of prey, such as either bacteria or fungi. Certain collembolans (springtails) even specialize on specific species of fungi. Other organisms are generalists and will feed on any microbial species they encounter.

Litter transformers

Arthropods are invertebrates with jointed legs, including insects, spiders, mites, springtails, centipedes, and millipedes. Many soil arthropods shred and consume plant litter and other organic matter, increasing the surface area accessible to decomposers. The organic matter in their fecal pellets is frequently more physically and chemically accessible to microbes than was the original litter. Some litter transformers, especially ants, termites, scarab beetles, and earthworms, are "ecosystem engineers" that physically change the soil habitat for other organisms by chewing and burrowing through the soil. Microbes (decomposers) living within their guts break down the plant residue, dung, and fecal pellets consumed along with the soil.

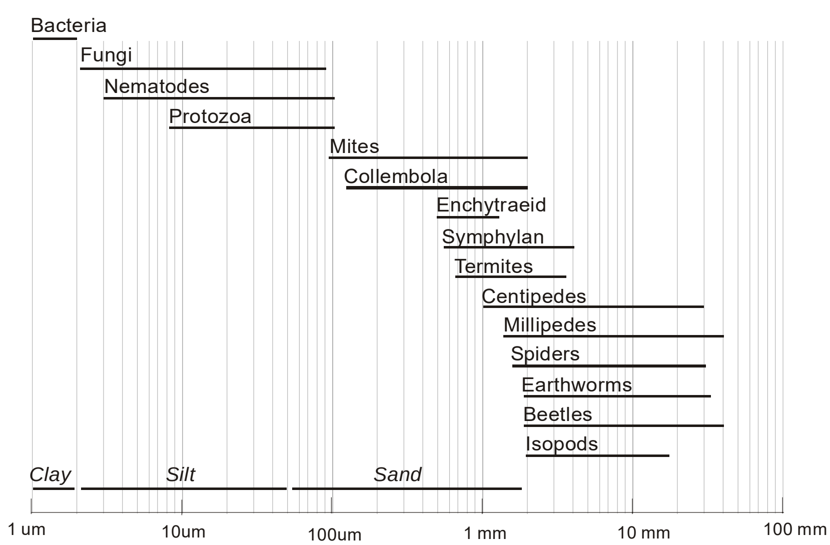
Mutualists

Mycorrhizal fungi, nitrogen-fixing bacteria, and some free-living microbes have co-evolved together with plants to form mutually beneficial associations with plants. Mycorrhizae are associations between fungi and plant roots in which the fungus supplies nutrients and perhaps water to the plant, and the plant supplies food to the fungi. These fungi can exist inside (endomycorrhizae) or outside (ectomycorrhizae) the plant root cell wall. The common arbuscular mycorrhizae (AM or VAM fungi) are endomycorrhizae.

Pathogens, parasites, and root feeders

Organisms that cause disease make up a tiny fraction of the organisms in the soil, but have been most studied by researchers. Disease-causing organisms include certain species of bacteria, fungi, protozoa, nematodes, insects, and mites.

Figure 2. Body width of soil organisms (Swift et al., 1979).



What controls soil biology?

People can adapt management strategies to affect the factors that control soil biological communities. Soil biological activity is determined by factors at three different levels. 1) At the scale of *individual organisms*, biological activity is determined by conditions such as temperature and moisture in the microbial habitats. 2) At the scale of *populations*, biological activity is determined by the amount of habitat diversity, the types of habitat disturbances, and the diversity and interactions among various soil populations.
3) At the scale of *biological processes*, functions such as nutrient cycling or pest control are affected by the interaction of biological populations with physical and chemical soil properties.

For example, consider the effect of tillage on earthworms at each of these scales. At the scale of individual organisms, a single tillage event may kill as many as 25 percent of individual earthworms. At the scale of populations, a single tillage pass may have little effect after a few months as the earthworms reproduce and rebuild their population. At the scale of soil processes, tillage will weaken soil structure over time and reduce the amount of surface residue available to fungi and earthworms. As fungal and earthworm activity declines, soil stability declines and alters the microhabitats for other organisms.

Microscale factors

The following environmental factors affect the types and activity levels of soil organisms. These factors may vary over short distances in the soil. Consider how each factor is impacted by climate, soil texture, time of day or season, and management practices including tillage, crop rotation, and irrigation.

Food (nutrients and energy)

All organisms require a source of food that supplies nutrients and energy. “Primary producers” are organisms that use photosynthesis to make their own food from sunlight and CO_2. “Consumers” are organisms that use organic compounds from other organisms as their source of both carbon and energy. A small group of bacteria get their energy from inorganic nitrogen, sulfur, or iron compounds, rather than from sunlight or organic compounds. These bacteria are important in cycling some nutrients required by plants. Soil organisms also require varying amounts of macronutrients (N, S, and P) and micronutrients (e.g. Fe, Cu, Zn). The amount of all these nutrients and the quality of nutrient sources will favor some organisms over others, depending on each species’ requirements and preferences.

Oxygen

Animals and most soil organisms are obligate aerobes, meaning they require oxygen. Some bacteria are obligate anaerobes, meaning they require oxygen-free conditions to function. Many organisms are facultative anaerobes, meaning they can switch metabolic pathways and function as either aerobes or anaerobes depending on environmental conditions. Anaerobes use nitrate, sulfate, or iron instead of oxygen as an electron acceptor. Aerobic respiration is the most common form of metabolism and typically produces ten times more energy per unit of organic matter than that generated through anaerobic metabolism. Anaerobic conditions and anaerobic microbes dominate in marshes and other saturated soils. However, even well-drained soils can have anaerobic and aerobic microsites within millimeters of each other. See box (next page) for a list of processes performed by aerobic and anaerobic organisms.

Anaerobic soil biological processes

Fermentation – Conversion of sugar to alcohol.

Denitrification – Reduction of nitrate to gaseous nitrogen.

Methane production – Reduction of CO_2 to methane (CH_4) in marshes and rumens.

Sulfur reduction – Reduction of sulfate to hydrogen sulfide or sulfur.

Iron reduction

Aerobic soil biological processes

Respiration – The conversion of oxygen eventually to carbon dioxide and water.

Ammonification – The creation of ammonia from organic compounds. May also occur anaerobically slowly.

Nitrification – The oxidation of ammonium to nitrite and then nitrate.

Other physical factors

Moisture, temperature, light, pH, and electrical conductivity (salinity) are other critical factors determining the level of biological activity within an ecosystem. Each species has different optimal conditions, but overall bacterial activity is highest at temperatures between 20°C and 40°C, at pH levels between 6 and 8, and when pore spaces are about 60% water-filled. Soil texture and porosity determine the amount of space available for soil organisms and for the movement of air and water through the soil. Thus, porosity, aeration, and moisture levels are linked. Relatively larger organisms, such as nematodes and small mites (figure 2), require large pore spaces to move. Many organisms, including protozoa and nematodes, are essentially aquatic and require water films.

Community-scale factors

The microscale factors listed above directly affect soil organisms. However, to understand soil biological function we also have to consider large-scale factors such as heterogeneity of habitat, disturbances, and biological interactions.

Heterogeneity of resources

Heterogeneity can refer to variation in food sources or any of the other microscale conditions listed above. Heterogeneity of soil habitats creates diversity and complexity in the structure of the soil food web. Plant diversity is an important means for creating heterogeneity because plants affect the food sources, the physical habitat (e.g. root structures and soil structure), and the chemical attractants and deterrents for soil organisms.

Disturbance

All human land uses, especially agriculture, are subject to natural and human disturbances including fire, harvest, tillage, compaction, overgrazing, disease, or pesticide applications. The frequency, severity, and timing of disturbances determine their effect on soil biological activity. According to the intermediate disturbance hypothesis, the greatest level of biological diversity and stability occurs with a “Goldilocks” amount of disturbance – not so much that processes are continually disrupted, and not so little that just a few species gain dominance. Conventional cropping systems are highly disturbed systems. Low-input, conservation tillage systems with crop rotations may be an example of an intermediately disturbed ecosystem.

Interactions with other organisms

Soil populations are affected by interactions with other soil organisms. One type of biotic interaction is *competition* for limited food and habitat. A second type is *predation* by larger organisms, such as nematodes and mites. A third type is *mutualism* – interactions beneficial to both parties, such as those involving mycorrhizae, symbiotic nitrogen fixers, many rhizosphere microbes, and microbes living in earthworm guts. When land management practices disproportionately affect one group of organisms over another, they impact the interactions among soil organisms.

General management strategies

Four broad management strategies are presented below. The diversity and functioning of a soil biological community are likely to improve when these strategies are used. Management plans should consider both the timing of management practices and disturbances, and the duration and degree of their effects on soil biology. The effects of management and disturbances vary by season, and the capacity of the soil community to recover from a particular practice or disturbance ranges widely.

1) Manage organic matter.

Regular inputs of organic matter are essential for supplying the energy that drives the soil food web. Each source of organic matter favors a different mix of organisms. (See boxes, this page and next.) Thus, a variety of sources may support a variety of organisms. The location of the organic matter—whether at the surface, mixed into the soil, or as roots—also affects the type of organisms that dominate in the food web.

Under any land use, organic matter inputs to the soil can be increased by improving plant productivity and increasing annual biomass production. In particular, good root growth is important for building soil organic matter. High biomass production should be combined with other organic matter management practices including minimizing residue removal and tillage, growing cover crops, and adding manure, mulch, or other amendments.

Components of organic matter

Organic matter is composed of a heterogeneous mix of compounds with various chemical bonding and branching characteristics. Each organism has the necessary enzymes for decomposing some compounds but not others. For example, lignin is a recalcitrant organic compound that can only be broken down by white and brown rot fungi.

The composition of organic matter from plants varies considerably, but generally comprises 60-70% carbohydrates (polysaccharides),
15-20% lignin, and 15% other compounds including proteins, nucleic acids, lipids, waxes, and pigments.

2) Manage for diversity.

The diversity of plant assemblages across the landscape and over time promotes a variety of microbial habitats and soil organisms. Up to a point, soil biological function generally improves when the complexity or diversity of the soil biological community increases.

Many types of diversity should be considered, such as diversity of land uses (buffers, forest, row crops, grazing land), plant types (perennial, annual, woody, grassy, broadleaf, legume, etc.), root structures (tap, fibrous, etc.), and soil pore sizes. Diversity is desirable over time as well as across the landscape. Land managers can increase diversity with appropriate grazing management, patchy or selective tree harvest (in contrast to broad clear-cutting), vegetated fencerows, buffer strips, strip cropping, and small fields. These landscape features provide refuges for beneficial arthropods. Diversity over time can be achieved with crop rotations. Rotated crops put a different food source into the soil each year, encouraging a wide variety of organisms and preventing the build-up of a single pest species.

3) Keep the ground covered.

Ground cover at or near the surface moderates soil temperature and moisture; provides food and habitat for fungi, bacteria, and arthropods; and prevents the destruction of microbial habitat by erosion. Minimize the length of time each year that soil is bare by maintaining a cover of living plants, biological crusts, or plant residue at the surface.

Living plants are especially important as cover because they create the rhizosphere—that area within one or two millimeters of living roots where soil biological activity is concentrated.

Microbes around roots take advantage of plant exudates and sloughed-off root cells. Maintaining a rhizosphere environment is one of the important benefits of using cover crops. In addition to preserving microbial habitat, cover crops help build and maintain populations and diversity of arthropods by preserving their habitat for an extended portion of the growing season.

4) Manage disturbances.

Some soil perturbations are a normal part of soil processes, or are a necessary part of agriculture and other land uses. However, some disturbances significantly impact soil biology and can be minimized to reduce their negative effects. These disturbances include compaction, erosion, soil displacement, tillage, catastrophic fires, certain pesticide applications, and excessive pesticide usage.

Carbon-to-nitrogen ratio

The carbon-to-nitrogen ratio (C:N) of organic matter can vary from about 4:1 (low carbon, high nitrogen) for bacteria to more than 200:1 to 600:1 for woody materials. Ratios for wheat straw are about 80:1, and young legumes may be 15:1. The C:N ratio of soil organic matter in agricultural soils averages 10:1. Fungi have a fairly constant C content of 45%, but N levels vary, resulting in C:N ratios of 15:1 to 4.5:1.

Low N materials have a low nutritional quality for microbes. When organic materials are added to soil, the carbon triggers microbial growth. If the amount of N in the added material is inadequate to support the increased growth, the microbes will absorb nitrogen from the soil and immobilize it in their tissues, thus depriving plants of nitrogen, at least temporarily. As a rule-of-thumb, materials with C:N ratios less than 25 or 30:1 will not trigger this N deficiency in plants. Materials with lower C:N ratios tend to decompose quickly. Materials with higher C:N ratios are slow to decompose and can lead to carbon storage or sequestration in the soil when accompanied by additional nitrogen inputs in reduced tillage systems.

C:N ratios of soil organic matter provide clues about the microbial community. For example, higher ratios tend to support more fungi compared to bacteria. A labile pool of soil organic matter with a low C:N ratio implies that the SOM consists of a high proportion of microbes.

Compaction

Ideally, soils are approximately 50 to 60% pore space comprising a variety of pore sizes and lengths. The size and continuity of pores controls whether larger microbes, such as protozoa, can prey upon bacteria and fungi. Compaction reduces the diversity of pore sizes and the amount of space and pathways available for larger organisms (figure 2) to move through the soil. This favors bacteria and small predators over fungi and the larger predators. Arthropods are severely affected by compaction. Among nematodes, the predatory species are most sensitive to compaction, followed by fungal-feeders, then bacterial-feeders. Root-feeding nematodes are least sensitive to compaction—perhaps because they do not need to move through soil in search of food. Compaction changes the movement of air and water through soil, can cause a shift from aerobic to more anaerobic organisms, and may increase losses of nitrogen to the atmosphere (denitrification). Rooting depth may be limited in highly compacted soils. This restricts the depth of the rhizosphere environment that supports microbes.

Erosion and sedimentation

Most soil organisms – especially larger ones – live in the top few inches of soil. Erosion disrupts and removes that habitat. Sedimentation buries the surface habitat and deprives organisms of space and air.

Soil displacement and tillage

Displacement and mixing of the soil occur during many activites including tillage, land leveling, grading, intense grazing, and site preparation and harvesting on forestlands. Some soil displacement can be useful such as tillage for seedbed preparation in cropland, limited disturbances in highly productive grassland systems, and soil scarification to ensure success of some types of reforestation. However, soil disturbances significantly change the biological habitat of the soil. If the extent of the disturbance is limited to small areas, the overall impact will also be limited. Broadly applied practices such as tillage, grazing, or clear-cutting can impact large areas. Even a single tillage or compaction event can significantly affect the location and quantity of the food supply and the physical habitat of soil organisms. If enough nitrogen is present, tillage and other practices that mix the soil usually lead to a flush of microbial activity and nutrient release, and loss of soil organic matter via CO_2 respiration. Where there is a loss of soil organic matter, microbial activity will eventually drop to a rate that is lower than the initial rate. Over time, tillage shifts the food web from being dominated by fungi to being dominated by bacteria.

Pesticides and herbicides

All pesticides impact some non-target organisms. Heavy pesticide use tends to reduce soil biological complexity. Total microbial activity often increases temporarily as bacteria and fungi degrade a pesticide. However, effects vary with the type of pesticide and species of soil organism. Labels generally do not list the non-target organisms affected by a product. In fact, few pesticides have been studied for their effect on a wide range of soil organisms. Pesticides that kill aboveground insects can also kill beneficial soil insects. Foliar insecticides applied at recommended rates have a smaller impact on soil organisms than fumigants or fungicides. Herbicides probably affect few organisms directly, but they affect the food and habitat of soil organisms by killing vegetation. A pulse of dead vegetation may trigger a flush of biological activity and decomposition. Crop rotations are useful for breaking pest cycles, reducing pesticide application rates, and for varying the families of pesticides used.

Considerations for specific land uses

The effects of management practices, operations, and natural disturbances often are specific to particular land uses, such as those discussed in this section. Each of the considerations below relates to the general management strategies described in the previous section.

Cropland

The highly disturbed soils of cropland may have as many bacteria and protozoa as other ecosystems, but tend to have far fewer fungi, nematodes, and arthropods. Reduced tillage and perennial cropping systems will support more of these larger soil organisms.

Crop biomass additions

Roots and surface residue from crops are convenient and valuable sources of soil organic matter and food for soil organisms. Corn harvested for grain will generate 3 to 4 tons of surface residue per acre and 1 to 2 tons of root biomass. Dense, sod-type crops produce generous amounts of root biomass. Recent research suggests that root contributions are more significant for building soil organic matter than are contributions from aboveground plant residue.

Surface residue encourages the decomposers—especially fungi—and generally increases food web complexity. Residue provides food and habitat for surface-feeding organisms, such as some earthworms, and for surface-dwellers, such as some arthropods. It also changes the moisture and temperature of the soil surface, and protects soil organic matter from erosion. The residue will increase some pathogens and reduce others. Soybeans, peanuts, and many vegetables leave little surface residue and should be rotated with high residue crops or cover crops.

Animal manure

Dung pats provide food and habitat for a variety of larger soil organisms. Manure in any form is a significant source of nutrients. Manure application substantially changes the mix of organisms in the soil compared to plant sources of organic matter. The implications of these differences are not clear, but they probably affect disease levels and nutrient cycling. Over-application of N or P (whether from organic amendments or synthetic fertilizer) can suppress certain soil organisms, especially mycorrhizal fungi, as well as lead to degradation of air and water quality.

Compost

Compost can be used to inoculate the soil with a wide variety of organisms and to provide a high quality food source for them. Composts have also been credited with reducing the incidence of plant disease (Ceuster and Hoitink, 1999). Some species thrive in both compost and soil, but many prefer one or the other. For example, the redworms (*Eisenia fetida*) commonly used to make vermicompost do not survive well in soil. The quality of compost varies substantially depending on the material used, peak temperature during the composting process, and the level of aeration. Organic materials decomposed with little oxygen (e.g. liquid manure) will contain a very different set of organisms and compounds than well-aerated compost. (For information about how to make compost, see NRCS conservation practice standard #317, Composting Facilities.)

Sewage sludge

Like manure, sludge can be an excellent food source for organisms. However, high levels of metals or salts in some sludge kill or reduce the activity of some organisms.

Cover crops

Cover crops have several positive effects on soil communities. Most soil organisms live in the rhizosphere – the area directly around living roots. By planting cover crops (also called green manure) the rhizosphere environment is available to soil organisms for a longer portion of the year. Cover crops typically increase the amount and diversity of roots and aboveground growth that become part of soil. Because of each crop's unique physiology, populations of specific soil organisms will increase or decline depending on the crop. For example, some cover crops exude compounds that inhibit disease-causing organisms.

Inorganic fertilizers

Fertilizer provides some of the nutrients needed by soil organisms and will favor those species that can best utilize the forms of nutrients found in fertilizers. The effect of acidity, alkalinity, or salt of some fertilizers (e.g. ammonium nitrate, ammonium sulfate, and urea formaldehyde) tends to reduce populations of fungi, nematodes, and probably protozoa. It is not clear how persistent these population reductions are in various situations.

Judicious fertilizer use can be positive for overall biological activity because it increases plant growth and organic matter inputs to the soil.

Genetically modified (GMO) crops

Each type of GMO is likely to have a different effect on soil biology. For example, Bt crops seem to have little direct effect on the composition of the soil biological community, yet decomposition rates of the crop residue differ from that of other corn varieties – perhaps because of changes in plant lignin composition, which may indirectly affect soil organisms via changes in food resources. (Lignin is a plant compound that is highly resistant to microbial attack.) However, soil type and crop variety seem to be more important than the presence of the Bt gene in determining decomposition rates (Saxena and Stotzky, 2001a, b).

Drainage

Improved water drainage tends to improve microbial activity by increasing oxygen availability. Poorly drained soils have a high level of anaerobic microsites and therefore a higher rate of denitrification (conversion of nitrate to gaseous nitrogen) compared to well-drained soils.

Irrigation and salt build-up

Where irrigation increases plant yield, it increases biomass production and soil organic matter, and therefore tends to increase biological activity and to alter the biological community structure. However, irrigation water can contain salts. To prevent salt accumulation that can reduce biological activity and crop yield, additional water must be applied to leach these salts from the root zone. Some irrigation techniques, such as furrow irrigation, require extreme soil disturbance that is detrimental to biological habitat. When the disturbance is a one-time event (i.e., intense but infrequent), as with installation of subterranean irrigation pipes, the disturbance is less likely to do lasting damage.

Soil inoculants and compost tea

Some commercially available inocula are intended to increase populations of specific soil organisms. Some products have a long track record of effectiveness, including nitrogen-fixing bacteria and some pest predators, such as bacteria, nematodes, or insects. Some products are unproven or unpredictable.

Inoculants will have little effect or only a temporary effect if the organisms cannot compete in their new environment. Because they must have supplies of organic matter as a food source, soils low in organic matter will not see long-lasting results unless a recurring supply of organic matter is added to the system. Furthermore, many functions performed by soil organisms result from the interactions of organisms, not from a few individual species.

When considering using inoculants, ask the following questions:

- Do you have assurances that the organisms claimed to be in the product are viable?
- Will the organisms survive in your soil environment long enough to have the desired effect?
- If you achieve positive results, was the change caused by the inoculated organisms or by associated management

practices, such as changes in tillage or added organic matter?

Before committing a whole farm to a new product, test it on a small area and compare results to a control strip managed identically but without application of the product. Monitor both short- and long-term effects.

Land leveling

Land leveling may have effects similar to erosion and sedimentation because biologically active surface soil is removed from some areas and deposited in other parts of the field. It may also expose subsoil with a less desirable texture or lower organic matter levels. This effect can be reduced by intense soil building practices after land leveling or by removing and stockpiling the topsoil just prior to land leveling and then spreading it over the newly leveled surface.

