FLORIDA ENVIROTHON

Canon ENVIROTHON

Soils Section

2003 Florida Envirothon Study Sections

SOIL KEY POINTS

- Recognize soil as an important dynamic resource.
- Describe basic soil properties and soil formation factors.
- Understand soil drainage classes and know how wetlands are defined.
- Determine basic soil properties and limitations, such as mottling and permeability by observing a soil pit or soil profile.
- Identify types of soil erosion and discuss methods for reducing erosion.
- Use soil information, including a soil survey, in land use planning discussions.
- Discuss how soil is a factor in, or is impacted by, nonpoint and point source pollution.

Florida's State Soil

Florida has the largest total acreage of sandy, siliceous, hyperthermic Aeric Haplaquods in the nation. This is commonly called Myakka fine sand. It does not occur anywhere else in the United States. There are more than 1.5 million acres of Myakka fine sand in Florida. On May 22, 1989, Governor Bob Martinez signed Senate Bill 525 into law making Myakka fine sand Florida's official state soil.

CONTENTS

INTRODUCTION

Welcome to the Florida State Envirothon's Soils Study Guide. As you prepare for the state Envirothon competition, you will want to become familiar with the information in this section. It is only a brief introduction to soil science. Numerous other resources are available to assist you. You may want to contact your Natural Resources Conservation Service or Soil and Water Conservation district office for additional information and assistance. Contact information for these offices is listed in the appendix. The Internet is also an excellent resource.

A broad ecological knowledge and its application to problem solving and critical thinking will be helpful. You should be able to do the following:

- Recognize soil as an important dynamic resource

- Describe basic soil properties and soil formation factors

- Understand soil drainage classes and know how wetlands are defined

- Determine basic soil properties and limitations, such as mottling and permeability by observing a soil pit or soil profile

- Identify types of soil erosion and discuss methods for reducing erosion

- Use soil information, including a soil survey, in land use planning discussions

- Discuss how soil is a factor in, or is impacted by, nonpoint and point source pollution

You will need to know the following:

- How to identify a soil
- How to use a soil survey
- How to use a Munsell soil color chart
- How to interrelate soils with watersheds, wildlife, and aquatic and terrestrial ecosystems
- That humans depend upon and impact soils

WHAT IS SOIL AND HOW IS IT FORMED?

What Is Soil?

Soil is a complex, self-renewing, living system. It is a vital natural resource. It is the resource that most terrestrial life depends on directly or indirectly for survival. It is a composite of inorganic minerals, organic humus, living organisms, moisture, and air. Soils are the product of interactions between abiotic and biotic processes and take thousands of years to form.

The study of soils is called pedology. It is derived from the Greek words *pedon* and *logos*, meaning soil and reason, respectively. In the United States, however, there is a tendency to simply use the term soil science.

How Is Soil Formed?

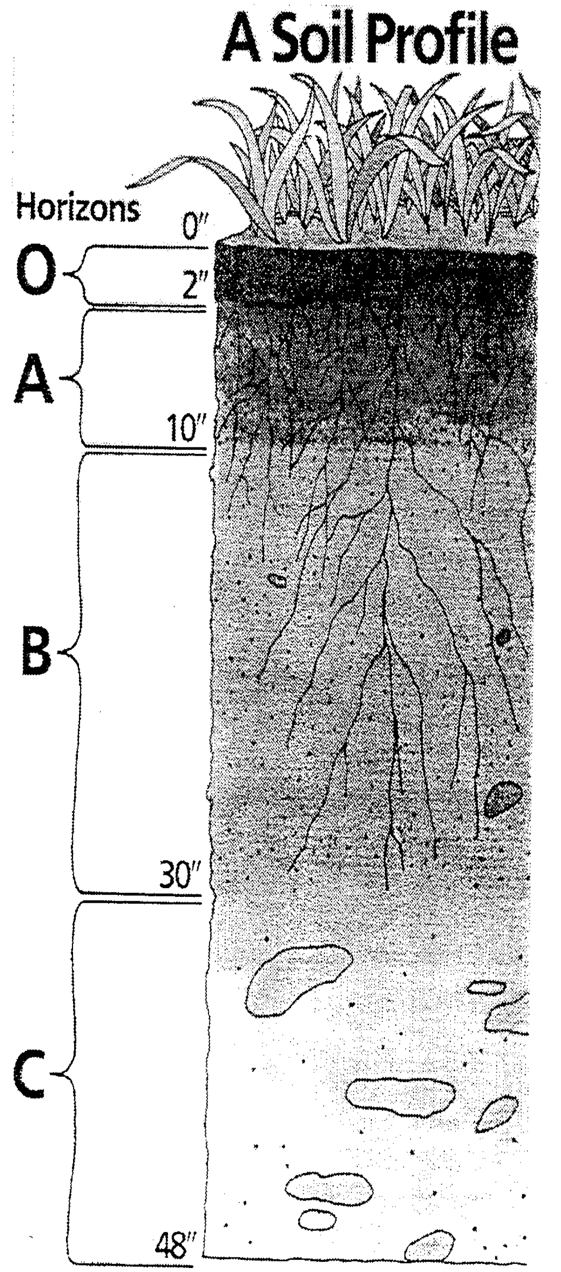
In the early years of soil study, it was thought that soil types were entirely determined by the parent material. In the late 1800s, following pioneering work of Russian soil scientist V.V. Dokuchaev, it was discovered that different soils develop over identical bedrock exposed to various climates. The idea that climate plays a major role in soil formation was introduced in this country in 1920 by C.F. Marbut, the chief of the United States Soil Survey at the time. Since then, other factors that influence soil development have been discovered. Those factors are classified into five major categories:

1. The type of parent(source) material
2. The climate under which the soil components have existed since accumulation
3. The plant and animal life in and on the soil
4. The relief of the land
5. The length of time the other factors have interacted

The five soil-forming factors are interdependent. Soil formation begins with the degradation of the parent material. The parent material is unconsolidated, chemically weathered mineral, rock, or organic matter. Precipitation, temperature, humidity, and wind are the climatic forces that act on the parent material to form soil. The relief of the land greatly influences how wind and water act upon parent material components as well as the types of plants and animals that inhabit the area. Animals, insects, bacteria, fungi, and other plants furnish organic matter. Differences in the amount of organic matter, nutrients, structure, and porosity of soil are caused by plant and animal actions.

Time is an important factor in soil formation. The physical and chemical changes brought about by climate, living organisms, and relief are slow. The length of time needed to convert raw geological materials into soils varies according to the nature of the material and the interaction of other factors. Some minerals weather fairly rapidly, while others are chemically inert and show little change over long periods of time.

Soils are deposited or developed in layers. Soils with clearly defined layers are said to be mature. Immature soil is one that lacks well-developed layers. A vertical column of soil, such as might be seen where roads have been cut through a hill or where a river has scoured through a valley, is called a profile. The soil layers in the profile are called horizons. They are defined as follows:



<u>O Horizon</u>. The O horizon is dominated by organic material. It contains fresh and decaying plant matter from leaves, needles, twigs, moss, lichens, and other organic accumulations.