Terraces and grassed waterways

Permanent vegetative structures add diversity to a landscape and thus can enhance the biodiversity of the area. They serve as a refuge for larger soil organisms such as arthropods and pest predators. However, like land leveling, the soil movement involved during construction of terraces can significantly disrupt soil biological habitat.

Tillage and no-till

Tillage enhances bacterial growth in the short-term by aerating the soil and by breaking apart soil aggregates to expose organic matter that had been protected from microbial decay. The bacterial activity increases the loss of carbon respired as CO_2, and triggers population explosions of bacterial predators such as protozoa. Ultimately, recurrent tillage reduces the amount of soil organic matter that fuels the soil food web.

The mechanical action of tillage tends to temporarily reduce populations of fungi, earthworms, nematodes, and arthropods. Over the long term with repeated tillage, these populations are likely to decline because of the lack of surface residue rather than because of the mechanical action of tillage.

The environment for soil organisms can differ significantly in no-till compared to conventionally tilled soils. For example, because the surface soil structure is not regularly disrupted, no-till soils are more likely to have:

- Anaerobic micro-environments,
- Cooler spring soil temperatures because of greater surface cover,
- More macropores to facilitate infiltration,
- Greater soil moisture and carbon near the surface, and
- Uneven distribution of organic matter throughout the topsoil.
- In addition, surface compaction may be a problem if compaction was present before the conversion to no-till, and if biomass inputs are low or traffic patterns are not controlled.

Organic matter decomposition rates are lower in no-till vs. conventionally tilled soils because of the lower level of soil disturbance. The lack of disturbance and the presence of surface residue encourage fungi and large organisms such as arthropods and earthworms. No-till soils generally have a higher ratio of fungi to bacteria.

Fallow periods

Because microbes concentrate around living roots, fallow periods of even a few weeks at the beginning or end of a growing season reduce an important microbial habitat. During long fallow periods, most arthropods will emigrate or die of starvation. Some organisms can form cysts, allowing them to lie dormant until conditions become more favorable. Mycorrhizal fungi also "starve" during a fallow period and take time to recover after the fallow period ends. Growing non-mycorrhizal plants is equivalent to a fallow year from the perspective of mycorrhizal fungi. Plants that do not support mycorrhizae include brassicas (mustard, broccoli, canola) and chenopods (beets, lamb's-quarters, chard, spinach). (See section on mutualists, page 4, for more information about mycorrhizae.)

Forestland

Forest soils have high ratios of fungi relative to bacteria, especially under coniferous forests. The fungi are predominately ectomycorrhizae that infect tree roots and then extend their hyphae into the soil. This greatly increases the tree's effective root zone, allowing access to a greater area of soil from which to extract water and nutrients. The mantle created by mycorrhizae around the root also prevents pathogenic fungi and bacteria from attacking the root system.

Arthropods can be quite numerous in forests because the soil is rarely disturbed. Earthworms are common in deciduous forests, but rare among conifers. Where non-native earthworms (e.g., fishing bait) have been introduced into deciduous forests, significant changes in understory vegetation have been observed (Minnesota DNR, 2004).

Tree harvesting

Tree harvesting removes nutrients from the area, reduces the total uptake of nutrients by plants, and can accelerate biological activity and decomposition. Tree harvest can change the activity, amount, and diversity of the microbial community. The degree of site disturbance during harvesting and the amount of slash remaining after harvest determines the effects on soil organisms. Techniques that minimize soil disturbance and compaction will have the least detrimental effect on soil organisms. Tractors, wheeled skidders, and mechanized harvesting equipment disturb the soil surface and can cause compaction that restricts biological activity. Cable, helicopter, and horse logging produce the least disturbance. Soil surface displacement and mixing of soil, duff, and slash temporarily increase microbial activity and may interfere with arthropod activity.

Clear-cutting generally has a negative effect on soil biological activity. The large number of roads, skid trails, and landings compact soil and are particularly susceptible to erosion. When erosion and loss of mycorrhizal host plants is severe mycorrhizal fungi may be lost from the ecosystem. Compared to soil under trees, bacteria and actinomycetes, such as streptomyces, are more prominent in clear-cut areas, between trees in thinned areas, and between intact forest patches. When reclaiming clear-cut forests it is beneficial to inoculate new tree seedlings with mycorrhizal fungi, forest soils, or litter containing these fungi. Retaining patches of intact forests among clear-cut areas provides a source of soil organisms to re-inoculate the harvested areas.

Thinning and fuel management

Thinning of forests has a positive effect on soil biological diversity, especially in single-age stands. Thinning increases the diversity of understory vegetation and thus creates more diversity of habitats and food sources for soil organisms. (This is an example of the intermediate disturbance hypothesis described on page 6.) However, excessive compaction and soil displacement can have negative effects.

Roads, trails, and landings

Compaction created under roads, skid trails, and landings compresses soil particles together and reduces pore sizes. This restricts the habitat for soil organisms, especially the nematodes and larger arthropods. The use of designated skid trails and restoration of landings after harvest minimizes the amount of forestland affected.

Slash piling and woody debris

Machine or hand piling of slash concentrates nutrient-rich branches, foliage, and sometimes topsoil. This increases soil organism populations and activity locally. Excessive nutrient leaching can occur in areas where microbial activity increases. Windrowing of slash has severe detrimental effects on areas between windrows because topsoil rich in soil organisms is scarified and placed in the windrows. Runoff may also erode nutrient-rich surface soil and organic matter from slash areas, potentially degrading water quality of nearby streams and lakes.

Wind damage increases the amount of dead wood available for soil organisms. Woody debris can enhance biological function because dead wood mitigates environmental extremes, such as heat and cold, in the microclimate of a disturbed area. In forests, downed logs serve as centers for biological activity including mycorrhizal hyphae, nitrogen-fixing bacteria, other microbes, arthropods, and even small mammals. In some systems, fungi extract water from large rotting logs and supply the water to growing trees during times of moisture stress. Downed logs also serve as natural dams to help reduce erosion and increase infiltration and thus improve recolonization by desirable species in highly disturbed areas.

Fire

Stand replacement fires – Stand replacement fires are common in single age stands of fire-adapted tree species such as lodgepole pine, jack pine, longleaf pine and black spruce. Fire is an integral part of the ecology of these forests. The microbial community tends to drop back to its previous level of activity after an initial flush of activity after a fire.

Cool or patchy fires **–** Frequent ground fires are an integral part of some forest ecosystems, such as ponderosa pine stands. These fires are not hot enough to burn the overstory trees, but the understory trees and brush are killed.

A short, cool fire rarely eliminates any group of organisms. If the fire is cool, nitrogen will not be volatilized, and the nitrogen in ash may stimulate plant growth and diversity of species. Arthropods will repopulate readily after a patchy fire.

Catastrophic wildfire – Hot, long-duration fires will kill most organisms, including microbes at or near the soil surface. The ignition of litter and duff as well as erosion after the fire reduces food available to soil organisms. The mineralization and subsequent leaching of nitrogen can significantly decrease soil fertility. Hydrophobic layers formed during hot fires can restrict the penetration of water into the soil for several years. This restricts plant and root growth thus reducing the food supply for soil organisms.

Insects and disease

The reduction of fire in some forests, such as Ponderosa pine forests, has led to an increase in insect infestations and disease. Diseased or dead trees increase the amount of woody debris that serves as fuel for hotter-burning, potentially catastrophic fires.

An invasion or increase of less disease-resistant tree species will make a forest stand more susceptible to insect infestation and disease.

Rangeland

Soil biological activity in rangelands may vary greatly over short distances. Activity may be high under shrubs and grasses and almost none in the bare spaces between plants.

Some seemingly bare spots are actually encrusted with soil organisms, such as cyanobacteria. Biological soil crusts are important for nutrient and water cycling, particularly in arid and semi-arid environments.

When plant assemblages change dramatically over time, for example, from grass- to shrub-dominated, the character of the soil biology may change to the extent that it may be difficult to convert the system back to the original plant assemblage with its associated soil community.

Grazing and vegetation management

Grazing and vegetation management are the most important tools for maintaining the benefits of the soil food web. Timely grazing, the proper frequency of grazing, and control of the amount of vegetation removed will maintain or enhance plant production and the supply of organic matter. Both overgrazing and non-grazing reduces root growth and thus the amount of organic matter inputs to the soil. Grazing stimulates root growth and production of root exudates, but overgrazing reduces the amount of leaf surface for photosynthesizing. (This is another example of the intermediate disturbance hypothesis. See page 6.) With reduced food supplies, biological activity decreases along with important soil functions, including nutrient cycling, water infiltration, and water storage. As these functions decline, the ability of the plant and soil biological communities to replenish soil organic matter also declines. Heavy grazing can reduce the abundance of nitrogen-fixing plants, causing a decrease in the nitrogen supply for the entire plant community. Where biological crusts provide important functions such as protection from erosion, the timing and intensity of grazing should be managed to minimize damage to crusts. Ensuring even manure distribution is another mechanism by which good grazing management enhances soil biological activity.

Fire

Prescribed burning in grassland communities generally produces cool temperature fires that have little or no direct effect on soil organisms. There can be short-term losses of habitat or food sources, but patchy fires leave refuges for larger soil organisms in adjacent unburned litter and grass.

Absence of fire or an increased length of time between fires commonly promotes vegetation shifts from grass-dominated to shrub- or tree-dominated plant communities. Such vegetation shifts affect the soil organisms through the change in residue composition and the depth of root zones that contribute food sources. Woody residue and roots will increase fungal populations. Bare soil between shrubs provides little food and will result in a decline in soil organism populations.

Catastrophic fire is likely to occur in dense shrub- or tree-dominated plant communities. The resinous wood and longer burn times promote hot fires that can effectively scorch the upper few inches of the soil. This will kill some soil organisms and reduce their food supply while also increasing the availability of some nutrients.

Invasive weeds

Invasive weeds can cause a shift in the types of soil organisms present because the quantity and quality of plant residue and root exudates will change. Weeds that cause increased litter buildup tend to promote more fungal dominance in soil. The encroachment of annuals into perennial plant systems will cause changes in organism community composition because soil biological activity corresponds with plant growth stages and periods of litter fall and root die-off.

Shrub removal

Removing shrubs by chaining, thinning, or applying herbicides promotes a shift to a different plant community and affects food sources for soil organisms. Less woody material and more herbaceous material will promote bacterial increases compared to fungi. Arthropod species will also change to those supported by the new plant community. As with tillage, the soil displacement and mixing that occurs during chaining will enhance bacterial decomposition of soil organic matter and residues. Compaction and herbicide effects, as described in “General Management Principles” above, may also be an issue during shrub removal.

Plowing and seeding

Plowing and seeding disturbances are related to the degree of soil mixing. Tillage that completely mixes or inverts the topsoil will result in a sudden, drastic change in habitat, increased organic matter decomposition rates, and thus reduced food sources for soil organisms. It also destroys larger pores and some macrohabitats. Use of a seed drill minimizes soil mixing and is much less of a disturbance to soil biology. Changes in the amount of residue either from plowing or the establishment of the seeded species will alter the food sources for soil organisms. Loss of residue can reduce or eliminate habitats for larger organisms in the food web, such as insects and arthropods.

Compaction from traffic

Grazing animals and vehicles may cause compaction, especially when traffic is concentrated in small areas or soil is too wet. See “General management strategies” for a description of the implications of compaction on soil biology.

Erosion

Off-road vehicle traffic or heavily used trails can create ruts that compact soil and channel water. The resulting accelerated erosion, rills, and gullies can strip or bury topsoil and have a negative effect on soil organisms. Erosion associated with vegetation shifts often results in the redistribution of topsoil, organic matter, resources, and habitat across short distances. At the shrub-intershrub scale, bare areas between shrubs provide the least habitat and resources for soil organisms. Areas of grass, shrubs, or trees have more diversity of soil organisms.

Assessment and monitoring

In contrast to soil physical and chemical parameters, there are few specific guidelines for managing soil biological properties. Thus, it is especially important that land managers track changes in soil biological functions over time to monitor the effects of management choices.

Monitoring is the identification of trends by systematically collecting quantitative data over time from permanently marked locations. Objectives for monitoring soil biological function include:

- Evaluation and documentation of the progress toward management goals,
- Detection of changes that may be an early warning of future degradation, and
- Determination of the trend for areas in desired condition, at risk, or with potential for recovery.

Assessment is the estimation of the current functional status of soil biological processes. It requires a standard for comparison. Objectives of assessments can be:

- Selection of sites for monitoring,
- Gathering of inventory data,
- Identification of areas at risk of degradation, and
- Targeting management inputs.

Techniques for measuring soil biological properties range from informal, qualitative observations to quantitative laboratory techniques. These techniques can be useful for learning about organisms' resource requirements and functions. However, soil biological tests can be difficult to interpret, and thus provide limited support for making specific management decisions. More information may be gleaned by assessing and monitoring properties affected by soil biological activity including soil surface stability (aggregate stability and slake tests), water infiltration rates (ring infiltrometer and rainfall simulation tests), decomposition rates, pest activity, and soil nitrate and carbon levels (microbial biomass and total organic carbon tests). These measures of soil properties assess the soil functions of interest to a land manager. However, they are likely to change more slowly than biological measures and thus are more delayed indicators. When deciding what to assess or monitor, keep in mind the objectives and the time and resources available.

For more about planning appropriate soil quality assessments see "Guidelines for Soil Quality Assessment in Conservation Planning" (NRCS, 2001c).

Types of tests

As discussed in the Soil Biology Primer, a variety of approaches can be used to describe the soil community, including 1) counting soil organisms or measuring biomass, 2) measuring their activity, or 3) measuring diversity, such as diversity of functions (e.g., biolog plates) or diversity of chemical structure (e.g. cell components or DNA). Each approach provides different information.

Methods for measuring biomass identify either the total number of organisms or only those that are active. A pitfall trap or Berlese funnel (NRCS, 2001b) can be used to collect larger organisms living in litter from a forest floor, pasture, or cropland.

Activity measurements provide a better understanding of soil biological function than do biomass measurements. One measure of biological activity is testing for various microbial enzymes (Dick, 1997). By choosing the appropriate enzyme, an enzyme assay can be used to assess the rate of carbon, nitrogen, or phosphorus cycling, or overall microbial activity. Enzyme assays have potential as a useful indicator and can be done with the equipment found in typical soil analysis labs, but most labs do not yet offer these tests.

Respiration, or the amount of CO_2 produced from the soil, is another measure of biological activity. The test can be done in the field (NRCS, 1998), but results are difficult to interpret. Respiration rates are extremely variable hourly, seasonally, and by region and soil type, so baseline or reference data are nearly meaningless. Furthermore, high respiration may indicate a healthy and active biological community, or it may indicate recent disturbance, such as tillage, that has triggered a flush of activity. High respiration represents a loss of soil carbon to the atmosphere, which is counter to the goal of carbon sequestration. Yet there are no guidelines for determining how much is too much. For these reasons, soil respiration tests can be useful in side-by-side demonstrations, but are of limited value as a soil biological indicator.

Cotton strip tests (NRCS, 1998 and 2001b) and a few other techniques measure decomposition rates over days or weeks, and therefore are not confounded by short term variation as much as are respiration tests. However, results are still difficult to interpret and require a standard or control for comparison.

With any of these measures of the soil biological community, refer to a specialist for help interpreting test results.

Get to know your community

To gain a general awareness of soil organisms and their effects, try these simple methods. Choose a few places to take a close look at what lives in your soil. Look under a shrub, in the woods, along a fence line, in a meadow, in a field, etc. Take time to examine the litter on the surface and look for organisms that move. Look for biotic crusts, burrows, fungal hyphae, and other evidence of soil organisms. Over the seasons, look for birds picking out earthworms behind a tillage implement. Observe the rate that dung pats decompose. Notice the amount of runoff or ponding after a rain.

Collecting samples for laboratory analyses

A small number of commercial labs will test soil biological properties. Typical measures are microbial biomass and direct counts of soil microbes. When choosing a lab and soil biology tests, consider the following.

- What quality control measures does the lab use to ensure reliable results?
- What is the significance of each test in terms of soil function?
- How will the test assist in your management decisions?
- Do interpretations of results consider your specific soil type and cropping systems?

The biomass (total amount of organisms) changes seasonally, but does not change drastically from day to day. However, activity levels (e.g., respiration) can change quickly, so note the time of year and the temperature and moisture conditions when sampling, and sample under similar conditions for future observations.

Samples should be placed in sealed bags and chilled (but not frozen) immediately.

Summary

Soil organisms are integral to soil processes, including nutrient cycling, energy cycling, water cycling, processing of potential pollutants, and plant pest dynamics. These processes are essential to agriculture and forestry, and for protecting the quality of water, air, and habitat. Therefore, land managers should consider the effects of their actions on the health and function of the soil biological community.

Despite the well-known importance of soil biological processes, the development of monitoring and management guidelines is in its infancy. However, land managers can learn the general principles of how their choices affect biological processes and can monitor changes in soil function.

Soil biological health generally improves when the following management practices are applied:

- Regularly adding adequate organic matter,
- Diversifying the type of plants across the landscape (in all land uses) and though time (in cropping systems),
- Keeping the ground covered with living plants and residue,
- Avoiding excessive levels of disturbances including soil mixing or tillage, compaction, pesticides, heavy grazing, and catastrophic wildfires.

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Cornell Waste Management Institute

Department of Crop & Soil Sciences
http://cwmi.css.cornell.edu

Rice Hall • Ithaca, NY 14853
607-255-1187
E-Mail: cwmi@cornell.edu

by:
Hannah Shayler
Murray McBride
Ellen Harrison

Soil Contaminants and Best Practices for Healthy Gardens

Why are Soil Contaminants a Concern?

Soil quality is affected by many factors, including past and present land use and nearness to pollution sources. Soil test results and site history can provide information to guide efforts to improve garden quality and protect the health of gardeners, their families, and others in the community.

There is no clear line of what is considered "safe". If contaminant levels exceed agency guidelines or are higher than levels recommended by other sources, it is wise to reduce the exposure of children and adults. Children are especially vulnerable to harmful health effects, so it is particularly important to address any concerns about soil contaminants in areas where children play or where fruits or vegetables are grown for food. The practices outlined below will help improve soil quality and limit people's contact with soil contaminants.

Best Practices for Healthy Gardens

Gardening and Land Use Practices

♦ Incorporate or top dress the garden area with clean materials such as uncontaminated soil, compost, manure, or peat moss.

♦ Adjust soil pH to near neutral. Most metals are more bioavailable in more acid soils and can harm plants or animals when pH is too low.

♦ Mulch walkways and other areas to reduce dust and soil splashback onto crops, or maintain healthy grass or other ground cover.

♦ Don't grow edible produce directly adjacent to buildings, where lead levels are likely highest.

♦ Build raised beds with clean soil to grow food crops in more contaminated areas. A layer of landscape fabric will prevent plant roots from entering the contaminated soil below the bed.

♦ For raised beds and other garden projects, don't use certain types of treated lumber that may have chemicals that will further contaminate the soil. In the past, some commercially-available treated lumber contained copper, chromium, and arsenic.

♦ In more contaminated areas, first consider whether the practices outlined here can sufficiently reduce the amount of contaminants in contact with crops. This can be verified by testing the soil or plant tissue.

♦ If it is not possible to protect crops from contamination, consider growing crops that are less likely to be contaminated (see page 3).

♦ Because of the many benefits of eating fresh fruits and vegetables, growing ornamental plants instead of food crops should only be considered as a last resort.

CWMI Resources for Healthy Soils

http://cwmi.css.cornell.edu/soilquality.htm

- **Sources and Impacts of Contaminants in Soils**
- **Guide to Soil Testing and Interpreting Results**
- **Best Practices for Healthy Gardens**
- **More Information about Arsenic and Lead**

Site history information and measures of soil quality, including levels of lead and other contaminants, can help guide efforts to create healthy gardens.

Food Preparation Practices

♦ Wash produce well to remove soil particles. A 1% vinegar solution (1 part vinegar to 100 parts water) can be used.

♦ Peel root crops.

♦ Discard outer leaves of leafy vegetables since soil may cling to them.

General Practices

♦ Wash hands and other exposed skin areas that come into contact with soil, especially before eating or preparing food.

♦ Use gloves when handling soil, and change gloves when wet or soiled.

♦ Watch children carefully to prevent them from eating soil.

♦ Frequently wash toys and pacifiers.

♦ Cover contaminated soil with clean soil, mulch or other materials, or keep these areas well vegetated.

♦ Limit access to more contaminated areas. Don't store things there, especially toys. Consider restricting access to these areas (by installing fences or lattice).

♦ Keep soil outdoors:

- Take off shoes.

- Use doormats.

- Clean floors often with a damp mop. Vacuum cleaners put dust in the air, unless they are equipped with a high efficiency particulate air filter.

- Wash boots and tools outside.

♦ Clean or replace filters on heating and cooling systems.

♦ Reduce exposure from pets that go outside.

- Wash pets.

- Wash hands after handling pets.

- Limit pets' access to more contaminated areas.

♦ Seal pressure-treated wood (and re-seal as needed).

How Do Plants Get Contaminated?

There are three main ways that heavy metals such as lead could contaminate garden crops. This information is important to help select the best crops for a particular situations.

(1) *Deposition from the air:* This used to be a major source of lead contamination in urban areas until leaded gasoline was phased out completely in the 1980s. Some lead deposition still occurs due to wind-blown dust from contaminated soils and streets. Other airborne contaminants can also end up on plants. This is a particular problem for leafy crops, which have a high surface area in contact with airborne particles.

(2) *Uptake into plant roots*: In most situations, unless soil is acidic (low pH) or very low in organic matter, not much lead is transferred from contaminated soils to garden crops through plant roots. However, roots are likely to have a higher concentration of lead than leaves and stems, and fruits or seeds are likely to be lowest in lead of all plant parts. Cadmium and some other heavy metals of concern are more readily taken up from contaminated soils into roots and plant tops.