<u>A Horizon</u>. The A horizon is formed at the surface or below the O horizon. It is an accumulation of organic matter and minerals. It is generally darker than the lower horizons because of the decaying organic matter. This horizon is where most plant root activity occurs. It may be referred to as the surface layer in a soil survey.

<u>E Horizon</u>. The main feature of the E horizon is the loss of silicate clay, iron, or aluminum, or some combination of these, leaving a concentration of sand and silt-sized particles.

<u>B Horizon</u>. The B horizon lies directly below an A, E, or O horizon. It is referred to as the subsoil. It is usually

lighter colored, denser, and lower in organic matter than upper horizons. As the recipient of material from upper and lower soil layers, the B horizon is often called the "zone of accumulation." As rain and irrigation waters percolate downward, they wash (leach) soil components through the A horizon and into the B horizon. The process by which these materials are moved downward by water is called leaching. For this reason, the A horizon is called the "zone of leaching." Some minerals are drawn upward from lower soil layers by high evaporation rates and plant absorption.

In many soils, a dense, nearly impermeable subsurface layer called fragipan develops. When this layer is the result of extreme compactness of soil particles, it is called claypan. In Florida, hardpan is the term applied when cementation of soil particles occurs. Layers cemented by calcium carbonate are called caliche and layers cemented by iron oxide are called ironpan. In many cases, the pan is so hard, water does not pass through it easily. This often causes water to flow horizontally through the soil until it reaches a break in the pan.

<u>C Horizon</u>. Still deeper is the C horizon or the substratum. This layer may consist of less clay or other less-weathered sediments than the layers above. Partially disintegrated parent material and mineral particles are in this horizon.

<u>R Horizon</u>. The very lowest horizon, the R horizon, is bedrock. It can be within a few inches of the surface or many feet below.

Each master horizon is subdivided into specific layers that have a unique identity. Those subdivisions are identified by suffix symbols which follow the master horizon letter.

These suffix symbols are as follows:

a	highly decomposed organic materials
b	buried soil horizon
c	concretions — grains, pellets, or nodules of various sizes, shapes, and colors consisting of concentrated compounds or cemented soil grains
d	physical root restriction
e	organic material of intermediate decomposition
f	frozen soil
g	strong gleying — soil that is formed under poor drainage, resulting in the reduction of iron and other elements and in gray colors and mottles
h	alluvial accumulation of organic matter
i	slightly decomposed organic matter
k	accumulation of carbonates

m	cementation
n	accumulation of sodium
o	residual accumulation of sesquioxides
p	tillage or other disturbance
q	accumulation of silica
r	weathered or soft rock
s	alluvial accumulation of sesquioxides and organic matter
t	accumulation of alluvial clay
v	plinthite
w	development of color or structure
x	fragipan character
y	accumulation of gypsum
z	accumulation of salts more soluble than gypsum

Hence, a B horizon with a large accumulation of clay might be designated as a Bt horizon.

The thickness of each layer varies with location (even in the same field). Few soils fit horizon descriptions perfectly. Under disturbed conditions, such as intense agricultural development or where erosion is severe, not all horizons will be present.

SOIL CHARACTERISTICS

Soil characteristics are used to identify soil types. Most soil characteristics can be determined by field determination. Some need to be verified by laboratory testing. The most common soil characteristics that soil scientists examine are texture, color, porosity, compaction, and permeability.

Texture. Soil texture is the term commonly used by the U.S. Department of Agriculture (USDA) to designate the percentages of sand, silt, and clay in a sample of soil. Other agencies may use other soil texture classification systems. Soil texture refers only to mineral particles smaller than 2 millimeters (mm). Each grouping of particle sizes is called a soil separate. Hence, sand, silt, and clay are soil separates. The USDA classification of mineral soil separates is as follows:

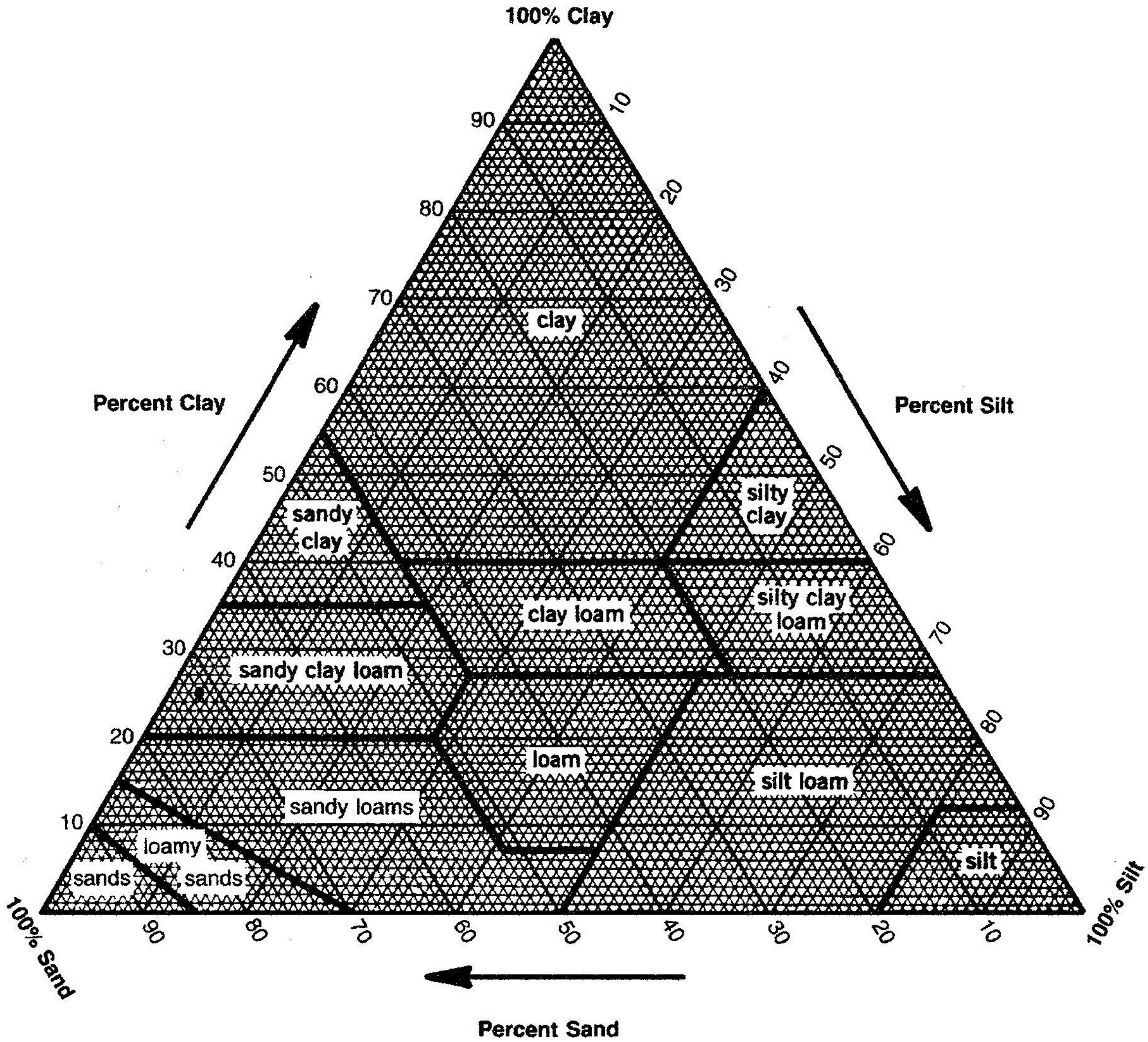
Very coarse sand	2.00–1.00 mm
Coarse sand	1.00–0.50 mm
Medium sand	0.50–0.25 mm
Fine sand	0.25–0.10 mm
Very fine sand	0.10–0.05 mm
Coarse silt	0.05–0.005 mm
Fine silt	0.005–0.002 mm
Clay	less than 0.002 mm