(3) *Direct contamination by garden soil*: Root and tuber crops are more likely to be contaminated than other types of crops because they are in direct contact with soil. Leafy vegetables (lettuce, spinach, collard greens) are also easily contaminated by soil splash and dust. Washing leafy crops can remove up to 80% of lead contamination, and much of the lead can be removed from vegetables such as carrots and potatoes by peeling. However, in situations where lead contamination is moderate to severe, growing these types of crops directly in the contaminated soil is probably not the best choice.

Luckily, there are several natural barriers that limit heavy metal transfer into crops.

♦ *Soil-Root Barrier*: Some toxic metals (such as lead) have low solubility in most soils, and do not readily enter the plant through roots.

♦ *Root-Shoot Barrier*: Most toxic metals bind relatively strongly in roots, and movement to other plant parts is limited.

♦ *Shoot-Fruit Barrier*: Most toxic metals are largely excluded from entering the reproductive parts (fruits, seeds) of the crop, remaining instead in the vegetative parts.

Which Garden Crops Are Suitable to Grow in Contaminated Soils?

Some garden crops can take advantage of these natural barriers. However, the physical contamination of crops by soil dust, splash or aerial deposition can often bypass the natural barriers of protection. Practices to reduce the physical contamination of garden food crops and to reduce human exposure therefore become important.

In addition to what is known about contamination pathways, the results of past research also provide some information about the potential for heavy metal transfer into garden crops. All of this information allows for recommendations for garden crops that are most and least suitable for growing directly in contaminated soils. These resources will be updated and expanded in the future as new information and research findings become available.

Most Suitable

♦ *Vegetable Fruits and Seeds*: tomatoes, eggplant, peppers, okra (seed pods only), squash (summer and winter), corn, cucumber, melons, peas and beans (shelled or cleaned very thoroughly), onions (bulb only)

♦ *Tree Fruits*: apples, pears

♦ *Berries*: blueberries, strawberries, raspberries, blackberries (if cleaned very thoroughly)

Least Suitable*

♦ *Green Leafy Vegetables*: lettuce, spinach, Swiss chard, beet leaves, cabbage, kale, collards

♦ *Other Vegetables*: broccoli, cauliflower

♦ *Root Crops*: carrots, potatoes, turnips

*Given the many health benefits of consuming fresh fruits and vegetables, every attempt should be made to use the steps outlined on the previous pages to create healthy garden conditions to grow a variety of desirable crops. However, eating fruits and vegetables grown in contaminated soils may have both benefits and risks.

In particular, the vegetables on the Least Suitable list should preferably be grown in areas where contamination is not a concern or where clean soil materials and composts have been used to create soils with low levels of contamination. This can be verified through soil testing if needed. Note that constructing raised beds with clean materials will help create healthy gardens in many situations, but may not eliminate airborne contaminants or soil dust and splashback from other areas.

Healthy Soils, Healthy Communities

Metals in Urban Garden Soils

Metals are naturally present in rock, soil, and other materials. They are also used in manufactured (*anthropogenic*) materials, and human activity can increase the levels of metals in soil. Urban soils often have higher levels of metals than rural soils because they have been affected more by human activity. Gardening in urban soils may increase your exposure to metals if you swallow or breathe in soil particles or eat food raised in or on the soil.

What metals can be found in urban gardens?

The table on this page lists several metals commonly found in urban garden soils, along with guidance values developed to protect human health, and ranges of "background" levels typically found in rural and urban soils in New York State (NYS) and New York City (NYC).

The following pages provide some basic information for gardeners about each of these metals: where they come from (both natural and anthropogenic sources), how they behave in soil, considerations for human and plant health, and what gardeners can do to help reduce exposure to metals in garden soils.

Metals commonly found in urban garden soils: Guidance values and background levels [a]

Metal	Level in soil (parts per million [ppm])		
	Guidance Value Protective of Public Health	NYS Rural Background Level	NYC Urban Background Level
Arsenic	16	< 0.2 - 12	4.1 - 26
Barium	350	4 - 170	46 - 200
Cadmium	2.5	< 0.05 - 2.4	0.27 - 1.0
Chromium	36	1 - 20	15 - 53
Copper [b]	270	2 - 32	23 - 110
Lead	400	3 - 72	48 - 690
Mercury	0.81	0.01 – 0.20	0.14 – 1.9
Nickel [b]	140	0 - 25	10 - 43
Zinc [b]	2200	10 - 140	64 - 380

[a] References, page 9

[b] Can be toxic to plants at levels below guidance values protective of public health

What levels of metals are acceptable in garden soils?

There are no standards protective of public health specifically for metals in garden soils in NYS, but there are guidance values developed for other purposes that gardeners can consider. The guidance values in the table on this page are residential soil cleanup objectives developed by the NYS Department of Environmental Conservation and the NYS Department of Health for the NYS environmental remediation programs (see References, p. 9). These values were developed to consider residential exposures, including gardening. However, they assume that you live on the property with the soil, and that you are exposed in some ways every day and over a lifetime. Exposure to metals in soils for an urban gardener may be less than this.

The guidance values also generally assume that metals are in one of the most toxic and available chemical forms, which is not always the case with metals in garden soil. Metals can be present in soil in different chemical forms. The behavior of metals in the environment, tendency to be taken up by plants, toxicity to plants and potential for health effects of human exposure to those metals depend on their chemical form. For example, some forms of metals can readily dissolve in water (soluble) and therefore can enter plants or the human body more easily than forms that cannot easily dissolve (insoluble). Human and plant toxicity depend upon the amount of metal that enters the body or plant.

Should I be concerned about exposure to metals in my garden soil?

Certain metals are essential in small amounts in the diet for good health, but eating or drinking large amounts of them can cause health effects. Other metals can cause health effects even in small amounts. Lead can pose a particular health concern, especially for young children. The likelihood that health effects will occur depends

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Cornell University College of Agriculture and Life Sciences Department of Crop and Soil Sciences

Cornell University Cooperative Extension New York City

not only on the specific metal, but also on who is exposed, how much, how often, and for how long. In general, the higher the levels are, the greater the concern.

Most of what we know about the potential health effects of exposure to metals comes from studies in which laboratory animals were given large amounts of the metals, or from studies of people exposed by accidents or in the workplace. An urban gardener would have less exposure to these metals in soil. However, metals that cause health effects after high-level exposures may also increase the risk of health effects in people exposed to lower levels for long periods of time.

In urban garden soils, it is not uncommon to find metals at levels near or above guidance values. Health risks associated with metals in soils at levels slightly or moderately above guidance values cannot be ruled out, but these risks are likely to be low.

More information about these metals is available from the Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR's frequently asked questions fact sheets for metals and other chemicals (ToxFAQs™) are available at http://www.atsdr.cdc.gov/toxfaqs/index.asp.

Can metals affect the health of my plants?

Yes. Some metals, such as copper and zinc, are taken up by plants and can be toxic to plants (*phytotoxic*) at levels below guidance values protective of public health. Levels of phytotoxic metals that may be of concern to gardeners are discussed in the sections below. Other metals may not harm the health or growth of the plant, even though they may be a concern for human health. Additionally, some metals are not easily taken up by plants under conditions commonly found in gardens.

Glossary:

Adsorb: adhere, become attached (for instance, become attached to a soil particle).

Anthropogenic: caused by human activity.

Carcinogen: a substance that can cause cancer.

CCA: a preservative containing copper, chromium, and arsenic that was used in treated lumber. CCA-treated lumber is no longer commercially available.

Exposure: contact (touching, breathing, eating or drinking a substance).

Hyperaccumulator: a plant that concentrates metals from the environment.

Insoluble: generally incapable of dissolving in water.

Organic matter: material made of compounds formed from the decay of living things; for example, compost.

pH: a measure of acidity (low pH) or basicity (high pH). Urban garden soils typically fall within a pH range between 5 (high acidity) and 8 (low acidity). A pH between 6.5 and 7.5 is considered to be in the neutral range.

ppm: parts per million, the units used to measure metals levels in soil. A level of 1 ppm means there is one particle of the metal in one million particles of soil. This equals about one teaspoonful in 10,000 pounds of soil.

Soluble: readily able to dissolve in water.

Phosphate: an essential nutrient for plant growth, present in many fertilizers.

Phytoremediation: using plants to reduce soil environmental contamination.

Phytotoxic: harmful to plants.

Saline: containing extra salts (which may affect plant growth).

Serpentinitic: soils containing certain characteristic minerals from serpentinite rock, common in certain areas.

Are there crops I can plant to remove metals from my garden soil?

Using plants to remove metals from soil (a type of *phytoremediation)* is generally not effective for reducing metals levels in urban garden soils. Many metals are not readily taken up into plant tissue when soil pH is near neutral (6.5 – 7.5), as it typically is in urban gardens. For those metals that are more easily taken up by plants (such as cadmium, copper, nickel, and zinc), the plants that take them up most readily are also relatively small in stature and slow growing, and they will take many years to "clean up" soils with metals levels even moderately above guidance values. Also, unlike some contaminants, metals are not broken down into less toxic compounds by phytoremediation. Metals that are removed from the soil go into the roots or other parts of the plants, which means the plants must be disposed of properly, and not eaten or composted.

How can I reduce exposure to metals in my garden soil?

The following sections describe steps gardeners can take to help reduce exposure to specific metals found in urban garden soils. For many metals, adjusting soil pH and adding organic matter (such as compost) can help keep metals in the soil from being taken up by plants. In addition, healthy gardening practices such as growing in raised beds filled with clean soil and compost, washing vegetables thoroughly, and being careful not to track soil indoors can help reduce exposure to all metals, as well as other contaminants that may be present in garden soils. You can find more information about healthy gardening practices on the *Healthy Soils, Healthy Communities* web page at http://cwmi.css.cornell.edu/healthysoils.htm.

Arsenic

Sources: *Natural* – Trace levels are normally associated with rock minerals and clays in all soils. Higher levels are present in ores of copper and lead, sulfide ores (pyrites) mined for metals, and in black shales and coal. *Anthropogenic* – Arsenic was historically used in pressure-treated lumber (the older "CCA" type) and some pesticides. It can also be found in coal ash.

Form and behavior in garden soil: Arsenic usually exists as the arsenate form, which behaves chemically like phosphate and is therefore fairly easily taken up by plants. It adsorbs poorly on organic matter but well on clays and iron oxides. It is more available to plants in non-acid (pH greater than 6.0) than acid (pH less than 6.0) soils. Uptake into food crops may be significant if levels of soil arsenic are unusually high. Leafy green vegetables are the strongest accumulators of arsenic.

Human health: Arsenic is a known human carcinogen (a substance that can cause cancer). Arsenic in soil at levels slightly or moderately above the guidance value poses no immediate risk, but there may be some increased risk if you are exposed a lot over a long time.

Plant health: Arsenic phytotoxicity is typically not a practical concern for gardeners. The growth and health of plants are unlikely to be significantly affected until levels in soil exceed those of concern for human health.

What gardeners can do: Unlike most metals, arsenic is not immobilized by organic matter additions or liming, and these measures may actually increase arsenic availability to crops. Soluble iron (ferrous) salts or iron oxide additions have helped to reduce arsenic availability in experimental situations. Phytoremediation has been demonstrated using certain subtropical fern species, which act as "hyperaccumulator" crops that take up large amounts of arsenic.

Barium

Sources: *Natural* – Barium is associated with common rock minerals such as feldspars and micas in soils. It is also found in some foods, such as Brazil nuts, seaweed, fish, and certain plants. *Anthropogenic* – Barium is used in oil and gas drilling muds (as a lubricant for drill bits), in the production of paints, bricks, tiles, and ceramics, as an additive for jet fuels, and as a contrast agent in X-ray diagnostic work. It can also be found in automotive brake linings.

Form and behavior in garden soil: Barium generally occurs as relatively insoluble sulfates and carbonates, or bound strongly to clays and organic matter, which limits the potential for plant uptake. Uptake into fruits and vegetable fruits is typically quite low. Some uptake into roots and leafy greens does occur. Lower soil pH increases barium solubility in the soil, and uptake into food crops may be more significant if soil is acidic (pH less than 6.0).

Human health: The most sensitive effect in laboratory animals of long-term exposure to barium (in drinking water) is kidney toxicity. Barium found in soils is usually in a very insoluble form, which is likely to be less toxic. The soil guidance value for barium was developed to consider soluble forms of barium.

Plant health: Barium phytotoxicity is typically not a practical concern for gardeners. Although barium can be considered weakly phytotoxic (by competing with calcium needed for plant growth), the growth and health of plants are unlikely to be affected until levels in soil greatly exceed guidelines protective of public health.

What gardeners can do: Organic matter additions and, for acidic soils (pH less than 6.0), liming, may reduce barium uptake by crops. Little is known about the potential effectiveness of phytoremediation for barium.

Cadmium

Sources: *Natural* – Cadmium can be found in black shales, which in some parts of the northeastern US are the parent materials of soils. It also occurs in rock phosphate deposits around the world, which are mined to produce commercial phosphate fertilizers. It is present in uncontaminated soils worldwide at trace levels. Many zinc ores contain low levels of cadmium. *Anthropogenic* – Cadmium usually occurs as an impurity in zinc metal, which is used in galvanized steel. Cadmium can also be found in electroplating waste, batteries, coal burning and incinerator emissions, and some fertilizers.

Form and behavior in garden soil: Cadmium is generally adsorbed more strongly on clays and organic matter as soil pH increases, but it is relatively easily released to the soluble and plant-available form compared to other metals. High levels of salts in soils can make cadmium more soluble. Uptake into food crops, especially leafy greens, may be a concern if soil has high levels of salts or if soil is acidic (pH below 6.0), but most urban garden soils have a pH near neutral (6.5-7.5).

Human health: Cadmium is a known human carcinogen (a substance that can cause cancer). Cadmium in soil at levels slightly or moderately above the guidance value poses no immediate risk, but there may be some increased risk if you are exposed a lot over a long time.

Plant health: Cadmium phytotoxicity is typically not a practical concern for gardeners. The growth and health of plants are unlikely to be significantly affected until levels in soil greatly exceed those of concern for human health.

What gardeners can do: Organic matter additions and liming (for acid soils) should reduce cadmium uptake by crops. Phytoremediation (by plants such as willows or "hyperaccumulator" plants that take up large amounts of cadmium) is possible because of the relatively high ability of cadmium to be taken up by crops. However, this strategy is unlikely to be practical for gardeners, as it would require several decades or more to reduce cadmium levels in even a moderately contaminated soil to levels more suitable for gardening.

Chromium

Sources: *Natural* – Chromium is found at high levels in serpentinitic rocks, which in some areas (including Staten Island in New York City) may form the parent material of soils. More commonly, it is found as a trace element bound in the structure of many soil minerals. *Anthropogenic* – Chromium is used for electroplating, in the manufacture of steel and in the textile, tanning and leather industries, and as a component of some paints and pigments. It is present in wastes from mining and processing of chromite ores. Chromium was historically used in pressure-treated lumber (the older "CCA" type).

Form and behavior in garden soil: Chromium in urban garden soils is very likely to be in a form called "trivalent" chromium rather than the more soluble and toxic "hexavalent" form (also known as "chromate"). This more toxic form is unlikely to be present unless pollution has increased soil chromium to high levels (for example, by spills or other pollution), pH is above 6.0, and organic matter content of the soil is low. The trivalent form adsorbs extremely strongly on clays and organic matter over a wide range of soil pH (5 to 8). Exposure through crop consumption is highly unlikely due to very little transfer of chromium from soils to above-ground plant parts. An exception is some plant species growing on serpentinitic soils that can accumulate high concentrations of chromium, possibly because they are taking up the soluble chromate form (chromate, if present, can be taken up by crops or leach to groundwater). Note that soil tests commonly available to gardeners do not typically specify the form of chromium present.

Human health: A small amount of trivalent chromium in the diet is essential for good health. In contrast, hexavalent chromium has caused cancer in people who worked with it and inhaled it (breathed it in) for a long time. Hexavalent chromium also caused cancer in animals that ingested (ate or drank) it daily over their lifetimes. Whether ingested hexavalent chromium causes cancer in humans in unknown. Hexavalent chromium in soil at levels slightly or moderately above the guidance value poses no immediate risk, but there may be some increased risk if you are exposed a lot over a long time.

Plant health: In its stable form in soil (trivalent chromium), chromium is quite insoluble and phytotoxicity is not a concern. However, soluble hexavalent chromium (chromate) is phytotoxic, but is unlikely to be encountered in garden soils.

What gardeners can do: If hexavalent chromium is present, adding fresh organic material can help convert the toxic hexavalent form to the much less soluble trivalent form, which is much less likely to be taken up by plants. Although some plants are able to take up chromium that is dissolved in water (particularly hexavalent chromium), phytoremediation has not been shown to be a practical solution for chromium-contaminated soils.

Copper

Sources: *Natural* – Copper is found in many types of rock, with higher levels found in black shales and some basalts. *Anthropogenic* – Copper was historically used in pressure-treated lumber (the older "CCA" type) and is found in some newer treated lumber products as well. It is used in fungicides in orchards, vineyards and gardens. Copper can also be found in dairy manure and sewage sludge composts.

Form and behavior in soil: Copper adsorbs very strongly on organic matter when soil pH is greater than 5.5, but also on clay minerals at near-neutral pH (6.5 – 7.5). The solubility of copper is generally quite low in soil unless pH is unusually low (less than 5.5) or high (greater than 7.5). Copper is an essential micronutrient for human health that is found in many foods. Excessive copper in food crops is unlikely because this metal is strongly retained in fine roots with relatively little transferred to aboveground portions of plants.

Human health: Small amounts of copper in the diet are essential for good health. Too little copper can cause a wide variety of serious adverse effects; too much copper may damage the liver.

Plant health: Copper in soil may be toxic to plants (*phytotoxic*) at levels below those that are a concern for human health. At levels above 75-100 ppm in soil, copper can cause toxicity and stunted growth in some crops. This is more likely to be a concern if pH is low.

What gardeners can do: Organic matter additions and liming (for acid soils [pH less than 6.0]) should reduce copper uptake and toxicity to crops. Phytoremediation (by "hyperaccumulator" crops that take up large amounts of copper) is possible. However, this strategy is unlikely to be practical for gardeners, as it would require several decades or more for these generally small, slow-growing crops to reduce copper levels in even a moderately contaminated soil to levels more suitable for gardening.

Lead

Sources: *Natural* – Lead is present in rocks including black shales, where it is associated with organic matter and sulfides. Lead sulfide (galena) ore deposits have been mined for this metal for centuries in the northeastern US and other areas. *Anthropogenic* – Historically, lead compounds were used as additives in paint and gasoline, resulting in widespread contamination of soil, particularly in developed areas. Other sources include incinerator emissions, mining and smelting activities, battery disposal and recycling, plumbing and roofing. Lead was commonly used until the 1960's in pesticides applied to orchards, vineyards, and gardens.

Form and behavior in soil: Lead adsorbs strongly on organic matter in particular if pH is higher than 5.0, but also adsorbs on clays at higher pH. In highly contaminated soils, lead may also be in the form of insoluble minerals such as carbonates, hydroxides or phosphates. Lead is not very soluble in soil unless pH is extremely low (less than 5.0) or high (greater than 7.5). Lead is generally not transferred easily into food crops because of its low solubility in soils and the tendency to bind in roots where it is prevented from migrating into leaves or fruits. However, if soil pH and organic matter are low, transfer into crops may be greater. Under certain conditions (soil with low pH, low organic matter content, or high levels of lead) lead can be taken up by plant roots into edible fruits or vegetables. These exposures may add to lead exposures from other sources. Physical contamination of vegetable crops (particularly leafy greens) with lead-contaminated soil particles that end up on plant surfaces can be a significant source of dietary exposure to lead.

Human health: Lead in soil can pose a particular health concern, especially for young children. Lead can harm a young child's growth, behavior, and ability to learn. Lead in soil can pose some risks even if test results are below guidance values, and the higher the level of lead in soil, the greater the concern.

Plant health: Lead phytotoxicity is typically not a practical concern for gardeners, as most garden plants take up very little lead compared to levels in soil.

What gardeners can do: To help limit children's exposure to lead in soil, it is important to watch children carefully while they are in the garden, remind them often to avoid touching their mouths after touching the soil, and make sure they wash their hands well after touching the soil. Organic matter additions and liming (for acid soils [pH less than 6]) may reduce lead uptake by crops, and mulching and other practices to control dust are likely to reduce physical contamination of crops with soil particles. Large additions of phosphate fertilizer have been shown to reduce lead solubility in some severely contaminated soils, but this may not be practical or effective for gardeners. Phytoremediation (removal of lead by plants) is not generally effective because there are no known lead-accumulating crops ("hyperaccumulators").

Mercury

Sources: *Natural* – Mercury is found in several forms in the environment. The highest naturally occurring mercury concentrations have been found in peaty and waterlogged soils. *Anthropogenic* – Mercury may be found in emissions from incinerators and coal-burning power plants, and is also used in certain commercial products and industrial processes.

Form and behavior in soil: Mercury is generally non-mobile, not leachable, and strongly bound in soils. Soil pH is less of an influence on mercury's behavior in soils than it is for many other metals. Mercury does not transfer readily to crops; therefore, consumption of garden crops is unlikely to be an exposure pathway of concern for human health. In soil, mercury is likely to exist mainly in a form known as "divalent" mercury, which bonds strongly to organic matter. There is some potential in flooded soils for mercury to form a more toxic compound called methylmercury, but it is likely that soils would have to remain flooded for many months for this process to occur.

Human health: Eating or drinking small amounts of divalent mercury does not cause health effects. Eating or drinking large amounts of divalent mercury can damage the kidneys and nervous system. Children and unborn babies are particularly sensitive to the effects of mercury because their nervous systems are still developing.

Plant health: Mercury phytotoxicity is not typically a practical concern for gardeners, because mercury binds so strongly to soil organic matter and minerals and is not readily taken up by plants.