The texture of a soil gives an indication of

- The relative water-holding capacity
- Mineralogy
- Susceptibility to being transported by wind or water
- Chemical properties

The process by which soil separates are obtained is called mechanical analysis. All mineral soils are made up of a mixture of soil separates. Textural class names of soils are based on the proportion of these separates. There are 12 major textural class names: sand, loamy sand, sandy loam, sandy clay loam, sandy clay, clay, clay loam, loam, silt loam, silty clay loam, silty clay, and silt.

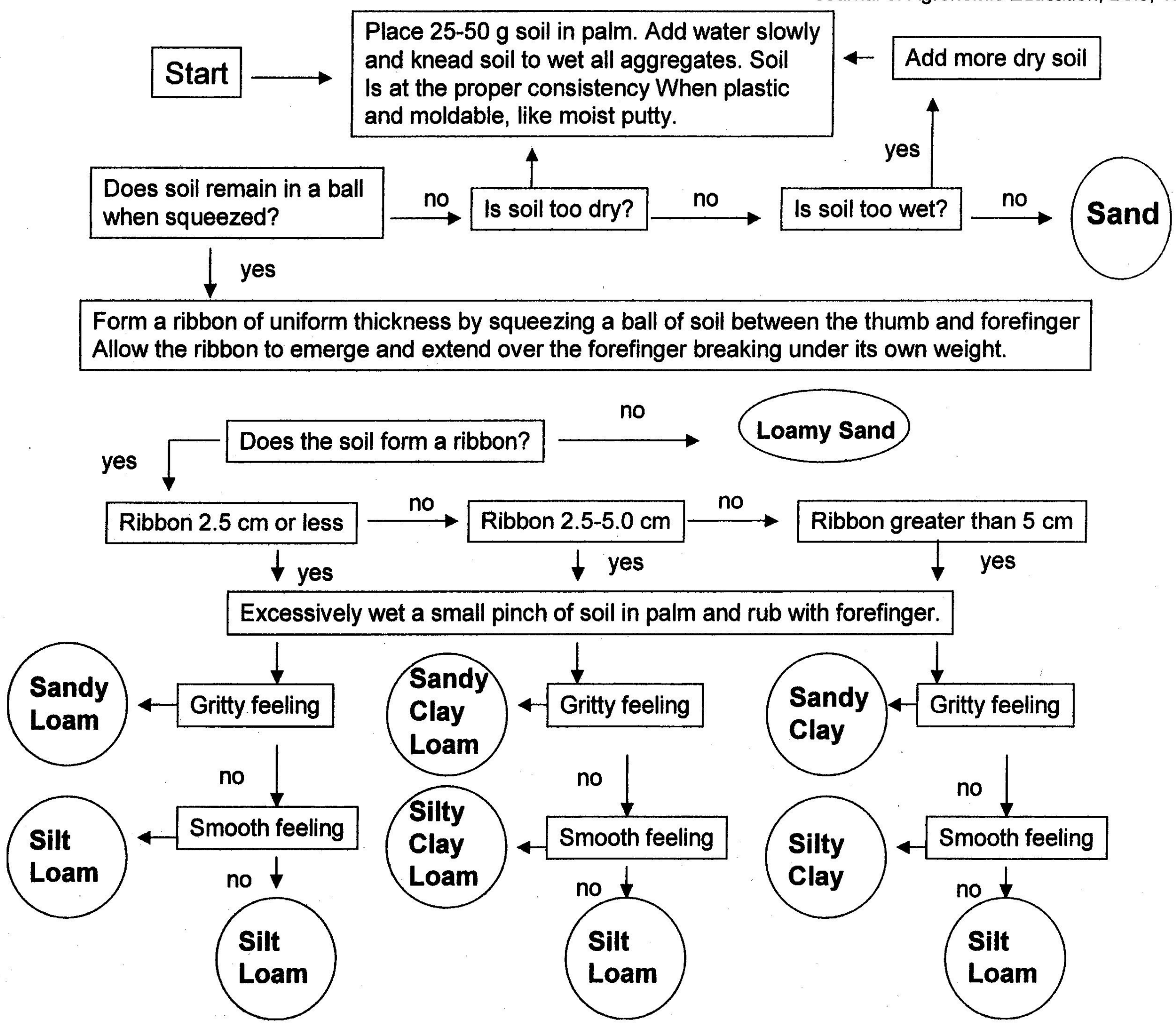
The determination of soil texture in the field is done by feel. That is, the soil is rubbed between the thumb and fingers and an estimate of the amount of the various separates present is made on the basis of the degree to which the characteristic properties are expressed. To determine the soil textural class, follow the procedure on page 11.



The USDA textural triangle showing the twelve major textural classes in the USDA system. Within the sands, loamy sands, and sandy loams, the proportions of the various separates of sands (very coarse sand, coarse sand, medium sand, fine sand, and very fine sand) must be considered in determining which textural name to assign. If the sand fraction of a soil sample is dominated by a particular sand separate, a modifier must be attached to the major textural name (e.g., coarse sand, loamy very fine sand, or fine sandy loam). See Factsheet SL29, Soil Texture in the appendix.

Texture by Feel

Source: " A Flow Diagram for Teaching Texture by Feel Analysis," by Steve J. Thien, Journal of Agronomic Education, Bol8, 1979.