What gardeners can do: Plants take up very little mercury under most conditions, which means soil amendments (such as organic matter additions and liming) are likely to have little effect on the amount of mercury found in plants. It also means that phytoremediation is unlikely to be effective. Healthy gardening practices that control dust and minimize direct soil ingestion would help reduce the potential for human exposure to mercury in garden soil.

Nickel

Sources: *Natural* – Nickel is found in serpentinitic rocks, which in some areas (including Staten Island in New York City) may form the parent material of soils. More commonly, it is found as a trace element bound in the structure of many soil minerals. *Anthropogenic* – Nickel is used in the manufacture of steel and other metal alloys, as well as in electroplating and in some kinds of batteries. Emissions from incinerators and fossil-fuel combustion can also contain nickel.

Form and behavior in soil: Nickel adsorbs fairly strongly (though not as strongly as copper) on organic matter when soil pH is greater than 5.5, but also on clay minerals at near-neutral pH (6.5 – 7.5). The solubility of nickel is generally low in soil unless pH is unusually low (less than 5.5) or high (greater than 7.5). Nickel is taken up more readily into plants than some other metals (such as copper), but relatively little nickel can be expected in the edible portions of food crops.

Human health: Small amounts of nickel in the diet are essential for good health. Too little nickel can cause a wide variety of serious adverse effects in humans. Too much nickel exposure in animals can cause a wide variety of adverse effects, but the most sensitive effects appear to be decreased body and organ weights.

Plant health: Nickel in soil may be toxic to plants at levels below those that are a concern for human health. At levels above 40-60 ppm in soil, nickel can cause toxicity and stunted growth in some crops.

What gardeners can do: Organic matter additions and liming (for acid soils [pH less than 6.0]) should reduce nickel uptake and toxicity to crops. Phytoremediation (by "hyperaccumulator" crops that take up large amounts of nickel) is possible. However, this strategy is unlikely to be practical for gardeners, as it would require several decades or more for these generally small, slow-growing crops to reduce nickel levels in even a moderately contaminated soil to levels more suitable for gardening.

Zinc

Sources: *Natural* – Zinc is present in low concentrations in many types of rock. It is concentrated in sulfide ore minerals such as sphalerite, which are mined for this metal. *Anthropogenic* – Zinc is used in galvanized steel (used in roofing, pipes, and gutters), wire fences and rubber (tires). It is used in some metal alloys, batteries, and pigments. Other sources include electroplating waste, mine spoils, emissions from coal burning, smelting and incinerators, some fertilizers, manure and sewage sludge composts.

Form and behavior in soil: Zinc is generally adsorbed on clays and organic matter above pH 6.0 but is relatively easily released to the soluble and plant-available form. It is quite soluble and plant-available if soil pH is low (less than 5.5).

Human health: Small amounts of zinc in the diet are essential for good health. Too little zinc can cause a wide variety of serious adverse effects; too much zinc can alter the copper content of red blood cells and reduce the level of an important enzyme in red blood cells.

Plant health: Zinc is an essential micronutrient for plants, but it can be toxic to plants at higher soil levels, even below those that are a concern for human health. Zinc levels above 150-200 ppm may cause toxicity and stunted growth in some crops. Nevertheless, because of the near-neutral pH (6.5 - 7.5) of most urban garden soils, zinc is usually not soluble enough to be toxic to plants.

What gardeners can do: Organic matter/compost additions and liming (for acid soils) can reduce zinc uptake and prevent toxicity to crops. Phytoremediation (e.g., by willows or hyperaccumulator crops) is possible because of the relatively high extent to which zinc can be taken up by crops. However, this strategy is unlikely to be practical for gardeners, as it would require several decades or more to reduce zinc levels in even a moderately contaminated soil to levels more suitable for gardening.

Healthy Gardening Practices

Please see our related resource “"What Gardeners Can Do: 10 Best Practices for Healthy Gardening", available at http://cwmi.css.cornell.edu/healthysoils.htm, which describes these steps gardeners can take to minimize contact with soil contaminants:

1. Use clean soil and compost.
2. Use raised beds.
3. Avoid using treated wood.
4. Maintain soil nutrients and pH.
5. Cover (or mulch) soil.
6. Keep an eye on children.
7. Don't track soil into your home.
8. Wash your hands.
9. Wash and/or peel produce.
10. Put a barrier under play areas.

Additional Resources

- Resources from *Healthy Soils, Healthy Communities* project (http://cwmi.css.cornell.edu/healthysoils.htm):
    - "What Gardeners Can Do: 10 Best Practices for Healthy Gardening" http://cwmi.css.cornell.edu/WhatGardenersCanDoEnglish.pdf
    - "What Gardeners Can Do: Tips for Urban Chicken Keepers" http://cwmi.css.cornell.edu/WhatGardenersCanDoChickens.pdf
- Agency for Toxic Substances and Disease Registry ToxFAQs™ - Information about contaminants: http://www.atsdr.cdc.gov/toxfaqs/index.asp
- Cornell Waste Management Institute fact sheets and other *Resources for Healthy Soils*: http://cwmi.css.cornell.edu/soilquality.htm
- NYSDOH brochure *Healthy Gardening: Tips for New and Experienced Gardeners*: http://www.health.ny.gov/publications/1301/index.htm
- NYSDOH Environmental Laboratory Approval Program (ELAP) list of certified laboratories: http://www.wadsworth.org/labcert/elap/elap.html
- NYSDOH Lead Poisoning Prevention website: http://www.health.ny.gov/environmental/lead
- U. S. Environmental Protection Agency information about Brownfields and Urban Agriculture: http://www.epa.gov/brownfields/urbanag/
- Agro-One Services - Testing for soil pH and fertility: http://www.dairyone.com/AgroOne/Form_H_Lawn_Garden_Landscape

References

Guidance values protective of public health are based on residential soil cleanup objectives developed for the NYS Environmental Remediation Programs. The regulation governing these programs (6 NYCRR Part 375) is available on NYSDEC's website at http://www.dec.ny.gov/chemical/34189.html. More information about soil cleanup objectives is presented in the technical support document for the regulations (click "Technical Support Document" on that page, or go directly to http://www.dec.ny.gov/docs/remediation_hudson_pdf/techsuppdoc.pdf.

NYS rural background ranges are the minimum to 95th percentile of levels in "source-distant" rural soils in NYS reported in the NYSDOH/ NYSDEC Rural Soil Background Survey. Source-distant samples came from areas that were reasonable points of human contact with soil, such as yards and trails, but at least five meters distant from potential pollution sources such as trash, roads, driveways or structures. A report on the survey is available at http://www.dec.ny.gov/docs/remediation_hudson_pdf/appendixde.pdf (or go to http://www.dec.ny.gov/chemical/34189.html and click "Technical Support Document – Appendices D and E").

NYC urban background ranges are the minimum to 95th percentile of concentrations measured in 27 samples from ornamental gardens, cemetery lawns, grass-covered vacant lots, and grass-covered courtyards in Manhattan. They were reported to NYSDEC by Consolidated Edison in a report authored by The Retec Group, Inc. entitled *Characterization of Soil Background PAH and Metal Concentrations in Manhattan, NY* (March 30, 2007).

Acknowledgments

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NEW YORK STATE Department of Health

Cornell University College of Agriculture and Life Sciences Department of Crop and Soil Sciences

Cornell University Cooperative Extension New York City

United States Department of Agriculture

NATURAL RESOURCES CONSERVATION SERVICE

HEALTHY, PRODUCTIVE SOILS
Checklist for Growers

Managing for soil health is one of the easiest and most effective ways for farmers to increase crop productivity and profitability while improving the environment.

Results are often realized immediately, and last well into the future. Using these four basic principles is the key to improving the health of your soil.

- Keep the soil covered as much as possible
- Disturb the soil as little as possible
- Keep plants growing throughout the year to feed the soil
- Diversify as much as possible using crop rotation and cover crops

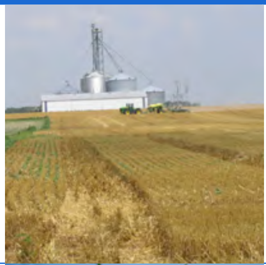
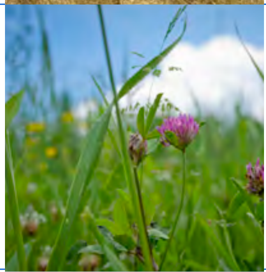
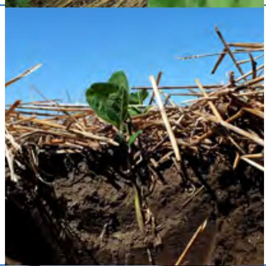
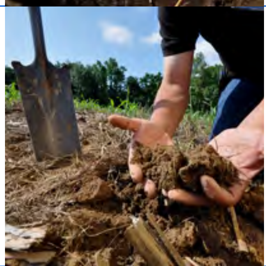
Use the checklist on the back of this page to determine if you're using some or all of the core Soil Health Management System farming practices.

It is important to note that not all practices are applicable to all crops. Some operations will benefit from just one soil health practice while others may require additional practices for maximum benefit. But these core practices form the basis of a Soil Health Management System that can help you optimize your inputs, protect against drought, and increase production.

More Information

To learn more about Soil Health Management Systems and the technical and financial assistance available visit **farmers.gov/conserve/soil-health** or contact your local NRCS office. To find your local NRCS office, visit **farmers.gov/service-center-locator**.

HEALTHY, PRODUCTIVE SOILS: CHECKLIST FOR GROWERS

WHAT IS IT?		WHAT DOES IT DO?	HOW DOES IT HELP?
☐ **Conservation Crop Rotation** A planned sequence of crops grown on the same ground over a period of time (i.e. the rotation cycle).		• Increases nutrient cycling • Helps manage plant pests (weeds, insects, and diseases) • Reduces sheet, rill, and wind erosion • Holds soil moisture • Adds diversity so soil microbes can thrive	• Improves nutrient use efficiency • Decreases use of pesticides • Improves water quality • Conserves water • Improves plant production
☐ **Cover Crop** Grasses, legumes, and forbs planted for seasonal vegetative cover.		• Increases soil organic matter • Prevents soil erosion • Conserves soil moisture • Increases nutrient cycling • Provides nitrogen for plant use • Suppresses weeds • Reduces compaction • Feeds soil life • Reduces residual nutrient loss	• Improves crop production • Improves water quality • Conserves water • Improves nutrient use efficiency • Decreases use of pesticides • Improves water efficiency to crops • Improves water infiltration
☐ **No Till** Limiting soil disturbance to manage the amount, orientation and distribution of crop and plant residue on the soil surface year-round.		• Improves water holding capacity of soils • Increases organic matter • Reduces soil erosion • Reduces energy use • Decreases compaction • Reduces soil evaporation	• Improves water efficiency • Conserves water • Improves crop production • Improves water quality • Saves renewable resources • Improves air quality • Increases productivity
☐ **Reduced Tillage** Using tillage methods where the soil surface is disturbed but maintains a high level of crop residue on the surface.		• Reduces soil erosion from wind and rain • Increases soil moisture for plants • Reduces energy use • Increases soil organic matter • Reduces soil evaporation	• Improves water quality • Conserves water • Saves renewable resources • Improves air quality • Improves crop production
☐ **Mulching** Applying plant residues or other suitable materials to the land surface.		• Reduces erosion from wind and rain • Moderates soil temperatures • Increases soil organic matter • Controls weeds • Conserves soil moisture • Reduces dust	• Improves water quality • Improves plant productivity • Increases crop production • Reduces pesticide usage • Conserves water • Improves air quality
☐ **Nutrient Management** Manage rate, source, placement, and timing of plant nutrients and soil amendments while reducing environmental impacts.		• Increases plant nutrient uptake • Improves the physical, chemical, and biological properties of the soil • Budgets, supplies, and conserves nutrients for plant production • Reduces odors and nitrogen emissions • Reduces excess nutrient applications	• Improves water quality • Improves plant production • Improves air quality
☐ **Pest Management Conservation System** A system that combines an integrated pest management (IPM) decision-making process with natural resource conservation to address pest and environmental impacts.		• Reduces pesticide risks to water quality • Reduces threat of chemicals entering the air • Decreases pesticide risk to pollinators and other beneficial organisms • Increases soil organic matter • Increase soil organism diversity and activity	• Improves water quality • Improves air quality • Increases plant pollination • Increases plant productivity • Supports pollinators and other beneficial insects

Improving Soil Health in Field and Forage Crop Production

Soil health is the continued capacity of soil to function as a living ecosystem that sustains plants, animals, and humans. Viewing soil as a living ecosystem that has 'health' reflects a fundamental shift in the way we think about soil. Soil isn't an inert growing medium that needs to be filled up with water and nutrients when it runs out. Rather, if the soil is healthy, it is teeming with large and small organisms that live together in a dynamic, complex web of relationships. Farm crops and animals become part of this unique 'cycle of life.'

A healthy soil enables a cropping system to run smoothly, just like the well-oiled hub of a wheel. In contrast, a 'sick' soil has an ecosystem that is out of balance, lacks certain key organisms, or lacks the food these organisms need. This results in problems such as low yield, increased runoff, soil moisture deficits, pest and disease problems, and nutrient deficiencies. In the past, it was common to treat the symptoms of poor soil health with temporary patches. For example, runoff problems might be dealt with by tilling the soil to increase pore space, not realizing that the fundamental problems were lack of soil armor (i.e., cover) to protect the soil from raindrop impact, absence of continuous living vegetation to capture solar energy to feed soil organisms which create spongy soil structure, and a living root system that stimulates aggregation!

Soil health is like the hub of a wheel, while continuous no-till is the rim.

Lack of soil health is usually the reason farmers, researchers, and policy makers struggle with no-till. If soil is healthy, success with no-till is achievable and problems such as the excessive use of pesticides or nutrient runoff are avoided. Considering the negative impacts of tillage on soil health, this publication takes the view that continuous no-till is needed to achieve soil health. Continuous no-till is the planting of all crops without the use of any prior tillage.

This publication emphasizes the natural principles of the no-till system. Soil health is like the hub of a wheel, while continuous no-till is the rim *(Figure 1, page 2)*. We will discuss 14 spokes connecting the hub and rim.

Continuous No-Till for Soil Health

No-till is a powerful tool to combat erosion. It increases residue cover and creates firmer soil and better soil structure. No-till reduces erosion by more than 80 percent versus chisel plowing in a corn-soybean rotation where crop residue is left after harvest. Even if some crop residues are removed in this rotation, soil erosion is still reduced more than 70 percent by using no-till. In continuous silage corn, the addition of a cover crop can decrease erosion by as much as 70 percent, whereas the removal of soybean residue can increase erosion by as much as 25 percent.

Instead of addressing soil erosion and soil degradation, there is a need to focus on building soils. Keeping growing crops on the landscape throughout the year, including cover crops with continuous no-till, can reduce soil erosion to very low levels. The soil building process becomes possible when soil loss is reduced to levels not reflected in current erosion prediction models.

Because it takes years to improve soil health, it is important that no-till is practiced continuously. Even one year of tillage can have a dramatic negative impact on soil health. A research study in central Pennsylvania showed the positive effect continuous no-till has on soil tilth. Soil aggregate stability in the soil surface of continuous no-till was 100 percent greater than in moldboard plow, 61 percent greater than in chisel/disk, and 25 percent greater than in short-term no-till *(Figure 2)*.

Because it takes years to improve soil health, it is important that no-till is practiced continuously.

Continuous no-till is defined as the planting of all crops without the use of any prior tillage. The no-till planter or drill accurately places the desired crop seed at the proper depth while providing good seed-to-soil contact. Planters and drills may or may not use coulters. They may be equipped with disk fertilizer openers to properly place plant nutrients. Shallow disk injection of manure or fertilizer is also considered to be consistent with continuous no-till planting. However, a focus on equipment would be self-defeating, no matter how important it is. This publication emphasizes the natural principles of the no-till system.

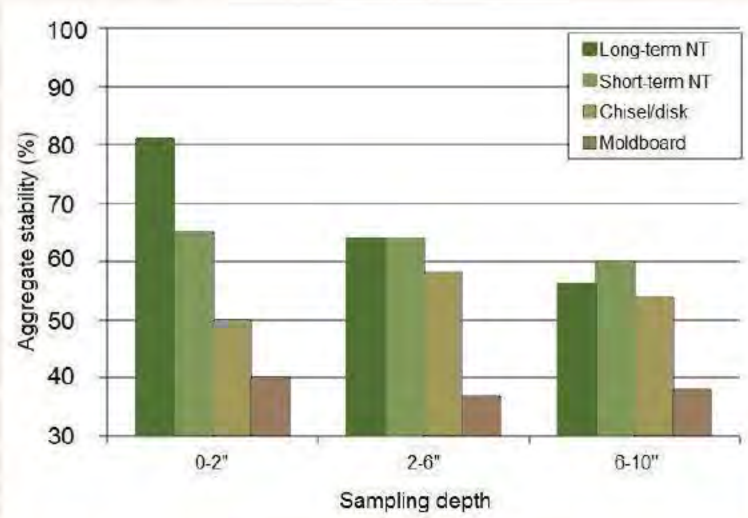


Figure 2. Building soil structure with no-till takes time. Aggregate stability in a long-term study was much higher in continuous no-till than in short-term no-till, chisel/disk, or moldboard plowed plots. *(Courtesy of Sjoerd Duiker)*

No-Till Soils

Soil aggregate stability is a measure of soil structure. Soil structure is the manner in which soil particles (sand, silt, and clay) are arranged and connected. Sometimes it is called soil tilth. In a healthy soil, the sand, silt, and clay particles are loosely connected, with plenty of pore spaces between them for water movement, aeration, root penetration, and biological activity to take place. Important substances that hold the particles together are glues produced by mycorrhizal fungi and bacteria, the fungal hairs made by different kinds of fungi, worm excretions and fine roots. If these are lacking, aggregate stability will be low. It is extremely important to have stable soil structure at the soil surface. This results in mellow (friable or loose) surface soil: the major reason planting gets easier allowing farmers to remove coulters and reduce down pressure on the planters after a few years in no-till. The stable surface soil structure also helps absorb and hold water in the root zone for improved water and nutrient uptake and retention and eventually, increased yields.

A recent review of different studies shows that the longer no-till is practiced, the larger the microbial biomass becomes *(Figure 3)*. These microbes are an important indicator of soil health. Some of these microbes, especially fungi, are highly sensitive to tillage. Tillage is like burning down the house, it disrupts the microbial biomass and the soil biological community has to rebuild.

Soil improvement with continuous no-till is not limited to the surface. Annually plowed soil will usually show a dense plow pan just below the depth of tillage, the absence of deep burrowing earthworms, and weak surface soil structure. This contrasts with the soil profile of a high-quality, continuous no-till soil that has granular surface structure, blocky structure below the surface layer, absence of a tillage pan, and continuous macropores created by decomposing roots and earthworms which go from the surface deep into the subsoil. Therefore, continuous no-till modifies the entire soil profile *(Figure 4)*. Over time, continuous no-till soil begins to resemble a natural prairie soil.

Because of the firm but porous nature of long-term no-till soil, the soil supports weight without detrimental effects. This is very important for field work or when grazing animals. One study found that soil with poor structure was not trafficable for 25 days out of a wet, cold month, while the same soil with good structure was not trafficable for only seven days. This explains why grazing no-till cover crops seldom causes excessive compaction if managed properly. In a compaction study in Pennsylvania, rutting caused by manure spreader traffic decreased the longer no-till had been practiced *(Figure 5, page 6)*.