The USDA textural triangle shows the 12 major textural classes in the USDA system. Within the sands, loamy sands, and sandy loams the proportions of the various separates of sands (very coarse sand, coarse sand, medium sand, fine sand, and very fine sand) must be considered in determining which textural name to assign. If the sand fraction of a soil sample is dominated by a particular sand separate, a modifier must be attached to the major textural name (e.g., coarse sand, loamy very fine sand, or fine sandy loam). See Factsheet SL29, Soil Texture in the appendix. Silts are similar to the silt loams, but contain even less sand and clay. The sands are generally so small that they are not detectable to the fingers. The clays are also of such low percentages that no stickiness occurs when the soil is moistened. Silts readily form a ribbon that holds together well when handled.

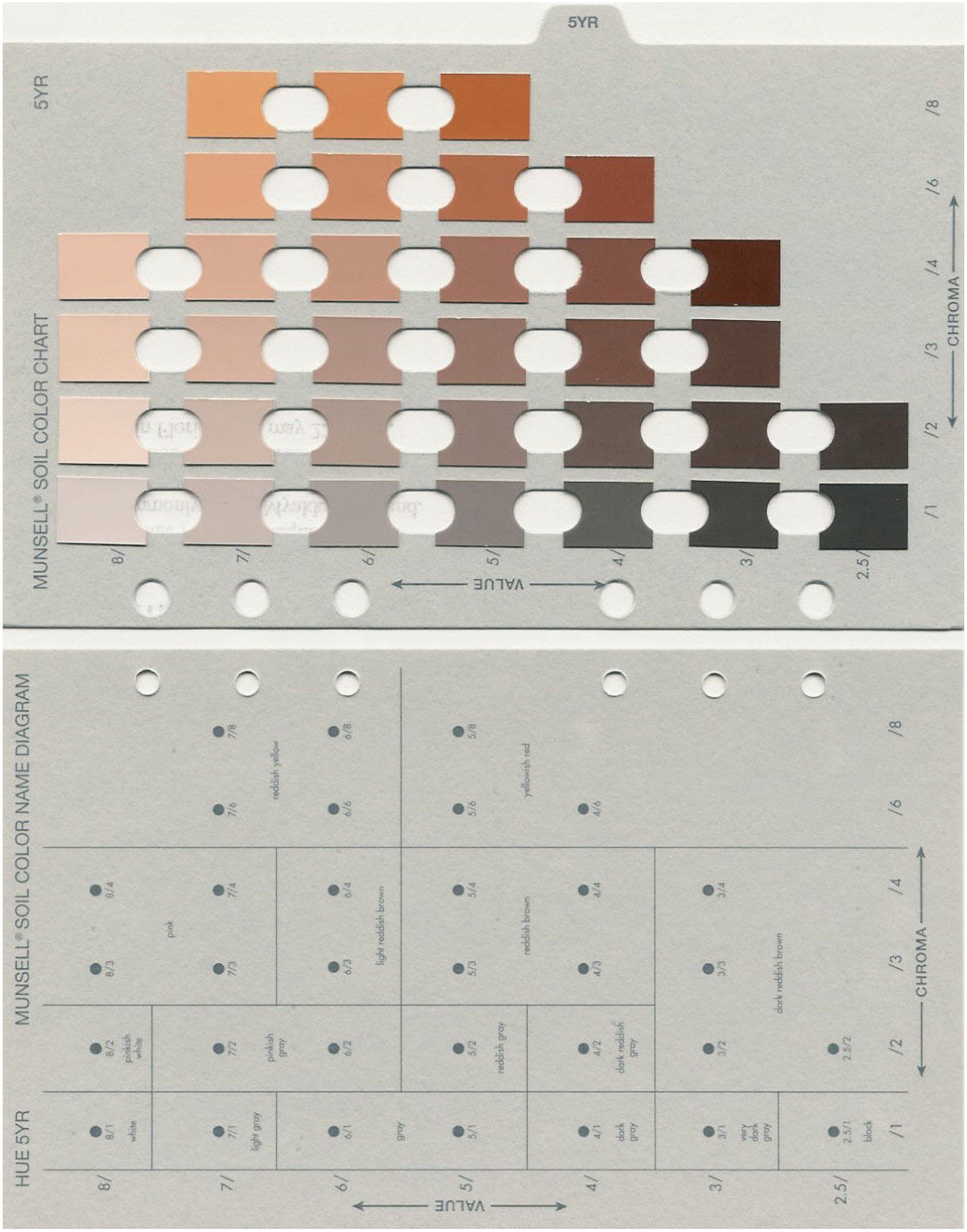
Color. Soil color is probably the most obvious feature of soil. A soil scientist can often associate soil color with specific physical, chemical, and biological properties of soil. Soil colors are produced by organic matter, iron compounds, silica, lime, manganese compounds, aluminum hydroxide, various salts, and coatings of silts and clays and are sometimes an indication of water table or depressional soils.

Soil colors are most conveniently measured by comparison with a chart known as the Munsell Soil Color charts. There are 322 different color chips in the Munsell Soil Color charts. The chips are arranged by three characteristics — hue, value, and chroma.

The hue indicates the color's relation to spectral colors such as red, yellow, green, blue, and purple. The colors displayed on an individual chart are the same hue, which is designated by a symbol in the upper right corner of the card. The symbols for hue are the letter abbreviation of the colors. Hence, R is for red, YR is for yellow-red, Y is for yellow, etc.

The value (sometimes called brilliance) indicates the relative lightness or darkness of the chip. Vertically, the chips become lighter as the column progresses from the bottom to the top, and the value increases with each step. The value for each chip is noted by the vertical scale on the far left of the chart. The notation for value consists of numbers from 0 for absolute black to 10 for absolute white.

The chroma is the chip color's relative purity or the degree of vividness in contrast to grayness. Horizontally, the chips increase in chroma from left to right. The chroma is noted by the horizontal scale across the bottom of the chart. The notation for chroma consists of numbers beginning with 0 for neutral grays and increasing at equal intervals to a maximum of about 20.


5YR
MUNSELL® SOIL COLOR CHART
VALUE
CHROMA
MUNSELL® SOIL COLOR NAME DIAGRAM
HUE 5YR
white
pinkish white
pink
light gray
pinkish gray
reddish yellow
light reddish brown
gray
reddish gray
reddish brown
yellowish red
dark gray
dark reddish gray
very dark gray
dark reddish brown
black

Soil colors are classed as achromatic and chromatic. The achromatic colors are white, all shades of gray, and black. They have a neutral hue and a zero chroma, but differ in value. All other colors are chromatic and represent various combinations of hue, value, and chroma.

When making soil color notations, the color name is written first, followed by the Munsell notation in parentheses. In writing Munsell color notation, the order is hue, value, and chroma, with a space, hue letter, and succeeding value number, and a diagonal line between the two numbers for value and chroma. Thus the notation for a yellowish-red colored soil of hue 5YR, value 5, and chroma 6 is yellowish-red (5YR 5/6).

Accurate comparison of a soil sample to the Munsell Soil Color charts is accomplished by holding the specimen behind the openings next to the closest matching color chip. Rarely will the soil sample be perfectly matched by any color in the charts.