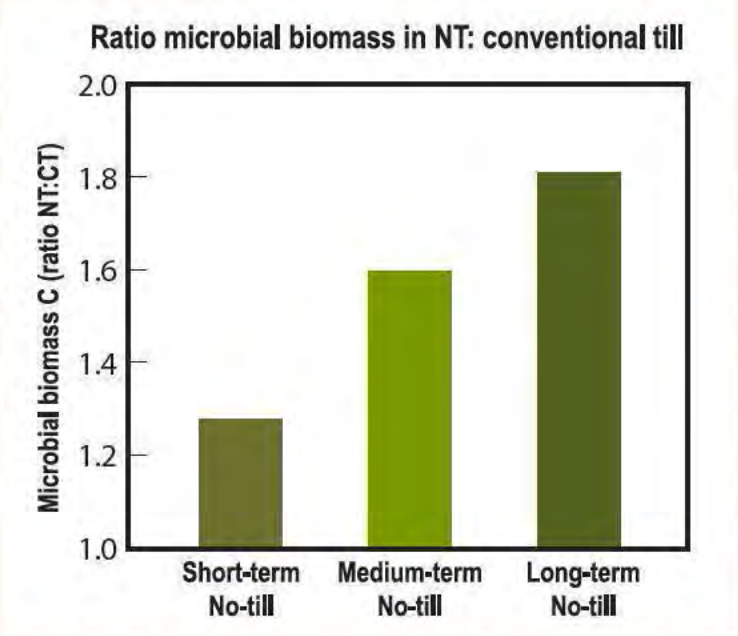


Figure 3. The ratio of microbial biomass carbon of no-till (NT) and conventional tillage (CT) for short term (0-2 yrs.), medium term (3-7 yrs.) and long-term (8-18 yrs.) no-till. It shows that microbial biomass increases the longer no-till is practiced. The samples were drawn from depths ranging from the top one to eight inches of soil and came from 40 different studies. *Source: Diva Souza Andrade, Arnaldo Colozzi-Filho and Ken E. Giller. 2003. The soil microbial community and soil tillage. Pages 51- 81 in Adel El Titi (Editor). Soil Tillage in Agroecosystems. CRC Press, Boca Raton, FL.*

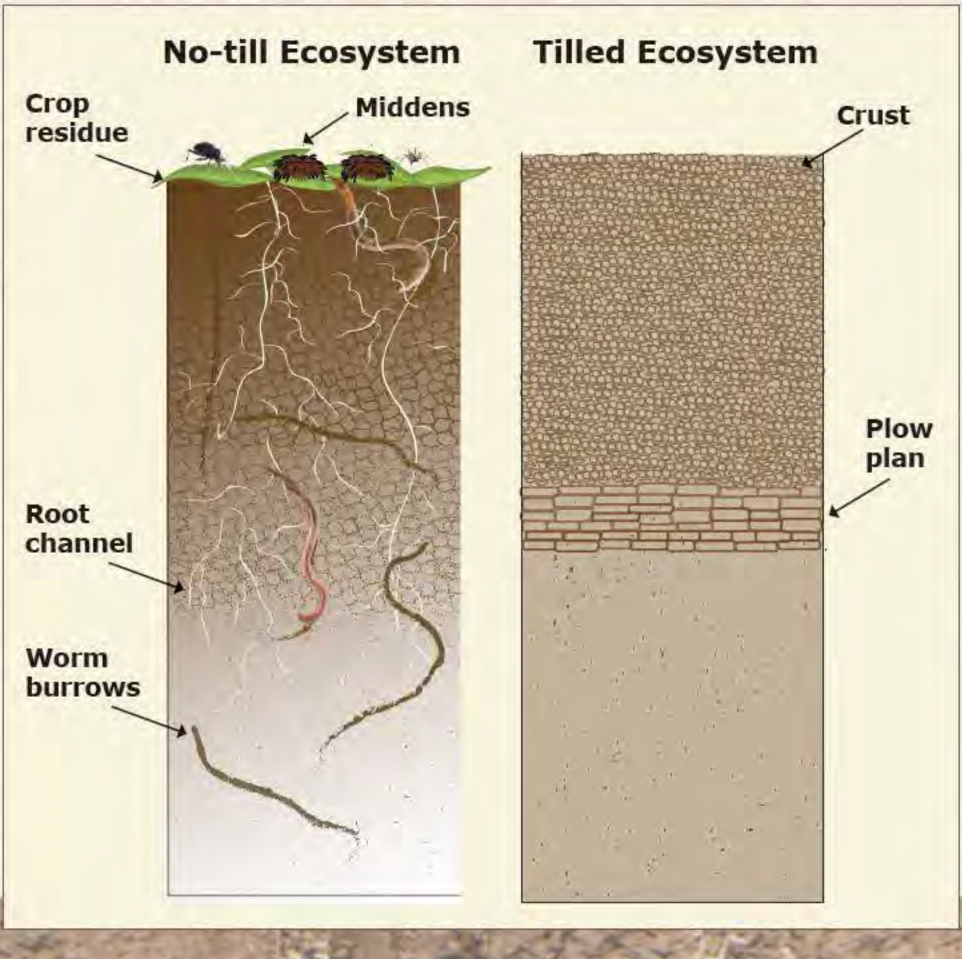


Figure 4. The entire soil profile will be modified when you use continuous no-till. The surface will be covered by mulch, granular aggregates, and earthworm middens. The topsoil will have a granular structure that gradually turns into a blocky structure with depth. The soil matrix is firm and yet the soil is perforated with thousands of pores created by roots, fungal hyphae, surface and deep-dwelling earthworms, and many other types of organisms. Old root channels and earthworm burrows leave pores that are continuous from the surface deep into the subsoil.

Figure 7. Mixing cover crops from different groups in the cover crop periodic table provides multiple benefits for soil health and beneficials. This is a mixture of warm season non-legume broadleaves (buckwheat and sunflower), cool season legumes (austrian peas), cool season non-legume broadleaves (brassicas), and warm season grass (corn). *(Courtesy of Lisa Blazure)*

Cover crops can be used for livestock feed which may provide an economic benefit to farmers. This is an important consideration for Pennsylvania farmers. Cover crops can be grazed or harvested as forage, reducing the purchase of imported feed. This results in more nutrients cycled on the farm and reduced nutrient build-up in the soil. Although above-ground growth is removed when the cover crop is harvested, the root system stays in the soil. Root systems have been shown to be more important than surface residue to increase soil organic matter. Overall, using cover crops for feed is considered to be a win-win situation for farmers and the environment.

Cover crop statistics have been collected in the last two years in selected counties but are not yet gathered as part of a state-wide effort. In a 2014 transect survey in five counties, cover crop use varied from 22-37 percent of crop acres. This is a major increase over earlier estimates that suggested only 10 percent of crop acres were followed by cover crops. In a study done by the U.S. Geological Survey and Penn State University in south-central Pennsylvania, cover crop use after corn was estimated using satellite images. The images selected enabled the researchers to estimate cover crop use after corn crops in four counties by analyzing how green the fields appeared. The data suggest that cover crop use after corn increased from 40-66 percent over the years 2009-2013 *(Figure 8)*. Much of this cover crop acreage followed corn silage.

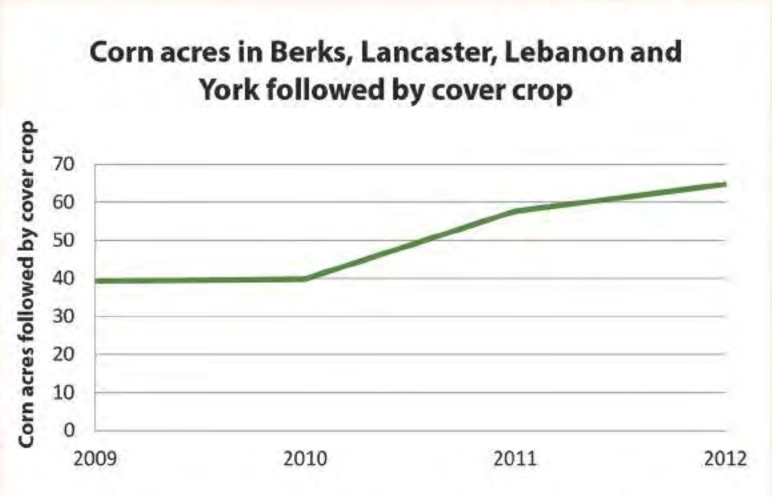


Figure 8. Percent corn acres followed by cover crop in Berks, Lancaster, Lebanon, and York as measured using remote sensing *(based on planted corn acres in 2012, from W. Dean Hively, Greg McCarthy and Sjoerd W. Duiker. Remote Sensing to monitor cover crop adoption in southeastern Pennsylvania. To be published in Journal of Soil and Water Conservation in December 2015)*

1. Diversify Crop Rotations

The first spoke is crop rotation diversity. Crop rotation is the 'repetitive growing of an ordered succession of crops on the same land over multiple years.' The first reason diverse crop rotations are important is that yields improve. Research from a long-term crop rotation trial in central Pennsylvania showed that, compared with continuous corn, corn yields were improved 7 percent when grown in rotation with soybeans, 15 percent in the first year after alfalfa/grass hay and 16 percent in a corn-oat-wheat-red clover hay rotation *(Figure 10)*. Interestingly, yield improvement of corn after alfalfa/grass hay was still present four years after termination of the hay.

The rotation effect on crop yield is well established agronomically (though not well understood) and confirmed in many different trials. Yet, it seems to be neglected. Why? It may be that agricultural systems have become focused on one or two crops due to high infrastructure and machinery costs. But, perhaps it is time to rethink this approach. Here are a few reasons why more diverse crop rotations are more beneficial:

Legumes in rotations fix atmospheric nitrogen through their symbiotic relationship with rhizobium bacteria and reduce the need for nitrogen fertilizer in the rotation. Part of the legume nitrogen can be counted as a credit towards the next, non-leguminous crop. Some legumes, such as peas, have been observed to have a very beneficial effect on following grass-type crops while terminated alfalfa sod supplies almost all the nitrogen required for a following corn crop.

Crop rotation is an important pest management tool. For example, corn rootworm is not an issue if corn is rotated with other crops. Weeds are also easier to control in a diverse crop rotation because of a range of practices to control them, such as narrow and wide row crops, winter and summer annuals, biennials and perennials, fertilizer placement (versus broadcast applications), different herbicide programs and application timings in the different crops, mowing, grazing, and harvesting at different times of the year. All these practices together work to reduce weed populations. By using diverse crop rotations in continuous no-till, herbicide use was reduced 50 percent compared with simple crop rotations on farms in the Great Plains.

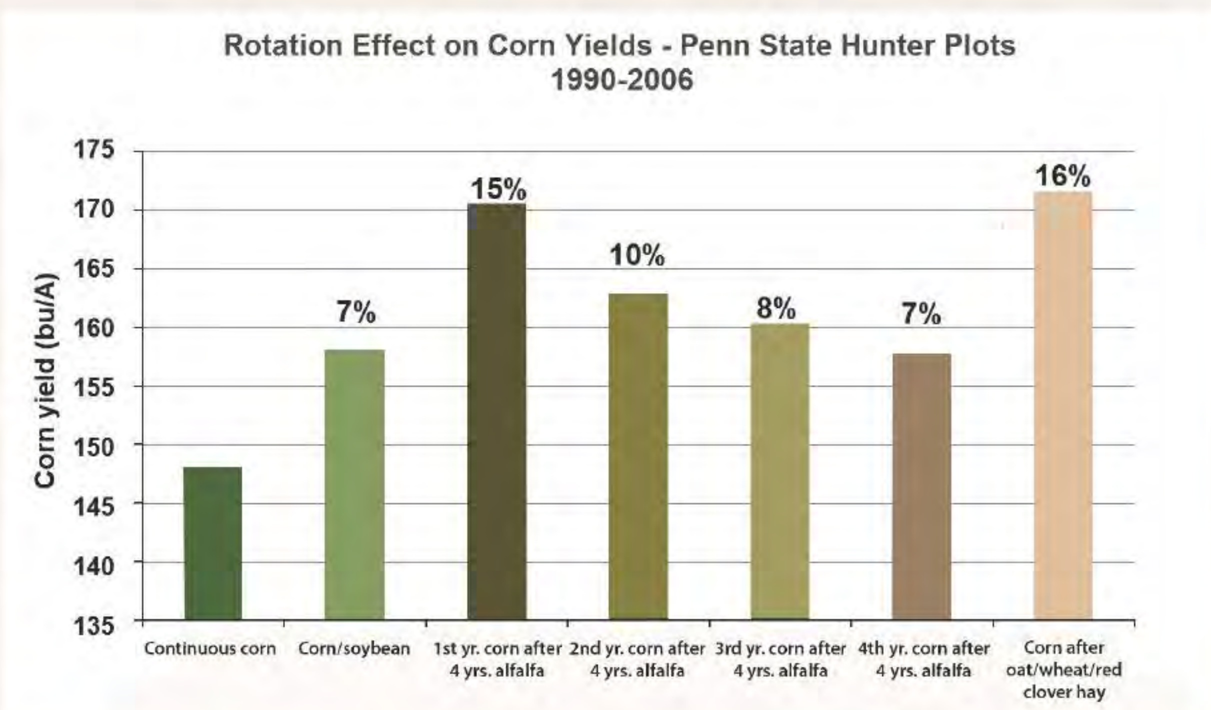


Figure 10. Crop rotation diversity increases crop yields as was shown in a long-term crop rotation trial on a Hagerstown silt loam soil in Centre County, PA. Percentages above the second to last bar indicate the percentage of corn yield increase over that in continuous corn (first bar). *(Courtesy of Scott Harkcom)*

Soil health is improved. Greater crop diversity above ground will also result in a more varied microbe food source and diverse microbial community below ground. Crops rotated with different root architectures, will impact soil structure in a variety of ways. Using massive, fibrous root systems will help improve aggregation, especially near the surface. The deep taproots of certain perennials can penetrate up to ten-feet deep. Old root channels will be available for subsequent crops, allowing for deep rooting and water percolation. In a long-term crop rotation trial in central Pennsylvania, aggregate stability was higher the more diverse the crop rotation *(Figure 11)*.

Machinery is used more efficiently. In simple rotations or monocultures, equipment is used only a few months in the year. With a diversity of crops that are planted and harvested at different times of the year, the combine, planter, and drill can be used more months of the year. It is also possible to use smaller, more affordable equipment.

There are fewer labor peaks. Labor needs are spread out over the year. Therefore, more diverse crop rotations also increase employment opportunities in rural areas.

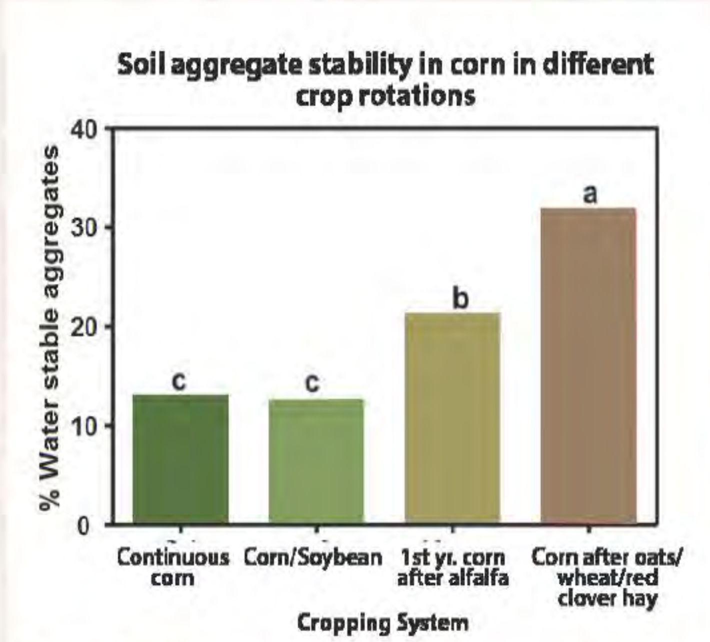


Figure 11. Aggregate stability was higher in diverse crop rotations in a long-term crop rotation trial in central Pennsylvania. *(K. K. Grover. 2008. Long-term cropping systems effects on soil aggregate stability, corn grain yields, and yield stability. A dissertation in agronomy. The Pennsylvania State University, University Park, PA)*

2. Plant Cover Crops

The second spoke is cover crops. Primarily grown for non-commercial purposes at times when soil would otherwise be without living vegetation, cover crops are used to:

Provide soil erosion protection. This is especially important if crop residue cover is minimal after harvest of the main crop.

Absorb, retain, and recycle nutrients. Some nutrients, such as nitrate, are soluble and can easily leach below the root zone. Cover crops take up soluble nutrients, protecting them from leaching. In a survey of cover crop biomass on working farms in different parts of Pennsylvania, every ton of dry matter (mostly rye) contained on average 57 pounds of nitrogen. Without cover crops, much of this nitrogen would have leached to groundwater and been lost to streams and rivers.

Maryland research confirmed that nitrate concentrations in soil water decreased remarkably when a cover crop of rye was used *(Figure 12)*.

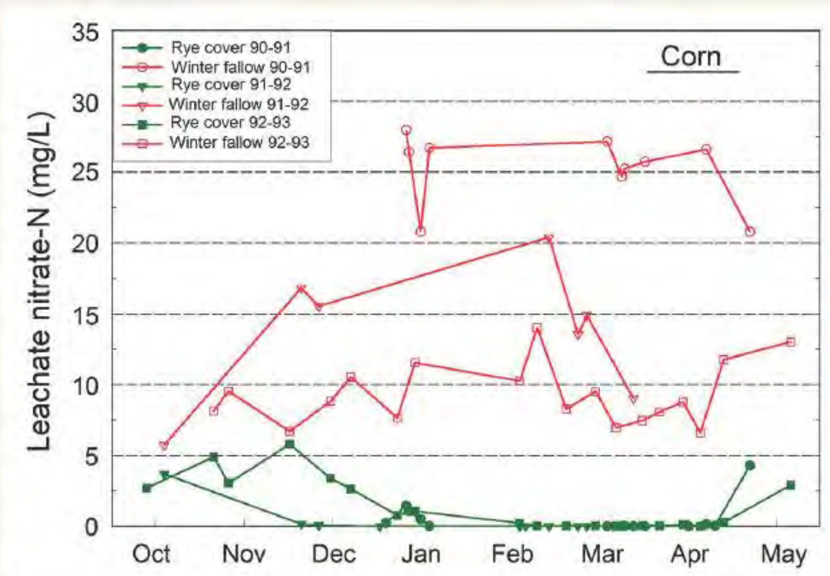


Figure 12. Nitrate-N concentrations in leachate decreased dramatically in Maryland when a rye cover crop was used. The rye effectively reduced nitrate losses to ground water and preserved N for future crops. *(K.W. Staver and R.B. Brinsfield. 1998. Using cereal and grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. Journal of Soil and Water Conservation 53(3): 230-240)*

Cover crops can make nutrients available from soil and release them to following crops upon decomposition. Some cover crops release organic acids that solubilize nutrients from soil particles. Research in Maryland showed that phosphorus was concentrated in the taproots of forage radish. Available phosphorus concentrations were increased where the root had decomposed in the spring *(Figure 13)*.

Fix atmospheric nitrogen. Leguminous cover crops fix large amounts of nitrogen from the atmosphere because of a unique bacterial infection in their roots that is beneficial to the legume and the bacterium. Because of this symbiotic relationship, no nitrogen has to be applied to these crops. The bacteria are called rhizobium, and different legumes are adapted to different rhizobium species. These bacteria can survive for many years in the soil. However, when the legume has not been grown in a field for a long period, it may be necessary to re-introduce the bacterium by mixing it with the seed prior to planting. Examples of legumes are alfalfa, soybeans, snap beans, hairy vetch, peas, red, white and crimson clover, cowpea, sunn hemp, and fava bean. While direct transfer of nitrogen from the living legume to companion crop has been shown to be small, when part or all of the legumes dies, the proteins in their cells decompose, releasing nitrogen that can be absorbed by another crop. A hairy vetch cover crop can supply all the nitrogen needed by a following corn crop, while a crimson clover cover crop can supply roughly 80-100 pounds per acre of nitrogen-equivalent to the following crop.

Cover crops can be used for grazing, green chop, silage, or hay if needed.

Provide weed control. There is no practice that provides complete weed control – even herbicides provide weed control only for a short period of time, after which the growing crop provides weed control by out-competing them. Cover crops also provide weed control by competing with weeds when they grow. Some cover crops release chemicals that inhibit germination and early growth of certain weeds, and the mulch left behind supplies a physical barrier and light control mechanism that inhibits weed emergence.

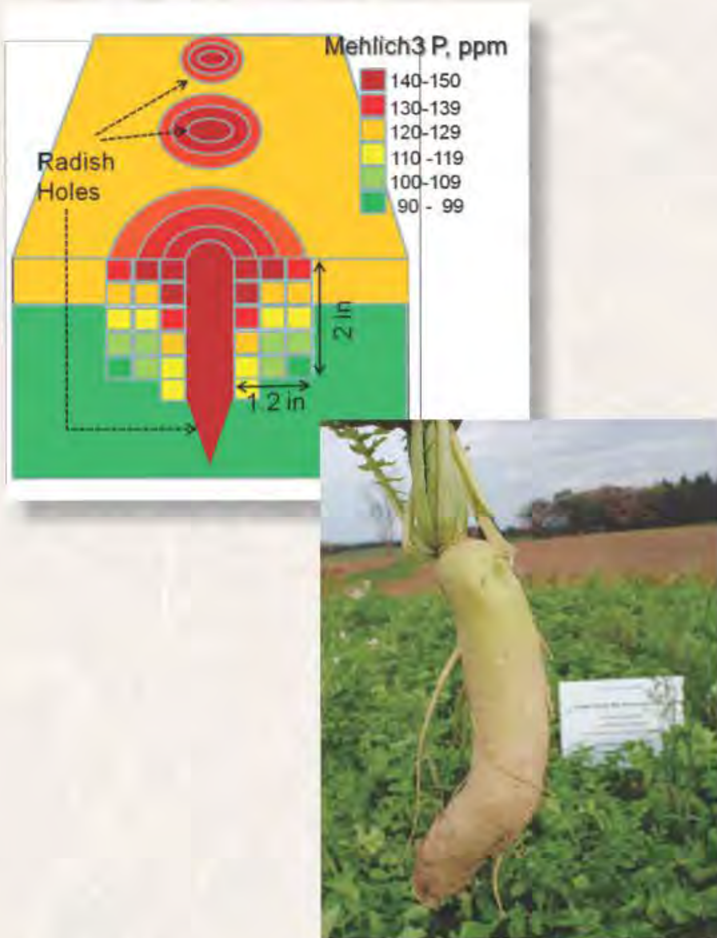


Figure 13. Available phosphorus was much higher in the vicinity of the holes of the decomposed taproots of forage radish in the spring. These cover crops can act like banded fertilizer by absorbing, retaining, and releasing phosphorus in available forms. *(From White and Weil, 2011).*

Provide forage. Although cover crops are not grown primarily for commercial purposes, they can be used for grazing, green chop, silage, or hay if needed. The use of cover crops for forage is beneficial because more feed is produced on the farm and fewer nutrients are imported in purchased feeds. This helps address the nutrient imbalance in Pennsylvania (nutrient importation in feed). Another important benefit of using cover crops for forage is that farmers are motivated to plant and manage the cover crops carefully to grow feed while providing environmental benefits at the same time. When cover crops are used for feed, it is recommended to leave a portion standing and provide enough time for regrowth to help feed soil microbes and provide soil armor.

3. Diversify Cover Crops

The third spoke is cover crop diversity. Mixing different cover crops and planting them together allows better use of water, light, and nutrients, often resulting in greater biomass production and better resource utilization *(Figure 14)*. Ecologists call this 'over-yielding.' This means plants compete less with plants from other species than with plants of the same species.

The different plant species use different resources, resulting in more efficient utilization. For example, plants with upright leaves catch a different spectrum of light than plants with horizontal leaves; legumes use atmospheric nitrogen while grasses and forbs use soil nitrogen; cool season grasses don't compete much with warm season grasses due to different temperature requirement, etc. The periodic table of cover crops can help you select cover crops with different characteristics when mixing species *(Table 1)*. Above and below-ground diversity also provides varied microbe food sources.