Munsell Soil Color charts are expensive to purchase, but a simplified version can be made by following the directions on the next page.

To practice with a real Munsell Soil Color chart, contact your local Soil and Water Conservation district office and ask a representative to bring one for demonstration.

<u>Porosity</u>. Porosity refers to the amount and size of spaces between soil or rock particles. Porosity determines the amount of water that a soil can hold. Sands and gravels have high porosity. Clays are very porous. Some can hold up to 60 percent of their total volume. High porosity does not always indicate good permeability. Porosity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems.

<u>Permeability</u>. Permeability refers to the rate of water and air movement through soil or bedrock, if present. It is an indication of downward movement of water when the soil is saturated. This may be considered internal drainage. Permeability can be estimated from texture, compaction, and arrangement of soil particles (structure). The drawing illustrates the common ways particles may affect the soil's internal drainage by either providing a pathway for water to drain or by retarding water movement.

Permeability is measured in the number of inches per hour (in/hr) that water moves downward through a saturated soil. Terms describing permeability and respective flow rates are as follows:

Very slow	less than 0.06 in/hr
Slow	0.06–0.20 in/hr
Moderately slow	0.20–0.6 in/hr
Moderate	0.6–2.0 in/hr
Moderately rapid	2.0–6.0 in/hr
Rapid	6.0–20 in/hr
Very rapid	more than 20 in/hr

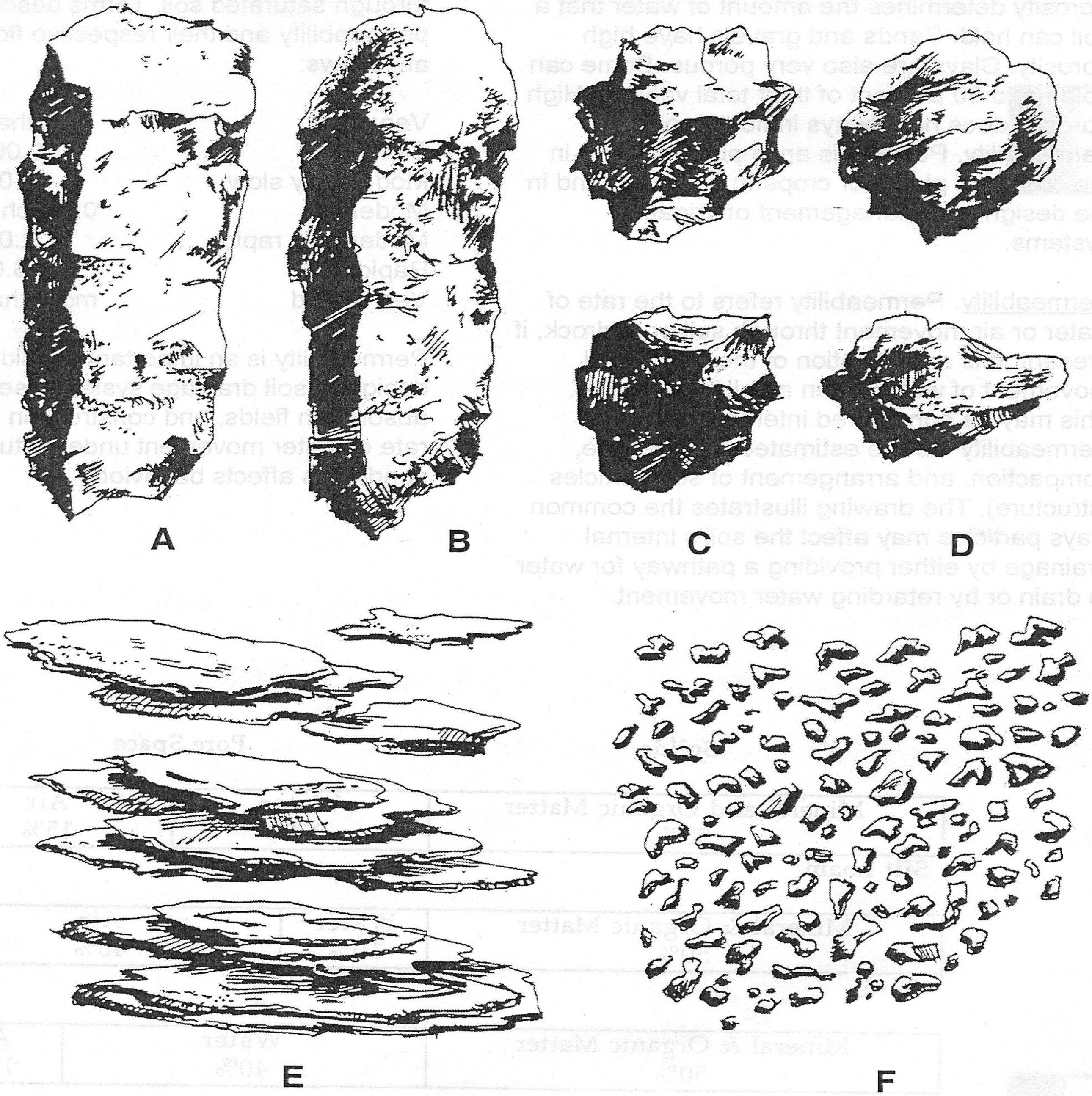
Permeability is an important consideration in the design of soil drainage systems, septic tank absorption fields, and construction where the rate of movement under saturated conditions affects soil behavior.

Solids	**Pore Space**	
Silt Loam		
Mineral and organic matter 50%	Water 25%	Air 15
Sand		
Mineral and organic matter 50%	Water 10%	Air 40%
Clay		
Mineral and organic matter 50%	Water 40%	Air 10%

The above diagram shows the difference in relative proportions of solid particles, water, and air in representative silt loam, sand, and clay soils.

A healthy topsoil has about 50 percent pore space where gases and water are transmitted and held. A balance between pores filed with water and pores filled with gas is necessary for the soil to provide good plant growth. Soil pores are destroyed by tillage, intense agricultural operations, or heavy vehicle and foot traffic. This destruction is known as soil compaction. The largest pores (macropores) are the most vulnerable to compaction. The macropores are essential to the movement of gases and water. Loss of macropores inhibits the movement of gases, including oxygen, into and out of the soil. Plant roots and many types of microorganisms cannot grow where oxygen is limited. Plant roots and microbes produce carbon dioxide, which also moves through the soil pores to the atmosphere.

The small pores (micropores) are important in holding and retaining water in the soil. The loss of these pores lowers the permeability of the soil, thereby restricting percolation and increasing runoff, erosion, and flooding.
Porosity and permeability influence the classification of soils by drainage patterns. Drainage classes refer to the periods of saturation or partial saturation during soil formation, as opposed to altered drainage. The latter is usually the result of human interaction. Seven classes of natural soil drainage are recognized.