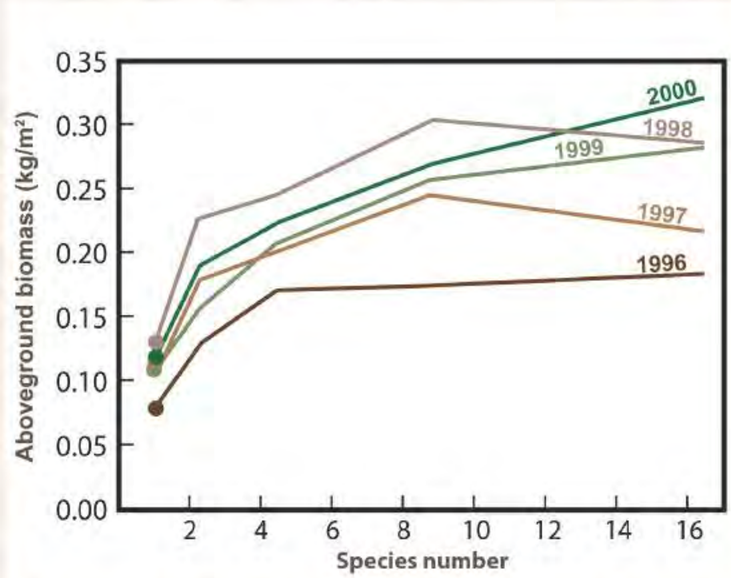


Figure 14. By increasing the number of species, the productivity of grassland plots increased. This is called 'overyielding' which means plants from the same species compete more with themselves than with plants from another species. By mixing cover crops greater benefits can be expected.

Table 1. Periodic table of cover crops showing cool season and warm season cover crops, grasses, broadleaves, and legumes to put together diverse cover crop mixtures.

Cover Crop Periodic Table

Cool Season Plants						Warm Season Plants		
Grass								Grass
Barley	Broadleaf Plants							Pearl Millet (wk)
Oat (wk)	Arugula						Safflower (wk)	Foxtail Millet (wk)
Ryegrass	Flax (wk)		Legumes				Buckwheat (wk)	Proso Millet (wk)
Wheat	Rape	Turnip (wk)	Winter Field Pea	Chickling vetch (wk)	Medic	Chickpea (wk)	Sunflower (wk)	Sudan grass (wk)
Cereal rye	Phacelia	Radish (wk)	Lentil	Red clover	Ladino clover	Cowpea (wk)	Amaranth (wk)	Teff (wk)
Triticale	Canola / Mustards	Beet	Spring Pea (wk)	Crimson clover	Bean (wk)	Soybean (wk)	Chicory	Grain Sorghum (wk)
Forage Oat (wk)	Ethiopian Cabbage	Tyfon (wk)	Vetch	Sweet clover	Alfalfa	Sun Hemp (wk)	Flower mix	Corn (wk)

(wk) = winter killed

(USDA NRCS)

4. Maximize Living Roots

The principle of maximizing living roots in soil year-round is the fourth spoke. Roots nourish microbes by providing a food source or by releasing nutritious compounds into the soil. It is estimated that plants release from 10-40 percent of the carbon fixed by photosynthesis through the roots. This carbon increases soil organic matter. Five different types of organic compounds released through roots are:

1. Cells are continually falling off root tips as roots grow;

2. Root tips produce an insoluble lubricating gel that helps the root penetrate small pores and provides the root tip protection against drying, helps gather nutrients, and binds soil particles together into aggregates that allow for better soil aeration and water percolation;

3. Soluble compounds called exudates are produced and leach from the root surface. These leacheates include organic acids, amino acids, proteins, sugars, phenolics, and other substances easily decomposed by microorganisms. The exudates have many functions; for example, they can solubilize plant nutrients such as phosphate from the soil particles, change the redox state on the root surface making iron more available, desorb nutrients from clay surfaces, or chelate zinc;

4. Sugars are fed directly by roots to fungi and bacteria that live in symbiosis with roots. Most well-known examples are rhizobia that fix atmospheric nitrogen in legume roots, and arbuscular mycorrhizal fungi that form bushy structures inside root cells connected to hyphae that extend the reach of the root into surrounding soil *(Figure 15)*.

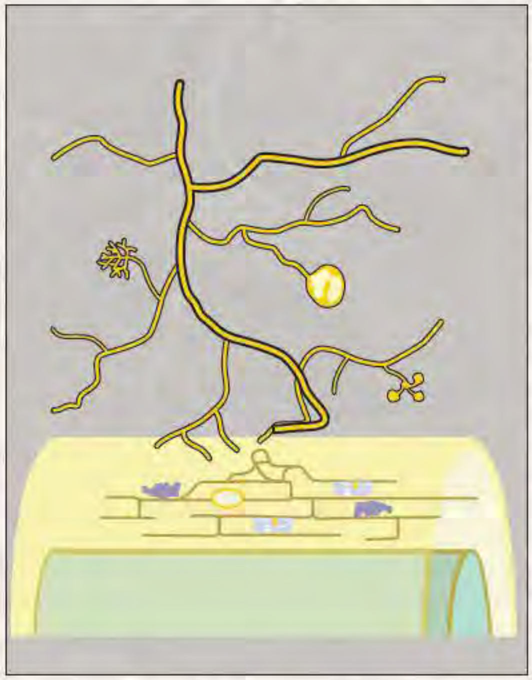


Figure 15. Schematic of the surface of a plant root with mycorrhizal fungi growing inside the root cells. Small bushy fungal structures called arbuscules grow inside root cortical cells. Water and nutrients are absorbed through the fine fungal hairs that extend into the soil and then passed on to the plant. Mycorrhizae release glomalin, an important glue that improves soil structure. (From mycorrhizaes.info/vam.html)

5. Dead cells are being lost from the root surface continuously as the roots develop. Subsequently, decomposer fungi and bacteria feed upon these dead cells located away from root tips.

The importance of living roots for soil structure improvement was evident in a Penn State study in which aggregate stability was measured at different times of the year in different crop rotations *(Figure 16)*. The study showed that aggregate stability increased during the period of active root growth and subsequently decreased when the root system declined. In the rotations with perennials, aggregate stability was always greater than in annual crop rotations due to prolonged presence of living roots.

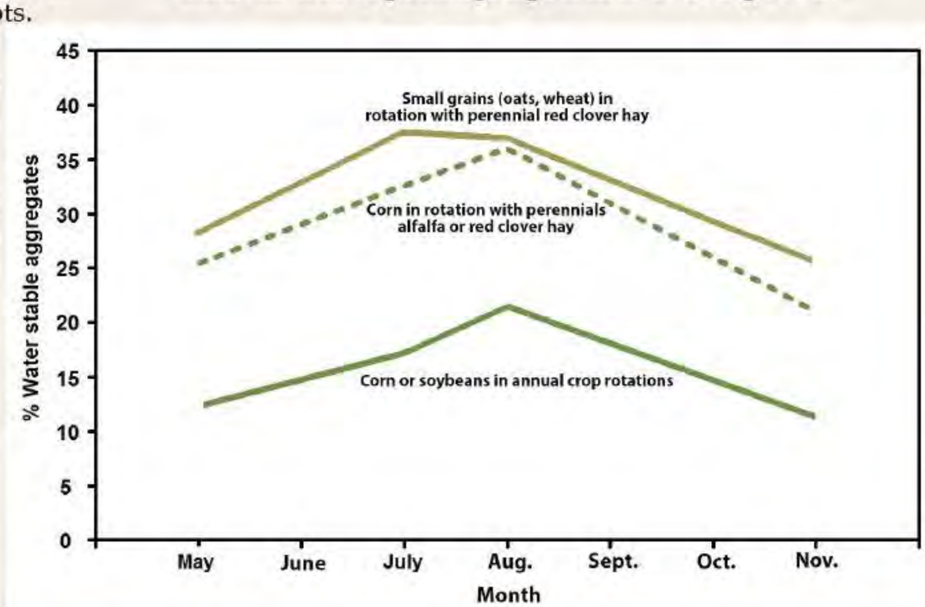


Figure 16. The dynamics of aggregate stability in a long-term crop rotation trial in central Pennsylvania. Aggregate stability increased with period of active root growth, peaked when root systems were at their top, and declined with root system decline. (*K. K. Grover. 2008. Long-term cropping systems effects on soil aggregate stability, corn grain yields, and yield stability. A dissertation in agronomy. The Pennsylvania State University, University Park, PA)*

5. Grow Living Plants

The fifth spoke is to have living plants in the field year-round. Living plants harvest sunlight and fix carbon dioxide from the air, producing different carbohydrates, and release oxygen. These carbohydrates include sugars, cellulose, hemicellulose, lignin, and many more. The carbohydrates are used to make plant cells and tissue. Because plants stand at the foundation of the soil food web, providing the energy source for most living organisms that cannot capture sun light, it is beneficial to have them growing in the field continually to keep the soil food web active *(Figure 17)*.

Cover crops are important because they keep living plants on the field during fallow periods. Cover crops should be planted as soon as the primary crop is harvested. Having a plan of how the cover crop will be established and the seed on hand prior to the planting window is very important. An exception to this may be when planting following small grain harvest because some cover crops, when planted too early, may be subject to winter kill. In this case it is justified to plant the cover crop a few weeks after small grain harvest.

It can be a challenge to plant cover crops early in the fall to produce enough growth to survive the winter and provide adequate cover. Cover crops should be selected that are adapted to fall and winter temperatures. Unfortunately, the harvest of summer crops such as corn or soybeans may be so late that cover crops produce little fall growth. Early-maturing corn hybrids and soybean varieties that can be harvested a week or two earlier than normal enable cover crops to produce better growth in the fall. Check variety trials to determine which short-season varieties can produce similar yields as long-season varieties in your geographic area.

Another opportunity for fall growth from a cover crop after corn grain or soybean harvest is to use interseeding (see next section). Late in the fall, a cover crop of rye or wheat can still be planted using 'dormant seeding.' Dormant seeding means that the seeds are in the soil but may not germinate or emerge until early spring. However, by planting time these cereals may be 6 to 12 inches tall. Dormant seedings are encouraged especially when some crop residues are present to help protect soil over the winter.

Living plants harvest sunlight and fix carbon dioxide from the air, producing different carbohydrates, and release oxygen.

Manure may be applied on a dormant seeding in the spring. If a recommended fall deadline for cover crop planting is not met, dormant seeding still may be a good choice, although planting cover crops earlier for living cover in the winter is preferable.

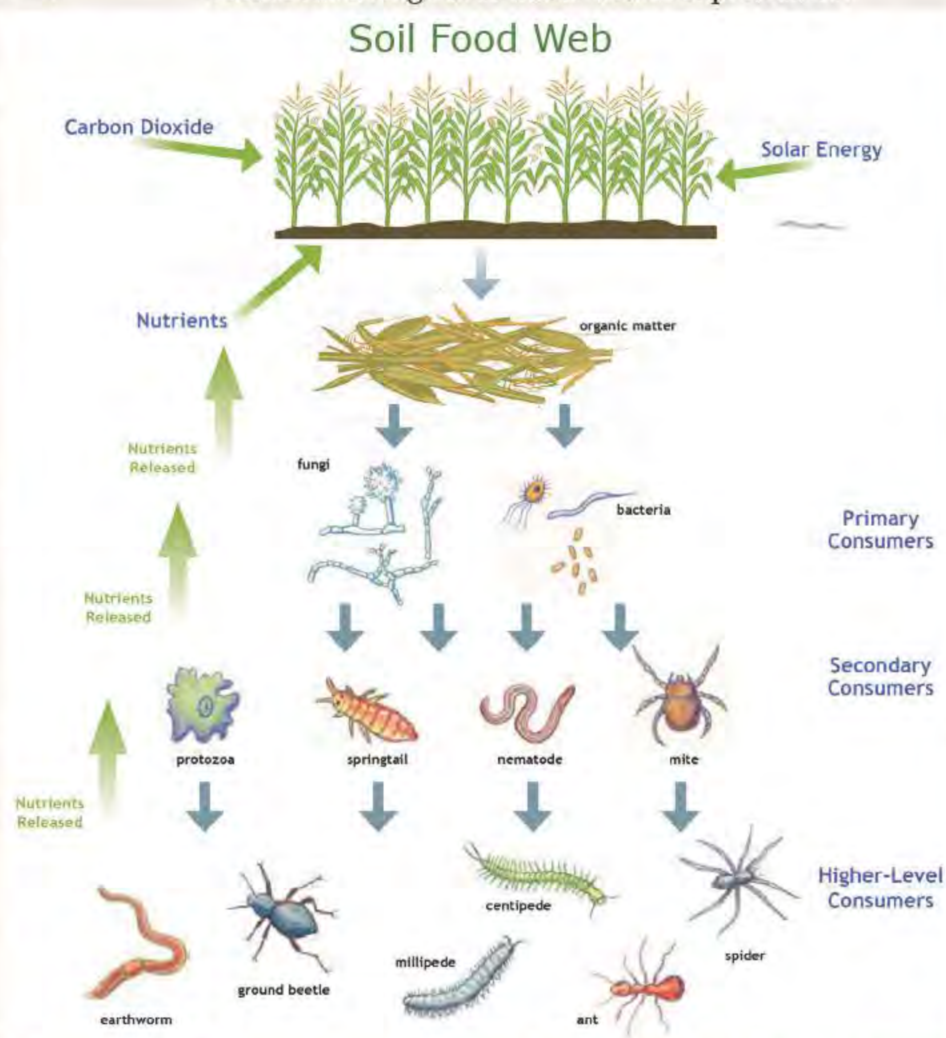


Figure 17. Plants stand at the beginning of the soil food web. Through photosynthesis they are able to capture the energy of sunlight and manufacture organic molecules that supply the energy for all other organisms. This dynamic system works best if living plants occupy the field year-long. *(Courtesy of www.landscapeforlife.org)*

6. Manage Carbon

The sixth spoke is carbon management. Carbon is not considered to be a plant nutrient and yet more than 40 percent of a plant is carbon (on a dry matter basis). Compare this with typical macronutrient contents of 1.5 percent nitrogen, 1 percent potassium, and 0.2 percent phosphorus. Farmers are really 'carbon managers'– they use plants to absorb carbon dioxide from the atmosphere and convert it into many different compounds, some of which are harvested *(Figure 18)*. A large portion of the carbon absorbed is used to feed soil organisms through the living roots. This carbon in the soil is of particular interest because it has such a profound effect on soil health.

A soil with high organic matter content is a good indicator of soil productivity. In the past this was called 'humus.' It is now recognized that humus is the highly stable form of carbon, and plants feed soil organisms with non-stable carbon compounds that are quickly consumed but contribute to the growth and activity of the entire soil food web. The below-ground part of the plant is probably more important than the above-ground part for increasing humus content. Therefore, it is important to have living roots in the soil year-round and return organic materials such as crop residues and manure to the soil. It is also important to limit soil disturbance because research has shown that large amounts of carbon dioxide are released when the soil is disturbed. The greater the volume of soil disturbed, the greater the carbon lost from the soil.

Maintaining a proper balance of carbon and nitrogen in the soil is very important in a healthy soil. As carbon is produced, a source of nitrogen needs to be available to provide the nutrients that microbes need to break down plant materials high in carbon, such as corn stalks or small grain straw. Rotations need to include legumes and soil organic matter content needs to be increased so that the soil has a larger source of nitrogen that can be made available when organisms and crops most need it. Using cover crop mixtures of both legumes and grasses is another way of providing microbes with both carbon and a nitrogen source to break down the carbohydrates and increase the level of organic matter in the soil.

It is important to have living roots in the soil year-round and return organic materials such as crop residues and manure to the soil.

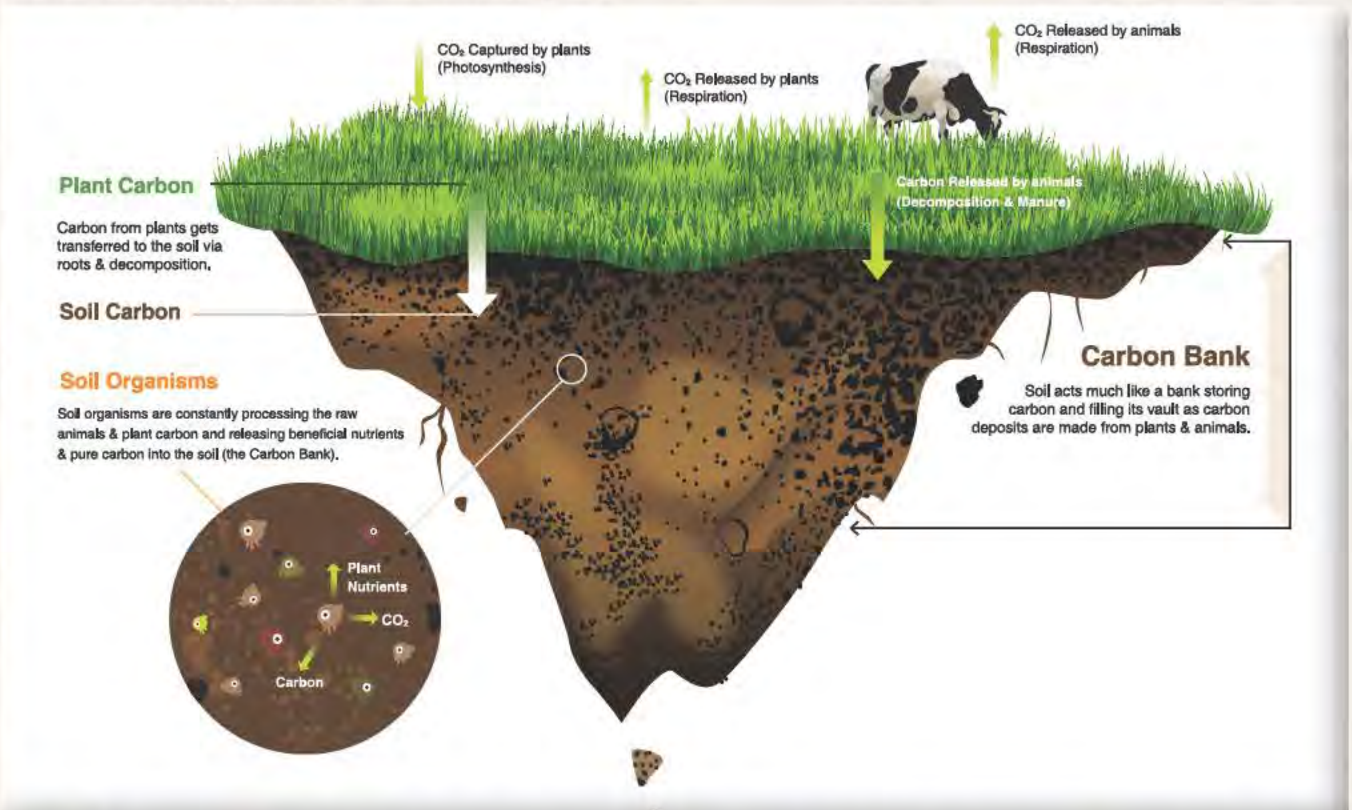


Figure 18. Managing carbon is key to soil health. *(From http://australiansoil.com.au/soil-management-benefits/)*

7. Use Interseeding

The seventh spoke is interseeding, sometimes referred to as 'relay cropping' – the establishment of a (cover) crop in a primary crop that is already growing. Examples of interseeding into annual crops are broadcast frost seeding red clover or yellow sweet clover in February/March into established winter wheat or barley. The practice of frost seeding has been quite successful because freeze-thaw cycles create some honey-combing of the soil surface which improves seed-to-soil contact. Seed predators are not yet very active and there usually is moisture at the soil surface to guarantee germination and early growth of the cover crop. The cover crop rarely compromises the yield of the main crop except that it may sometimes interfere with straw harvesting if the cover crop grows tall. The larger challenge is the competition of the main crop with the cover crop, which may cause the cover crop to struggle to establish. In most cases, however, there is a stand of clover visible after the small grain harvest that can be grazed, harvested, or terminated the following spring.

Broadcasting cover crops into summer crops is usually done in mid-June. This practice is relevant in corn for grain or soybeans because their harvest is late in the season for cover crop establishment. If a cover crop can be established prior to harvest it will be very beneficial. A high-boy type seeder which drops seeds between the rows can be used, or seeds can be broadcast using airplane or helicopter in corn or soybeans. These practices have not been as successful as frost seeding for the following reasons: (1) herbicide residues; (2) lack of honeycombing; (3) seed predation; and (4) lack of moisture for germination and early growth. Interseeders have been developed to overcome these challenges.

One unique interseeder can establish cover crops between rows of corn or soybeans planted on 30-inch spacing in no-till soils *(Figure 19)*. This interseeder guarantees good distribution of the seed which allows for lower seeding rates than in broadcasting, good seed-to-soil contact is achieved by using double disk openers, and there is greater protection of the seed from predators. Herbicide residues can still be a problem. Guidance on corn herbicides that can be used without hurting the cover crop is published in the Penn State Agronomy Guide Cover Crop Chapter.

Interseeding can also be practiced in perennial forages. Since most above-ground biomass of forage crops is removed it is common for forage fields to lack soil armor (cover) over winter. Such is the case with pure alfalfa stands. Planting a winter grain or other forage crop into the alfalfa in early to mid-August will provide soil armor, diversity, increased

Figure 19. Interseeding at 4-6-leaf stage (around the middle of June) enables establishment of cover crop if primary crop harvest is too late for cover crop establishment. New machinery has been developed that not only seeds the cover crop, but also applies side-dress nitrogen, and post-emergence herbicides, saving on operator time. *(Courtesy of Chris Houser)*

forage production, as well as possibly improved forage quality. In addition to winter grains, other cover crops such as oats, tillage radish, and some other small seeded cover crops can also be planted into alfalfa. There are many cover crops that make excellent forage, especially in mixtures. More diversity for soil microbes improves soil health. When planting into recently harvested forage crops, there is little above-ground biomass and planter adjustment and the planting process should not be difficult.