Drawings illustrating some of the types of soil structure: A - prismatic; B - columnar; C - angular blocky; D - subangular blocky; E - platy; and F - granular

Excessively drained. Water is removed from the soil very rapidly. Excessively drained soils are commonly very coarse-textured, rocky, or shallow. Some are steep. All are free of mottling related to wetness.

Somewhat excessively drained. Water is removed from the soil rapidly. Many somewhat excessively drained soils are sandy and rapidly pervious. Some are shallow. Some are so steep that much of the water they receive is lost to runoff. All are free of the mottling related to wetness.

Well-drained. Water is removed from the soil readily, but not rapidly. It is available to plants throughout most of the growing season, and wetness does not inhibit growth of roots for significant periods during the growing seasons. Well-drained soils are commonly medium textured. They are mainly free of mottling.

Moderately well drained. Water is removed from the soil somewhat slowly during some periods. Moderately well drained soils are wet for only a short time during the growing season, but periodically they are wet long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within or directly below the solum or periodically receive high rainfall, or both.

Somewhat poorly drained. Water is removed slowly enough that the soil is wet for significant periods during the growing season. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. Somewhat poorly drained soils commonly have a slowly pervious layer, a higher water table, additional water from seepage, nearly continuous rainfall, or a combination of these.

Poorly drained. Water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil is not continuously saturated directly below the plow depth. Poor drainage results from a high water table, a slowly pervious layer within the profile, seepage, nearly continuous rainfall, or a combination of these.

Very poorly drained. Water is removed so slowly that free water remains at or on the surface during the growing season. Unless the soil is artificially drained, most crops cannot be grown. Very poorly drained soils are commonly level or depressed, are frequently ponded, or have impermeable layers close to the surface. Yet where rainfall is high and nearly continuous, they can have moderate or high slope gradients. Wetlands is a general term used for areas where the soil is covered or saturated with fresh or salty water for at least one month per year and where special vegetation has grown because of the wet conditions. Wetlands are usually at a low elevation compared to the surrounding land, but may be at a higher level with impermeable soil. They are located between terrestrial (dry upland) and aquatic habitats. Wetlands are one of the most important natural resources in Florida and provide many benefits to humans and wildlife. Some benefits are

- They can store rain and slow runoff, which helps to control flooding and erosion.
- They are valuable for recreation and beauty.
- They filter and absorb pollutants and purify water.
- They provide habitat for a wide variety of plants and animals, including 90 percent of the plants, 30 percent of the birds, 15 percent of the mammals, and 50 percent of the fish on the United States endangered species list.
- They help stabilize shorelines and reduce coastal storm damage.
- They provide important spawning and nursery grounds for approximately two-thirds of the nation's shellfish and important commercial and sport species of marine fish.
- They provide important rest areas for the millions of migrating birds every year.

The value of wetlands has not always been clear. For many years, wetlands were considered nothing more than a nuisance. It was a common practice to drain wetlands to provide land for agriculture and urban expansion. It is estimated that Florida has lost 60 percent of the original 20 million acres in the state. Even with this tremendous loss, Florida contains more than 20 percent of the remaining wetlands in the United States.

SOIL CLASSIFICATION

Various soil classification systems have been used for centuries. Most of the systems were based on specific purposes for local areas. Unfortunately, they relied upon opinions which were difficult to reproduce and therefore had limited use and meaning. In 1951, the soil taxonomy classification system was developed and is still is used today. The taxonomic system recognizes six categories: order, suborder, great group, subgroup, family, and series.

Soil orders reflect the dominant soil-forming processes and the degree of soil formation. Each order is identified by a word ending in the suffix *sol*. There are 12 soil orders, only seven of which are found in Florida (indicated by an asterisk [*]). The soil orders and their dominant features are as follows:

<u>Alfisols</u>.* Well-developed soils with a relatively fine-textured subsoil horizon that has a base saturation of 35percent or more.

<u>Andisols</u>. Soils of volcanic origin.

<u>Aridisols</u>. Dry soils that occur in arid or semi-arid regions.

<u>Entisols</u>.* Soils with little or no horizon development.

<u>Gelosols</u>. Soils of cold climates influenced by permafrost.

<u>Histosols</u>.* Soils composed of relatively thick (usually 16 inches or more) organic materials (muck and peats).

<u>Inceptisols</u>.* Soils of humid regions with profile development sufficient to exclude them from the Entisols, but insufficient to include them in Spodosols, Ultisols, or other well-developed soils. Soils that appear to be like Mollisols but have less than 50 percent or more base saturation may also be Inceptisols.

<u>Mollisols</u>.* Soils with thick (usually 10 inches or more), dark surfaces that have a base saturation of 50 percent or more in the surface soil.

<u>Oxisols</u>.* Highly weathered soils of the tropics.

<u>Spodosols</u>.* Soils with a spodic horizon (a dark-colored subhorizon with a mixture of organic matter and aluminum, with or without iron).

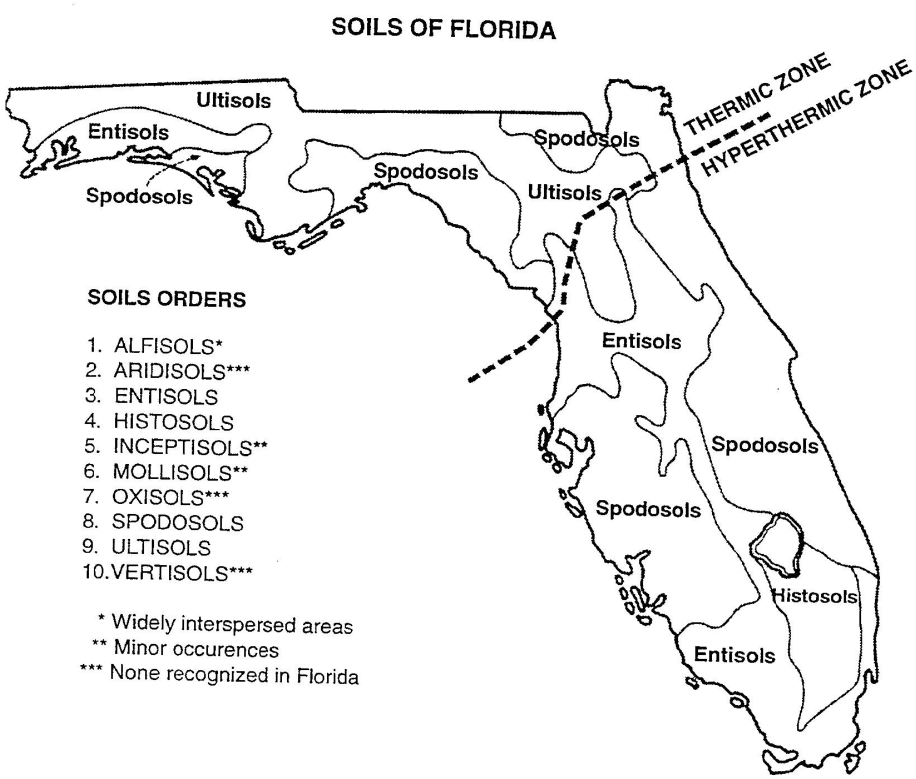
Ultisols.* Well-developed soils with a relatively fine-textured subsoil horizon that has less than 35 percent base saturation.

Vertisols. Soils with more than 30 percent clay which appreciably expand upon wetting and contract upon drying.

To determine the order to which a soil belongs, you must know the key to soil taxonomy.

Soils are further differentiated by

- Suborders
- Great groups
- Subgroups
- Families
- Series



SOIL USES

Knowledge of soil characteristics helps to determine the land's capability for farming and ranching, proper agricultural and urban use, and conservation practices necessary. Land uses include crop and pasture lands, rangeland, forestry, recreation, wildlife habitat, and engineering uses, including building sites, sanitary facilities, water management, and construction materials.

<u>Farming</u>. Identification of soil types helps to analyze potential erosion problems, soil drainage, soil fertility, and soil tilth, all of which are important factors in determining which crops are best suited to an area and the productivity potential for those crops.

<u>Ranching</u>. Rangeland is land on which the natural vegetation is predominately native grasses, grasslike plants, and shrubs, suitable for grazing by domestic livestock and wildlife. In addition to livestock forage and wildlife habitat, rangeland provides wood, water, recreation, and scenic beauty. Rangeland includes grassland, open forest, wetlands, and shrubland.

Range management requires a knowledge of the kinds of soil and of the plant communities. The objective of range management is to control grazing so that the plants growing on the site are about the same in kind and amount as the natural plant community for that site. Such management generally results in the optimum production of vegetation, reduction of undesirable brush species, conservation of water, and control of erosion. Sometimes a range condition somewhat below the potential meets grazing needs, provides wildlife habitat, and protects soil and water resources.

<u>Forestry</u>. Knowledge of soils can be used by forest managers to increase the productivity of forest lands. Some soils respond better to fertilization than others, and some are more susceptible to erosion after roads are built and timber is harvested. Some soils require special efforts to reforest. Soils vary in their ability to produce trees.

<u>Recreation</u>. Recreational uses include camping areas; picnic areas, playgrounds, paths and trails for hiking, horseback riding, and bicycling; and golf courses. Provision of camping areas requires the consideration of a number of factors, including preparation of tent or RV sites, parking areas, sanitary facilities, roads, and the installation of utility lines.

The best soils for camping areas have mild slopes, few or no stones or boulders, absorb rainfall readily and remain firm, are not dusty when dry, and are not subject to flooding. Picnic areas are subject to heavy foot traffic. The best soils are not subject to flooding and do not have slopes, stones, or boulders that increase the cost of shaping sites or building access roads and parking lots. Playgrounds require soils that can withstand intensive foot traffic. The best soils are level, are not subject to flooding, are free of stones and boulders, and are firm after rain and not dusty when dry. These same soil considerations are important for paths, trails, and golf courses.

Wildlife Habitat. Numerous elements provide for good wildlife habitat. They include grain and seed crops, grasses, and legumes, wild herbaceous plants, hardwood trees coniferous plants, wetland plants, shallow water areas, and open land. A primary factor in evaluating wildlife habitat is the plant diversity in the area. Increasing dominance by a few plant species is commonly accompanied by a corresponding decrease in wildlife. Soils affect the kind and amount of vegetation that is available to wildlife as food and cover.

Engineering Uses. Engineering uses require a careful examination of soil characteristics and properties. Soil strength, shrink-swell potential, permeability, drainage, and erosion potential are all important factors to consider for building sites, roads, and sanitary facilities. Florida's five water management districts pay careful attention to soils as a part of their management plans and regulatory requirements.

Soil Conservation

Soil is basic to the quality of life in Florida. It has important socioeconomic value in addition to producing timber, food, and fiber. Soils have aesthetic value and support open space, wildlife habitats, and recreational areas. They also serve as engineering media for construction purposes and municipal, industrial, and agricultural wastes. Soils are instrumental in groundwater recharge. As such, it is important to properly manage and conserve Florida's soils.

Of particular concern in soil conservation is erosion control. Erosion is defined as the wearing away of the land surface by water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion my be classed as geologic or accelerated. Geologic erosion is 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 floodplains and coastal systems. Geologic erosion is also known as natural erosion.

Accelerated erosion is much more rapid than geologic erosion. Accelerated erosion is mainly the result of the activities of humans or other animals or of a natural catastrophe such as a hurricane or a wildfire.

There are a number of conservation practices that can help protect our soil resource from erosion. The first principle in wind erosion control is to cover the soil. Vegetative cover slows the wind at ground level, protects soil particles from being detached, and traps other blowing soil particles. One of the most permanent wind erosion control methods is a wind barrier. There are also numerous agricultural practices such as crop residue management — leaving crop remains in the field as mulch — crop rotation, planting cover crops, strip cropping, and planting buffer strips that protect soil from erosion.

Besides conservation of this valuable resource, erosion control also plays an important role in helping to curb nonpoint source pollution. Nonpoint source pollution occurs when rain or irrigation water runs over the land or through the ground, picks up pollutants, and deposits them in lakes, rivers, and coastal waters or introduces them to groundwater. Usually, these pollutants are solely thought of as fertilizers, pesticides, other chemicals, oils, animal wastes, or heavy metals. Soil sediments also contribute to nonpoint source pollution. They clog waterways, reduce aquatic species habitat and spawning areas, and reduce water clarity, inhibiting aquatic plant growth. Erosion control practices have multiple benefits.

There are many conservation practices that help to protect and preserve Florida's soils. These practices include the use of soil-improving crops, control of noxious plants, selective tree harvesting, terracing of ridges and embankments, mulching, and prudent use of pesticides and fertilizers.

Numerous agencies and organizations play a role in the conservation of Florida's soils, including Florida's water management districts, the University of Florida's Institute of Food and Agricultural Science (IFAS), the Florida Farm Bureau, the Florida Department of Agriculture and Consumer Services (FDACS), the Florida Department of Environmental Protection (FDEP), and the Florida Association of Environmental Soil Scientists (FAESS). Some agencies particularly concerned with soil conservation are the Florida Association of Conservation Districts (FACD), the Natural Resources Conservation Service (NRCS), and local Soil and Water Conservation districts. Local offices for each can be found in most Florida counties.