8. Plant Green

The eighth spoke is planting green. This practice refers to no-till planting primary crops into actively growing cover crops. This practice can be used when planting a crop such as corn or soybeans into a cover crop. It contrasts with planting into a cover crop that was killed one or two weeks before planting. Research has shown that by planting green, cover crop biomass can easily be doubled because cover crop growth is at its peak. Some important potential benefits of this practice include:

Research has shown that by planting green, cover crop biomass can easily be doubled because cover crop growth is at its peak.

- **Greater above- and below-ground cover crop biomass.** This helps to increase water infiltration and reduce surface runoff and soil erosion.
- **Legume covers will fix more atmospheric nitrogen** when growing an extra week or two.
- **The cover crop scavenges more nutrients** that might otherwise be lost by leaching to groundwater.
- **The cover crop will take up soil moisture** and help the soil to dry out and warm up quicker in periods of excess soil moisture.
- **The cover crops will harvest more solar energy and increase total soil carbon** important to increase the soil's water-holding capacity and nutrient pool.
- **The living cover crop root system produces easily digestible organic compounds** that feed living soil organisms in the rhizosphere (the zone close to roots). These organisms play important roles in building soil structure and nutrient recycling.
- **Hairpinning problems** of cover crop residue being pushed into the seed slot **should be eliminated or greatly reduced** because of better cutting of the green standing cover crop than that of dying crop residue that has been sprayed with herbicide but is not yet crisp and dry.
- **Potentially fewer problems with slug and cutworm pests** that move to the seedlings of the main crop when the cover crop is dead.
- **Potentially less soil or residue-borne disease** because of reduced splash from previous crop residue and soil onto the young seedlings of the primary crop.
- **Greater amounts of mulch in the crop** reduce weed pressure and result in cooler mid-summer soil temperatures.

Planting green is a new practice that is still under evaluation. Both the planter and attachments need to be in good condition and down pressure properly adjusted. It is important to account for thickness of standing or rolled plant cover when planting green. Down pressure on closing wheels needs to be set properly and seed openers need to be in good condition. Some farmers reduce the seeding rate of the cover crop so it is easier to plant in the spring. Shading of the primary crop seedlings by a tall cover crop can be undesirable, especially with corn. Cover crop rollers are available to mount on planters that flatten the cover crop onto the soil surface and part the cover crop so the double disk openers have less plant material to cut *(Figure 20, page 18)*.

Soil fertility needs to be optimized when planting green in a cover crop that has a lot of carbon in relationship to nitrogen. In this case, microbes may absorb nitrogen from the soil to decompose the cover crop residue and may cause a nitrogen shortage for the primary crop. This can be addressed by applying extra manure or nitrogen fertilizer, preferably placed close to the new seedling. Pest and disease benefits of planting green need more research, although preliminary results look promising.

Figure 20. A cover crop roller/row cleaner system designed by a Pennsylvania farmer/engineer from Perry County. It can be attached to a corn planter. It parts the cover crop in front of the double disk. *(Courtesy of Sjoerd Duiker)*

9. Enhance Soil Armor

The ninth spoke is soil armor. It may be broken down into two separate categories *(Figure 21)*. First is passive armor; this is the dead plant residue that remains on the soil surface following crop harvest or crop termination. Second is active armor; typically represented by an actively growing economic or cover crop.

Maximizing soil armor will weatherize cropping systems against the effects of drought, excess rainfall, and extremes in temperature. Maximizing soil armor is accomplished by leaving all crop residue remaining after grain harvest. The residue needs to be either left standing or be spread evenly over the surface of the field for success. If residue is clumped or concentrated in swaths, it will compromise establishment of the following crop, create non-uniform soil temperature and moisture conditions, and provide non-uniformity in food sources for biological life.

It is best to leave as much residue standing as possible during harvest so that there will not be a thick blanket of loose residue through which to plant. When residue is left standing, the soil warms up quicker in the spring and dries out faster than if the residue remained on the soil surface as mulch. The standing residue will be anchored in the soil, which facilitates planting of the next crop. Eventually, the dead stalks will fall and decompose on the soil surface. In situations where crop residues must be removed to meet the operation's objectives, it is essential to plant cover crops in a timely manner to compensate for the removed residue. Individuals who provide the best overall soil armor have learned how to combine both passive and active armor.

Some no-tillers experience problems with heavy residues, especially corn stalks. Issues include wet soils that delay spring planting and difficulty achieving adequate seed placement and slot closure. Some techniques to manage heavy corn stalks include:

- Let corn stalks stand after harvest.
- Apply manure to help soil microbes speed up residue decomposition.
- Plant cover crops into the residue; the drill cuts up the crop residue in smaller pieces and the increased biological activity and microclimate created by the cover crop favors residue decomposition.
- Use planter attachments to move residue from the row.

Figure 21. Soil armor includes passive armor, which is the crop residue from the previous crop, and active armor, which is the living cover crop. Both provide food sources for soil biological organisms and 'weatherize' your cropping system. *(Courtesy of Sjoerd Duiker)*

Irrespective of the management, having a healthy biologically active soil is key to the breakdown of residues, especially those with a high carbon to nitrogen (C:N) ratio and high lignin content *(Table 2)*. Fungi specialize in breaking down lignin so high-fungal populations found in long-term no-till soils will be beneficial. Long-term no-till is beneficial for earthworms that assist in the breakdown of crop residues. A readily available source of nitrogen to complete decomposition is important. A soil with high organic matter content will have more nitrogen available for microbes to decompose high C:N residue.

Table 2. Typical C:N ratios of organic materials

Material	C:N ratio
Soil bacteria	5
Actinomycetes	6
Soil Fungi	10
Hairy vetch cover crop	11
Alfalfa, young	13
Finished compost	15
Rotted manure	20
Alfalfa, mature	25
Rye, vegetative	26
Rye at flowering	37
Corn stover	57
Small grain straw	80
Hardwood sawdust	400

N.C. Brady and R.R. Weil. 1999. The nature and properties of soils, 12th Ed. Prentice-Hall, Upper Saddle River, NJ, USA.

On the other hand, residues higher in nitrogen, for example those from legume crops like soybeans, break down rapidly and leave very low levels of soil armor. Cover crops with higher C:N ratio should be used to improve soil armor. By knowing the carbon to nitrogen ratio of crop residues and cover crops it is possible to maintain adequate and manageable levels of soil armor.

Fifty percent soil armor is considered acceptable, but higher levels provide more soil erosion protection, help conserve soil moisture and reduce soil temperature during the summer months, and help protect and feed soil organisms. This is very different from the older recommendations when 30 percent residue was considered adequate.

Managing soil armor in forage cropping systems is challenging since minimal amounts of residues remain after harvest. This is especially true in pure stands of legumes such as alfalfa. One way to address this is to grow perennial grass/alfalfa mixtures instead of pure alfalfa. If this is not desirable, it is possible to interseed annuals, such as small grains, into pure alfalfa in early to mid-August following a forage harvest. To add more diversity, other low-growing species may be added. This provides active soil armor, increases forage production, and usually improves forage quality as well. It is also a good practice to leave the last cutting of the year standing to feed the microbes and protect the soil. However, if the last cutting is to be removed, then interseeding a winter small grain in August following a harvest will assure that some additional growing cover will remain as soil armor during the winter months and into the early spring.

> **"Feed the soil and the soil will feed the plant."**
>
> *- Carlos Crovetto, no-till pioneer*

10. Manage Nutrients

The tenth spoke is nutrient management. Adequate soil fertility is important to manage soil health for optimal crop production and environmental protection. Both nutrient excesses and nutrient deficiencies can have a negative impact on soil microbes and in turn on plant health and crop yield. A deficiency in one nutrient causes imbalances and can significantly impact both plants and biological processes. More diverse cropping systems and diverse cover crops increase the availability of nutrients from the soil and must be accounted for when considering the purchase of additional plant nutrients. The impact of plant roots and soil biology on the availability of nutrients for plant growth is discussed in several other sections of this publication. Currently, scientists and others are still learning how to best evaluate the impact of plant roots and soil biology on plant nutrition. Carlos Crovetto, long-term no-till pioneer from Chile, emphasizes: "Feed the soil and the soil will feed the plant." When soil health is improved it may be possible to use less fertilizer than generalized recommendations. To adjust rates it will become increasingly important to use the services of a Certified Crop Advisor (CCA) to help effectively manage nutrients in crop and forage production.

While it has long been acknowledged that organic matter and soil biology are a source of nitrogen for agricultural crops, laboratories had difficulty measuring this nitrogen in quick, inexpensive tests. As a result, for the last 50 years, soil tests have only measured the inorganic forms of nitrogen (nitrate, nitrite, and ammonium) and nitrogen recommendations may be based on these measures or are simply estimated based on yield goal. New tests are being evaluated that give measures of soil biological activity and predict the available nitrogen from organic matter. One test measures the carbon dioxide (CO_2) respiration of soil microbes. The more microbes in the soil sample and the more food sources they have, the more CO_2 produced. The test is a critical component of another laboratory test called the Soil Health Tool. This test uses water and mild organic acids (like those produced by plant roots) to measure available carbon, nitrogen, and other nutrients. The combined result of the new tests and lab analysis will generate improved understanding of soil health effects on plant nutrition. By using soil health analysis farmers can measure their progress as they implement management practices to improve soil health.

11. Manage Manure

The eleventh spoke is manure management. Manure is a source of nutrients and organic matter and helps to feed soil microbes and increase soil organic matter content *(Table 3)*.

Solid, semi-solid, or slurry manure contains significant amounts of organic matter and is more beneficial to the soil than liquid manure. Some guidelines in managing manure to optimize its value and minimize any negative impacts to the environment include:

- Apply manure when temperatures are low to limit volatilization of ammonia.
- Apply manure when moderate precipitation is predicted so the urea infiltrates the soil instead of being volatilized.
- Use shallow disk injectors to reduce nitrogen losses and minimize odors.
- Always apply manure on a growing crop whether it be a forage or cover crop so nutrients are absorbed by the living plants.

Table 3. Effects of 11 years of annual solid dairy manure on soil properties

	Solid Manure Application Rate (Tons/Acre/Year)			
	None	10 Tons	20 Tons	30 Tons
Organic Matter	4.3	4.8	5.2	5.5
CEC (me/100 g)	15.8	17.0	17.8	18.9
pH	6.0	6.2	6.3	6.4
P (ppm)	6.0	7.0	14.0	17.0
K (ppm)	121.0	159.0	191.0	232.0
Total pore space (%)	44	45	47	50

Fred Magdoff and Harold van Es., 2000. Building better soils for better corps. Handbook Series 4. Sustainable Agriculture Network, Beltsville.

Since manure is not normally applied to a growing grain crop, it is best to apply it to the preceding cover crop or use it on forages. Increasing numbers of producers apply manure to perennial hay and cover crops and use purchased nitrogen on the grain crop (typically corn) that can be sidedressed at the time of high crop nutrient demand.

In order to use manure most efficiently, and to meet state regulations, soil tests, manure analyses, and other information relevant to producing crops with manure should become part of a manure management plan. It is important to follow this plan and document the application of manure by field. A Certified Crop Adviser can assist in managing manure and nutrients in general.

Another way to manage manure application on the land is to use a separator to separate manure into liquids and solids, which are subsequently applied separately. The liquid portion contains more urea and soaks in the soil quickly where it is protected from volatilization, whereas the solids containing more of the phosphorus can be applied on soils most lacking in phosphorus. Manure digesters generate energy from methane gas while they separate liquids and solids and improve the stability of manure nitrogen. When liquids are separated from solids, the liquids can be applied either by irrigation or by using a drag hose to speed up application and reduce the potential for soil compaction. Drag hoses have more applicability than once believed and can speed up manure application and reduce compaction when soils are too wet to carry the weight of manure trucks or spreaders.

12. Manage Pests

The twelfth spoke is Integrated Pest Management. Managing pests is a challenging part of continuous no-till systems. Crop diversity and soil health improvement increases the number of beneficial organisms and helps keep pests in check. Insecticides commonly used in crop and forage production can also harm populations of natural enemies. For example, it has been shown that seed-applied systemic insecticides can be taken up by slugs eating young seedlings without harming them, but the ground beetles that prey on these slugs are killed *(Figure 22)*. Another example is the use of broadcast insecticide sprays applied after planting that kill pests as well as many beneficial insects. It is important to use insecticides and seed treatments only when they are needed using economic threshold populations as indicators and not just for the sake of 'insurance' against potential problems. In the long term it is more economical and effective to build populations of beneficial insects who keep pest populations in check. A Certified Crop Advisor can offer guidance with pest management. Ensure that the advisor you select is one who is familiar with methods of building soil health and working with nature to manage pests. By using methods of integrated pest management, soil health in continuous no-till is improved, making cropping systems more profitable.

13. Avoid Compaction

The thirteenth spoke is to avoid soil compaction. One of the great benefits of using continuous no-till is that the soil supports weight better and is less sensitive to compaction. This is due to high organic matter content near the soil surface, high microbial and earthworm activity, and a firm soil matrix that is perforated by biopores for water infiltration and percolation, gaseous exchange, and habitat provision for soil organisms and roots.

However, once compaction is caused the no-tiller may experience its aftermath for several years. It is important to understand what causes compaction and to avoid it as much as possible. Soil compaction is primarily of concern when the soil is wet. Soil moisture acts as the lubricant that allows soil particles to slide over each other and be packed to higher density. Continuous no-till soil is beneficial because the soil drains excess water more readily than tilled soil that lacks continuous macropores, but it is important to stay off soil that is too wet.

Figure 22. Pesticide applications can have unintended consequences. They can kill insects such as these firefly larvae that are a predator of slugs, while leaving the slug unaffected. Pesticides should therefore only be applied when needed, using crop scouting and economic thresholds. *(http://backyardsfornature.org/wp-content/uploads/2013/07/firefly_eats_slug-image-by-Phillip-SITNAM7-in-Climax-Michigan.jpg)*

Shallow compaction is caused by the pressure exerted on the soil surface. The weight and footprint of equipment or animals determine how much surface compaction is caused. Tire inflation pressure is important – the lower the tire pressure, the larger the footprint and less the opportunity for compaction. Equipment using tracks increase footprint and therefore reduce surface pressure too. Massive, living root systems in the soil help the soil resist compaction and bounce back from its causation. Fibrous cover crop root systems are effective to achieve reduced compaction.

Shallow compaction or tightness near the soil surface can be associated with the transition to continuous no-till without cover crops and soil armor and can cause increased soil erosion due to increased surface runoff. Even in long-term no-till, without soil armor or crop canopy or both, soils can become tight near the soil surface and lose their ability to infiltrate rainfall. This happens when the soil surface is not protected from the pounding of raindrops, especially during intense storms. It is therefore important to provide continuous cover but also to make use of different root systems. Besides the fibrous root systems tap root systems are beneficial to create macropores and maintain soil porosity. Forage radishes, turnips, red clover, alfalfa, and sunflower are examples of (cover) crops with taproots.

Soil compaction at intermediate depth (two- to four- inches deep) may be a problem in no-till. Compaction by heavy equipment may cause platy soil structure at this depth. This layer is more sensitive to compaction than the surface because its organic matter content is not as high, root density is lower, and the soil moisture content is high many days of the year due to the conservation of moisture by crop residue. Compaction of this layer may easily become a problem where farmers do not make use of living cover year-round. The living root system reduces moisture content and acts as a 'geotextile' that makes soil resist compaction and reduces platy soil structure. Compaction at intermediate depths can also be the remnant of tillage with a disk or vertical tillage tool that was operated at the same depth year after year when soil moisture content was too high resulting in massive soil structure.

Some Pennsylvania farmers can triple crop yield in one year by integrating crops and animals.

Deep compaction can be associated with prior plow pans or the use of heavy equipment when soil moisture content is too high. When evaluating soil compaction the first step is to check the soil type to see if that soil mapping unit naturally has a restrictive feature such as a fragipan. Natural compaction is difficult to remedy but can be somewhat alleviated by using cover crops and primary crops with deep roots that can penetrate these layers. Deep burrowing animals such as earthworms help alleviate deep compaction and are enhanced by the soil health practices in this publication.

Soil damage by prior tillage resulting in compaction is not easily alleviated. Using a subsoiler may be called for if soil compaction is very serious. It is important to use a subsoiler that does not invert the soil but fractures it. Unless subsoiling is done when the soil is dry, the impact will be minimal and sometimes causes new compaction. Normally, the only time the soil is dry enough to consider subsoiling is in mid-summer or in early fall, following harvest of a crop such as a small grain. In a corn-soybean rotation, there are limited periods of time when the soil moisture content is optimal for successful subsoiling. It is better to avoid tillage and rely on nature to alleviate compaction.

14. Integrate Crops and Livestock

The fourteenth spoke is crop and livestock integration. The trend in agriculture has been to separate crop and livestock production. Farmers who include animals as part of the farm operation are more likely to adopt cover crops for manure and compaction management, and as a possible feed for ruminant animals *(Figure 23)*. Further, manure from ruminant animals is a great soil amendment to improve soil health in cropland. More intensive crop rotations are possible with livestock on the farm because crops can be grazed or harvested early for green chop, silage, or hay. Some Pennsylvania farmers can triple crop yield in one year by integrating crops and animals. Crop diversity tends to be greater on animal farms because of the nutritional needs of the animals. However, the animal and crop enterprises are usually separated, even if present on the same farm.

Farmers from different parts of the world, including some innovators in Pennsylvania, have shown that integrating grazing ruminant livestock and crop production can have advantages:

- **Increased profits** due to reduced costs and increased revenue. For example, grazing animals on crop residue and cover crops results in a new income stream and better land utilization.

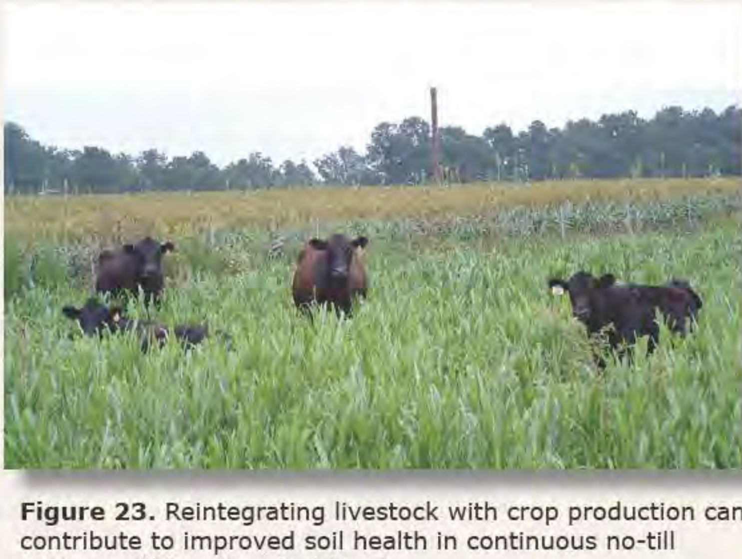


Figure 23. Reintegrating livestock with crop production can contribute to improved soil health in continuous no-till systems. *(Alan Franzluebbers)*

- **Reduced risk** through diversification of enterprises. The farm becomes less sensitive to price fluctuations in one commodity and to weather variability because crops are not all grown at the same time of the year.
- **Easier pasture renovation** after annual crops. By rotating to an annual (cover) crop it is possible to completely eradicate the old unproductive stand so that a clean, improved perennial pasture can be established.
- **Increased whole herd-carrying capacity** for graziers. Some perennial forages produce little during the summer heat. By including summer crops or summer annual forage mixes such as sorghum, sudangrass, or their hybrids, grazing corn, sunflower, sunn hemp, cowpea, forage soybeans, buckwheat, and others, the farmer will have higher productivity. Some winter annuals start growth early in the spring, providing pasture at a time when perennial forages are not yet productive.
- **Decreased fertilizer needs** due to the effective use of manure and urine in intensive grazing operations and integration of legumes in the crop rotations.
- **Decreased crop disease, weed and pest pressure** through the increased diversity.
- **Improved soil health** because of the rotations of annuals and perennials, grasses, legumes, and forbs; the manuring, urinating, and salivating of the animals; and trampling of part of the crop residue into the soil when ultra-high density grazing is used. The diversity of root systems and symbiotic relationships of crops, bacteria, and fungi stimulate soil microbial activity and aggregate stability.

Additional Best Management Practices for Erosion Control

While improved soil health can alleviate most erosion issues, there can still be some problems of concentrated surface water flow. One common scenario is where springs or seeps exit the hillside or where runoff from another area flows into a field. In these situations, producers may need to utilize grassed waterways and structural practices to manage concentrated flow. These practices may also be needed in larger drainage areas with potential concentrated flow erosion within cropland areas. Some no-tillers address areas that have been gullied by filling them with appropriately sized rock and field stones to stabilize the area and retain the ability for some water to flow through the stones. Another scenario is when the soil is frozen and begins to thaw at the surface. Snow melt or heavy rainfall at this time can be devastating since infiltration is almost zero, no matter how healthy the soil, resulting in near 100 percent runoff. This is where living cover and heavy residues may need to be coupled with surface water management practices. In continuous no-till, concentrated flow erosion is not hidden as it is where gullies can be covered up by tillage every year. In continuous no-till, visible erosion can be the culmination of a number of years. It may be for this reason that some individuals have associated no-till planting with soil erosion. In reality, however, soil erosion with tillage is much higher but rills and small gullies are covered up every year. Nonetheless, if there are problems with concentrated flow erosion they need to be addressed quickly to avoid gully formation in continuous no-till.

NCF-Envirothon 2024 New York

Soils and Land Use Study Resources

Key Topic #4: New York Soils, Conservation, and Land Use

14. Explain how glacial geomorphic processes and resulting landforms affect soil formation in New York State.

15. Describe the various soil regions within New York State, and how they impact dominant land use and resource concerns.

16. Identify various soil conservation systems and the conditions for their successful application.

Study Resources

Resource Title	Source	Located on
New York Soils	*Matthew W. Havens, Soil Scientist, USDA-Natural Resources Conservation Service, 2023*	page 95-96
Brief Summary: Soils of New York	*USDA Agriculture Handbook 296. USDA-Natural Resources Conservation Service, 2023*	page 97-98
Geology of New York State-Chapter 3 New York State Soils	*NYSDOT Geotechnical Design Manual, 2013*	page 99-102
NRCS and Urban Agriculture	*USDA, Natural Resources Conservation Service, 2023*	page 103-104

Study Resources begin on the next page! ➡

New York Soils

By Matthew W. Havens, Soil Scientist, USDA-Natural Resources Conservation Service

Glaciers. That's a word to know about when talking about the soils of New York State. Throughout earth's history most all of New York has been covered with glacial ice at one time or another. The only area that has not been covered with glacial ice is a small section south of the Allegheny River in Cattaraugus and Allegany Counties.

Glaciers have been advancing and retreating in this area for around 90,000 years. The last glacial advance was between 22,000 to 20,000 years ago. During this last glacial advance the ice was thick enough to cover the Adirondack Mountains and Catskill Mountains. The enormous pressure of thousands of feet of ice forced the ice to "flow" outward from places where it was thickest. The movement was slow but relentless. The flow was mainly north to south, with some minor deviations where tongues of ice followed the pre-glacial valleys. As the ice melted, many different types of glacial deposits were left behind. Some of the major types of deposits are glacial till, glacial outwash, and deposits from glacial lakes that were impounded in front of the ice. These deposits would become the parent material for our present-day soils.

The area where the competition is being held is in the Ontario-Erie Plain and Finger Lakes Region. It is entirely in New York State and is just over 10,000 square miles in size. Most of the area is a nearly level to rolling plain. Low remnant beach ridges are commonly interspersed with a relatively level lake plain in the northern part. Drumlins (long, narrow, steep-sided, cigar-shaped hills) are prominent in and east-west belt in the center of the area. The Finger Lakes consist of gently sloping to rolling till plains.

The bedrock underlying this area consists of alternating beds of limestone, dolostone, and calcareous sandstone and shale. Most of the surface is covered with calcareous till, lake-laid silts and clays, and sandy or gravelly outwash.

The soils of the area are relatively young due to glaciation. However, some are old enough to have formed argillic horizons (layers with more clay than the horizon above). The pH's are naturally in the slightly acid to slightly alkaline range, and the slopes are nearly level to gently sloping over much of the area, which makes them favorable for agriculture. They are shallow to very deep, excessively drained to very poorly drained and sandy to clayey.

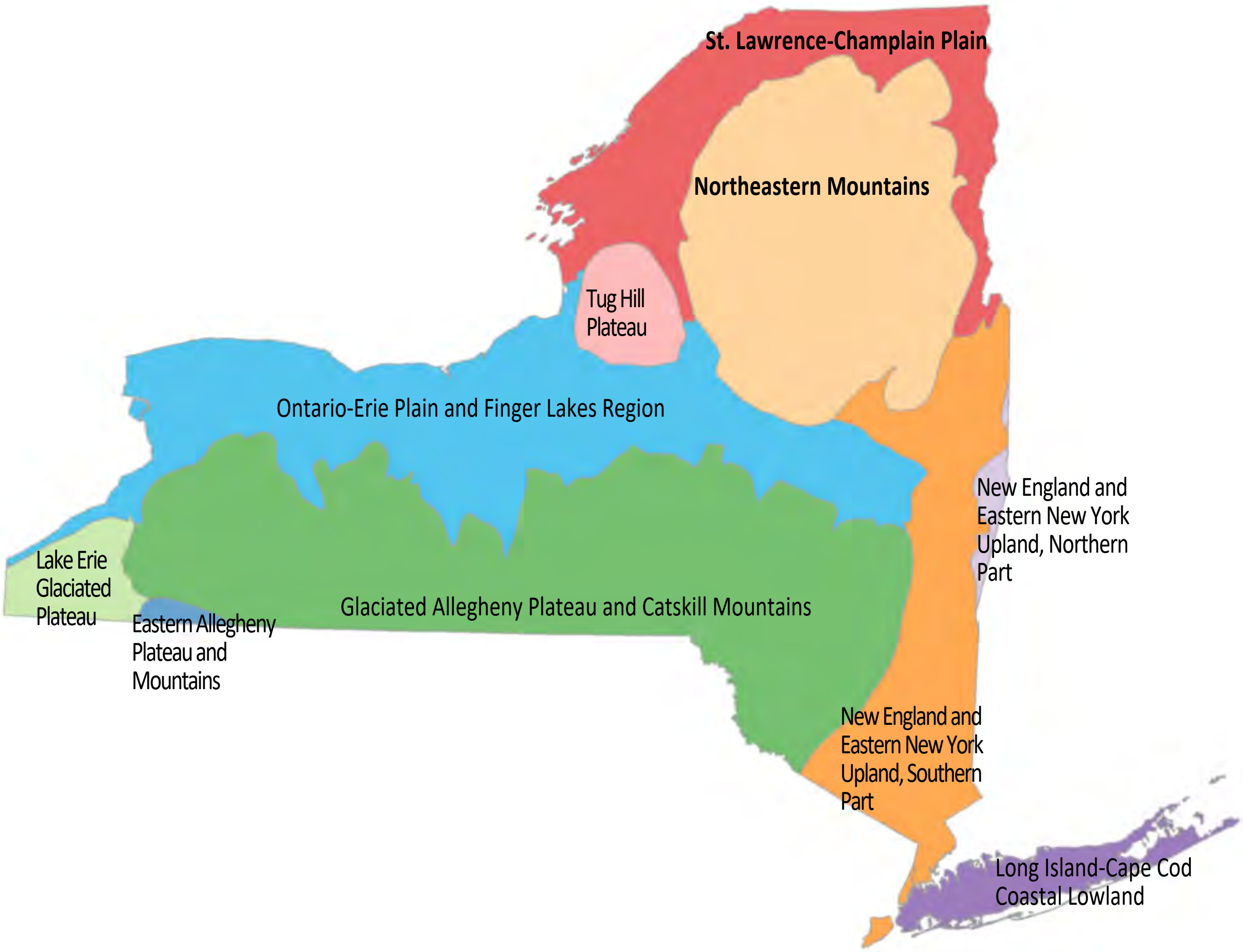
Here are some common soil series in the region:

Appleton series—Soils that formed in brown loamy calcareous dense till on till plains.
Aurora series—Soils that formed in brown, moderately deep, loamy calcareous till over limestone or shale on till plains.
Canandaigua series—Soils that formed in brown calcareous silts and clays on lacustrine plains.
Cazenovia series—Soils that formed in red loamy calcareous till and reworked lacustrine deposits on till plains.
Galen series—Soils that formed in brown loamy and sandy outwash on deltas and lacustrine plains.
Hamlin series—Soils that formed in silty neutral alluvium.
Hilton series—Soils that formed in red loamy calcareous dense till on till plains.
Honeoye series—Soils that formed in brown loamy calcareous dense till on till plains.
Lairdsville series—Soils that formed in red, moderately deep, clayey calcareous till over shale on till plains.
Lamson series—Soils that formed in brown loamy and sandy outwash on deltas and lacustrine plains.
Niagara series—Soils that formed in brown calcareous silts and clays on lacustrine plains.
Palmyra series—Soils that formed in brown loamy calcareous outwash on outwash plains.
Schoharie series—Soils that formed in red calcareous fine-family clays on lacustrine plains.
Teel series—Soils that formed in silty neutral alluvium.
Wampsville series—Soils that formed in red loamy calcareous outwash on outwash plains.

The State Soil of New York is the Honeoye Series

Brief Summary: Soils of New York

Major Land Resources Area (MLRA)



Major land resource areas (MLRAs) are geographically associated land resource Regions (LRRs). Land resource regions (LRRs) are concepts of unique, mostly continuous broad landscapes. They are delineated on small-scale national maps used in national planning. LRRs are the geographical regionalization of the United States and its Territories. They consist mainly of broadly related patterns of geology, soil, climate, physiography, vegetation, water resources, and land use based on publication scale. MLRAs are geographical concepts based on subdivisions within a land resource region. They identify areas with similar physiography, geology, climate, water resources, soils, biological resources, and land use based on publication scale. MLRAs are typically used in regional multistate or individual State planning processes. The dominant physical characteristics of the major land resource areas are described briefly in Agriculture Handbook 296. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin; USDA Agriculture Handbook 296 The first paragraph lists the extent of each MLRA in each state and the total area. Major cities, highways, and culturally significant Federal- and state-owned lands within each MLRA are also listed. The remaining headings for each MLRA include physiography, geology, climate, water, soils, biological resources, and land use.

New York has ten different MLRA's within four different LRR's:

LRR L - Lake States Fruit, Truck Crop, and Dairy Region
MLRA 101 - Ontario-Erie Plain and Finger Lakes Region
The parent material of soils is Calcareous till, lake-laid silts and clays, and sandy or gravelly outwash underlain by alternating beds of limestone, dolomite and calcareous sandstone and shale of Ordovician, Silurian and Devonian age. The major use of the soil is: cropland, orchards, vineyards, forestland, and urban.
LRR N – East and Central Farming and Forest Region
MLRA 127 - Eastern Allegheny Plateau and Mountains
The bedrock is alternating beds of sandstone, limestone, coal and shale. The bedrock is Permian to Mississippian age. Some outwash and glaciofluvial deposits are in the river valleys. The major use of the soil is: agriculture and forestland.
LRR R Northeastern Forage and Forest Region
MLRA 140 - Glaciated Allegheny Plateau and Catskill Mountains
The soil parent material includes significant deposits of glacial outwash, consisting of unconsolidated sand and gravel fill most of the valley floors. Some glacial lake sediments and ice-contact and stratified drift deposits occur in most of the valleys. The bedrock is alternating shale and sandstone of Devonian age. The major use of the soil is: forestland, agriculture, recreation, and urban.
MLRA 139 - Lake Erie Glaciated Plateau
The bedrock in this area consists mostly of alternating beds of sandstone, siltstone, and shale of Upper Devonian, Mississippian, and Pennsylvanian age. The surface is mantled with glacial till, outwash of unconsolidated sand and gravel, glacial lake sediments, and stratified drift deposits (kames and eskers). The outwash, lake sediments, and stratified drift deposits that fill valleys are important sources of ground water. Younger stream deposits cover the glacial deposits in some of the river valleys. The major uses of the soil are: agriculture and forestland.
MLRA 144B - New England and Eastern New York Upland, Northern Part
Till mantled, rolling to hilly uplands underlain with bedrock of limestone, dolomite and marble, interspersed with basalt. Major uses of soil: forestland, agriculture, urban, and recreation.
MLRA 144A - New England and Eastern New York Upland, Southern Part
Consist of almost entirely of till hills, drumlins and bedrock-controlled uplands with a think mantle of till. It is dissected by narrow glacio-fluvial valleys. The bedrock includes Devoian to Pennsylvanian-age sandstone, shale and limestone. Major uses of soil: forestland, agriculture, and urban.
MLRA 143 - Northeastern Mountains
Area is glaciated with rugged mountain peaks. A thick mantel of glacial till covers most of the bedrock. Sandy glacial outwash has been deposited in many streams, valleys and stratified drift has been deposited on the walls of the valleys. The bedrock consists mainly of igneous, (granite

3.4 NEW YORK STATE SOILS

3.4.1 Discussion

The State of New York, with the exception of a small area roughly bounded by the loop of the Allegheny River north of the Pennsylvania State line, has been subject to multiple glaciations. These glaciations, particularly the last one, seemed to have been the extension of an ice cap that had its center west of Hudson Bay. As the ice flowed out from this center, it passed over vast areas of preexisting soil and bedrock, which it was able to pick up and carry on top of, within, ahead of, and beneath the advancing ice mass. When climatic conditions changed, the ice mass wasted away by melting, depositing this huge quantity of material, mantling the area formerly occupied by the ice. The generic term for this soil forming mantle is "till".

Till was deposited in many ways, but basically the two commonest forms are "moraines" and "till plains". A moraine was formed when the ice front was stationary for long periods, that is, the rate of melting was about the same as the rate of advance. With this thought in mind, one can picture the tremendous deposits that were left, and the rough, rugged topography that was bound to result. One can also see that a moraine would occur at the farthest advance of the glacier and also that moraines might occur at any time, when climatic conditions were right, during the retreat of the glacier. This was actually the case. For convenience, the moraine at the farthest advance is called the “end moraine”, the others “recessional end” or “terminal moraines”.

Till plains were formed when the glacier melted and retreated at a steady rate, depositing its load of debris in a fairly uniform manner. The thickness of the deposit varies greatly, from less than a foot to 50 ft. or more.

Sometimes as the ice advanced, its bottom load was too great to carry. When this occurred, “basal till” (called hardpan by old timers) was laid down. As the glacier retreated, it left ordinary till on top of the basal till. The ordinary till is much less dense than the basal till, the latter having been compressed by the over-riding ice.

Texturally, tills are completely heterogeneous, and may contain (but are not necessarily containing) all soil fractions from the finest clay to huge boulders, The stone fragments of till are usually angular to sub-rounded; very seldom are they as well rounded as a water-deposited gravel would be. There is no continuity or stratification in tills as a generalization, but pockets and lenses of pure sand, silt, clay gravel or boulders do occur. Quite frequently, the pockets of granular material are water bearing.

Another ice deposit, of great importance through the central part of the State, is the "drumlin". Drumlins are elongated, streamlined, cigar-shaped hills from a few to 100 ft., or more, high and from a few hundred feet to a mile, or more, in length. The mechanics of their deposition is obscure, but apparently they were a "bottom-of-the-ice" phenomenon, deposited while the ice was advancing. In any case, textually they are till, but much more compact than the tills of the moraines or till plains, indicating that some great weight has compressed them. Some of the drumlins have a rock core, but they are in the minority. Investigation by drilling is necessary to ascertain the presence of the rock core. Rock core drumlins are no different in appearance from the ordinary kind.

While the glacier was melting, great quantities of water were released. When the glacier had been building a moraine, this water was impounded behind the moraine, much as a lake is impounded behind a dam. The moraine, being a poorly constructed dam, could not retain the water when it reached a good depth, so that the dam would break, releasing great quantities of water in a trench. This water, as it passed through the moraine at high speed, would pick up the moraine material and transport it down stream. As the ground over which this great outwash of water was flowing leveled off, the velocity decreased and the water dropped part of its load. The coarser material - cobbles and boulders - settled out first, then gravel and sand, and finally, as the water became still or stagnant, the silt and clay. Such a deposit it called “outwash”; its topography is a smooth to pitted plain. Sometimes, when the outwash occurred in a valley, the outwash deposit is in the form of terraces along the valley walls. Texturally, outwash is sand and gravel, frequently stratified because of its water deposition. Gradation and quality, of course, varies with the deposit.

The deposition of great masses of glacial debris blocked drainage channels, in some cases completely reversing stream flow. Under these conditions, it was inevitable that lakes, some ephemeral and some of comparatively long duration, would be formed. If the melt water discharged directly into the lake, the coarser material formed "deltas". Wave action in the lakes formed "bars", "spits" and "beaches", exactly as these are formed in lakes today. Finally, the fine grained particles were carried out into the lakes where the water was still, allowing the fine material to settle out forming "bottom sediments", usually called "lacustrine bottom sediments" to distinguish them from the "marine bottom sediments". Since the speed of settlement of a particle in water is a function of its size, the coarser particles of silt and very fine sand settled most rapidly, this deposition apparently taking place during warm weather. During the cold seasons, material was not supplied to the lake as rapidly because the surface was frozen, inhibiting wave action; and the finer clay size particles settled out. As a result, "bottom sediments" are laminated or "varved", a "varve" being a double layer, the bottom being of silt, the top layer of clay-sized particles, each varve representing a year's accumulation. Generally speaking, the bottom sediments are rather soft and weak soils, no load except their own weight ever having been applied to them.

Marine bottom sediments are the salt water counterpart of the lacustrine bottom sediments. In general, they do not have the varved structure of the lacustrine sediments. Marine sediments usually have a honeycomb structure that makes them softer and weaker than the lacustrine soils, especially when disturbed. This makes them "sensitive".

There are two other landforms, products of the wasting ice that are of importance. These are the "kame" and the "esker". The kame is an ice front phenomenon, formed by a stream running off the ice front and carrying with it glacial debris of all kinds and piling it up, much like an alluvial fan, against the ice. As the ice melted, the “fan” collapsed, leaving a roughly cone shaped mound of poorly sorted, partially stratified, sand, gravel and cobbles. Other kames were formed by the melt water running into a hole in the ice and carrying the gravel and other material with it. Such holes are called "moulins" and the kames "moulin kames". From an engineering viewpoint, there is no difference in the two types.

The esker on the other hand, is the trace of a stream running within or below the ice or in ice walled canyons cut in stagnant ice, also carrying debris which it deposited along its course as its velocity changed. The result, after the glacier left, was a serpentine ridge, roughly triangular in cross section, of sand, gravel and cobbles, with little or no evidence of sorting or stratification. Eskers in this State are comparatively small, but in some parts of the world they are up to 150 or more miles in length, counting the gaps which break their continuity.

The glacial melt-water deposits all have their characteristic landform. Outwash is a smooth to pitted plain, sloping gradually down valley, or valley wall terraces. Deltas also have a smooth to pitted top but the sides are steep. Bars and spits are gravelly ridge-like forms, while beaches are more gently sloping. Bottom sediments take the form of level to gently undulating plains, often eroded by post glacial streams. Marine bottom sediments are generally smooth and nearly level plains. The kame is a rounded hillock, while the esker is a serpentine ridge.

A few soils of the State are the result of post glacial processes or at least were little affected by glacial action. The residual soils of the unglaciated area were formed by the weathering in place of the underlying bedrock. These soils in New York State are usually shallow to bedrock, the transition from soil to rock being very gradual rather than a sharp contact line. The soil is a reflection of the type of bedrock, for instance, sandstones would leave a sandy soil and shales leave silts and clays. The topography of the residual areas is that of the bedrock.

In the hilly areas of the State, particularly in the Southwestern Plateau, there are areas of colluvial soils. These are soils derived from erosion products of adjacent hillsides and have very much the character of the soils above them in elevation. In general, they are quite stony. Their topography is usually a slope slightly concave upward, gentler than the hill above, but steeper than the valley floor.

The alluvial soils are the soils of the areas contiguous to present-day streams, laid down by the streams during flood stage. They are heterogeneous in texture both vertically and horizontally. Sometimes, they are excellent gravel sources, while at other times they are soft, plastic silts and clays with varying amounts of organic material.

Cumulose soils are the mucks, peats and marls. Muck is the remnants of plants, so decomposed as to retain little if any fibrous structure, the organic matter being more or less mixed with inorganic silt and clay. Peat is formed by dead plants falling into water where there is not enough air to support bacterial action. The result is only partial decay, and consequently, peat is very fibrous and retains most of the plant forms. In general, muck is black, very dark grey or dark brown, while peat is dark to light brown.

Marl, or "bog lime", is calcium carbonate precipitated from the hard water of ephemeral lakes and more or less mixed with silt, clay and shells. It is white to dark grey in color and usually occurs beneath peat deposits.

Of minor extent in this State, but of considerable local importance, are the "eolian" or windblown deposits, usually in the form of rounded to irregular hillocks called "dunes". Most of the dune areas of this State are characterized as "ancient dunes", the area between Albany and the Adirondacks being typical. It is thought that these dunes were formed at the close of the ice age in this area when much of the surface was covered with deposits washed from the wasting ice and vegetation had not as yet started to grow. Adiabatic winds coming off the glaciers were periodically high-velocity, scouring the outwash immediately in front of the glacier and piling it as dunes on the adjacent plain. The material of these dunes is fine sand with some silt-size grains. The gradation is very uniform, and the particles are much rounded.

The foregoing brief outline of the processes of soil deposition forms the framework of a broad grouping of New York State soils. It can be inferred, and field experience has proven that, on a broadly generalized basis, each of the landforms mentioned, no matter where found, has engineering characteristics in common. That is, thick tills in the eastern part of the State will be very similar to those in the west, and the bottom sediments of the Hudson Valley, in a general way, resemble those of the Erie-Ontario Plain.

USDA United States Department of Agriculture

NRCS AND URBAN AGRICULTURE

Who We Are
USDA's Natural Resources Conservation Service helps farmers care for the natural resources on their land – soil, water, air, plant and animals.

How We Help Urban Farmers
NRCS provides technical and financial assistance to growers in:

- **Soil Health** - As experts in soil health, NRCS conservationists can advise urban growers on things like what cover crops to grow, using farmers' soil tests and our soil surveys.
- **Irrigation and Water Conservation** - We can help urban growers conserve water, by assisting with things like drip irrigation.
- **Weeds and Pests** - We can help with pest and weed management by planting buffers for beneficial insects, through mulching, using cover crops and various other means.
- **High Tunnels** – NRCS can provide financial assistance for high tunnels, used to extend the growing season and to protect plants from harsh weather, air pollution and pests. By making local produce available for more months in the year, fewer resources are used to transport food to plates.

NRCS AND URBAN AGRICULTURE

Why Urban Farming?

Urban agriculture pioneers are taking action in their communities, growing not only fresh, healthy produce, but increasing opportunity and knowledge and improving the beauty of their neighborhoods. Through community gardens, produce is being grown and donated to those who need it and children and adults are learning about agriculture first-hand. Farmer's markets are offering easy-access to fresh foods in areas where grocery stores are miles away and are providing new income streams for residents.

NRCS serves all agriculture – large to small, conventional to organic, rural to urban. As American agriculture continues to grow in new directions, NRCS conservation assistance is growing along with it. By bringing cultivation and opportunity to both rural and urban areas, we address many needs -- Restoring the health of the soil. Restoring the health of people.

Get Started

Starting an urban farm comes with a unique set of challenges and opportunities. NRCS can help with the challenges of conservation, and support urban farmers in their efforts to achieve local, healthy, sustainable food for their communities. Start by contacting your local NRCS Service Center, at **https://offices.sc.egov.usda.gov/locator**.

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