APPENDIX

Soil Biology Primer (The Living Soil)
Soil Vocabulary
Key to Soil Orders in Florida (UF/IFAS factsheet)
Soil Texture (UF/IFAS factsheet)
Soil Quality — Introduction (USDA, NRCS))
Soil Quality — Indicators for Soil Evaluation (USDA, NRCS)
Soil Quality Indicators: Aggregate Stability (USDA, NRCS)
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Soil Quality Indicators: Organic Matter (USDA, NRCS)
Soil Quality Indicators: pH (Reaction) (USDA, NRCS)
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Agricultural Management Effects on Earthworm Population (USDA, NRCS)

SOIL BIOLOGY PRIMER
(THE LIVING SOIL)

BACTERIA

A Few Important Bacteria

Nitrogen-fixing bacteria form symbiotic associations with the roots of legumes like clover and lupine and trees such as alder and locust. Visible nodules are created where bacteria infect a growing root hair. The plant supplies simple carbon compounds to the bacteria, and the bacteria convert nitrogen (N_2) from air into a form the plant host can use. When leaves or roots from the host plant decompose, soil nitrogen increases in the surrounding area.

Nitrifying bacteria change ammonium (NH_4^+) to nitrite (NO_2^-) then to nitrate (NO_3^-) — a preferred form of nitrogen for grasses and most row crops. Nitrate is leached more easily from the soil, so some farmers use nitrification inhibitors to reduce the activity of one type of nitrifying bacteria. Nitrifying bacteria are suppressed in forest soils, so that most of the nitrogen remains as ammonium.

Denitrifying bacteria convert nitrate to nitrogen (N_2) or nitrous oxide (N_2O) gas. Denitrifiers are anaerobic, meaning they are active where oxygen is absent, such as in saturated soils or inside soil aggregates.

Actinomycetes are a large group of bacteria that grow as hyphae-like fungi. They are responsible for the characteristically "earthy" smell of freshly turned, healthy soil. Actinomycetes decompose a wide array of substrates, but are especially important in degrading recalcitrant (hard to decompose) compounds, such as chitin and cellulose, and are active at high pH levels. Fungi are more important in degrading these compounds at low pH. A number of antibiotics are produced by actinomycetes, for example, streptomyces.

Where Are the Bacteria?

Various species of bacteria thrive on different food sources and in different microenvironments. In general, bacteria are more competitive when labile (easy to metabolize) substrates are present. This includes fresh, young plant residue and the compounds found near living roots. Bacteria are especially concentrated in the rhizosphere, the narrow region next to and in the root. There is evidence that plants produce certain types of root exudates to encourage the growth of protective bacteria.

Bacteria alter the soil environment to the extent that the soil environment will favor certain plant communities over others. Before plants can become established on fresh sediments, the bacterial community must establish first, starting with photosynthetic bacteria. These fix atmospheric nitrogen and carbon, produce organic matter, and immobilize enough nitrogen and other nutrients to initiate nitrogen cycling processes in the young soil. Then early successional plant species can grow. As the plant community is established, different types of organic matter enter the soil and change the type of food available to bacteria. In turn, the altered bacterial community changes soil structure and the environment for plants. Some researchers think it may be possible to control the plant species in a place by managing the soil bacteria community.

FUNGI

Fungi are microscopic cells that usually grow as long threads or strands called hyphae, which push their way between soil particles, roots, and rocks. Hyphae are usually only several thousandths of an inch (a few micrometers) in diameter. A single hyphae can span in length from a few cells to many yards. A few fungi, such as yeast, are single cells.

Hyphae sometimes group into masses called mycelium or thick, cord-like "rhizomorphs" that look like roots. Fungal fruiting structures (mushrooms) are made of hyphal strands, spores, and some special structures like gills on which spores form. A single individual fungus can include many fruiting bodies scattered across an area as large as a baseball diamond.

Fungi perform important services related to water dynamics, nutrient cycling, and disease suppression. Along with bacteria, fungi are important as decomposers in the soil food web. They convert hard-to-digest organic material into forms that other organisms can use. Fungal hyphae physically bind soil particles together, creating stable aggregates that help increase water infiltration and soil water-holding capacity.

Soil fungi can be grouped into three general functional groups based on how they get their energy. Decomposers — saprophytic fungi — convert dead organic material into fungal biomass, carbon dioxide (CO_2), and small molecules, such as organic acids. These fungi generally use complex substrates, such as the cellulose and lignin, in wood, and are essential in decomposing the carbon ring structures in some pollutants. A few fungi are called "sugar fungi" because they use the same simple substrates as do many bacteria. Like bacteria, fungi are important for immobilizing, or retaining, nutrients in the soil. In addition, many of the secondary metabolites of fungi are organic acids, so they help increase the accumulation of humic-acid rich organic matter that is resistant to degradation and may stay in the soil for hundreds of years.

Mutualists — the mycorrhizal fungi — colonize plant roots. In exchange for carbon from the plant, mycorrhizal fungi help solubolize phosphorus and bring soil nutrients (phosphorus, nitrogen, micronutrients, and perhaps water) to the plant. One major group of mycorrhizae, the ectomycorrhizae, grow on the surface layers of the roots and are commonly associated with trees. The second major group of mycorrhizae are the endomycorrhizae that grow within the root cells and are commonly associated with grasses, row crops, vegetables, and shrubs. Arbuscular mycorrhizal (AM) fungi are a type of endomycorrhizal fungi. Ericoid mycorrhizal fungi can by either ecto- or endomycorrhizal.

The third group of fungi, pathogens or parasites, cause reduced production or death when they colonize roots and other organisms. Root-pathogenic fungi, such as Verticillium, Pythium, and Rhizoctonia, cause major economic losses in agriculture each year. Many fungi help control diseases. For example, nematode-trapping fungi that parasitize disease-causing nematodes and fungi that feed on insects may be useful as biocontrol agents.

Where Are the Fungi?

Saprophytic fungi are commonly active around woody plant residue. Fungal hyphae have advantages over bacteria in some soil environments. Under dry conditions, fungi can bridge gaps between pockets of moisture and continue to survive and grow, even when soil moisture is too low for most bacteria to be active. Fungi are able to use nitrogen up from the soil, allowing them to decompose surface residue, which is often low in nitrogen.

Fungi are aerobic organisms. Soil which becomes anaerobic for significant periods generally loses its fungal component. Anaerobic conditions often occur in waterlogged soil and in compacted soils.

Fungi are especially extensive in forested lands. Forests have been observed to increase in productivity as fungal biomass increases.

Protozoa

Protozoa are single-celled animals that feed primarily on bacteria but also eat other protozoa, soluble organic matter, and sometimes fungi. They are several times larger than bacteria, ranging from 1/5,000 to 1/50 of an inch (5 to 500 •m) in diameter. As they eat bacteria, protozoa release excess nitrogen that can then be used by plants and other members of the food web.

Protozoa are classified into three groups based on their shape: Ciliates are the largest and move by means of hair-like cilia. They eat the other two types of protozoa, as well as bacteria. Amoebae also can be quite large and move by means of a temporary foot or "pseudopod." Amoebae are further divided into testate amoebae (which make a shell-like covering) and naked amoebae (without a covering). Flagellates are the smallest of the protozoa and use a few whip-like flagella to move.

What Do Protozoa Do?

Protozoa play an important role in mineralizing nutrients, making them available for use by plants and other soil organisms. Protozoa (and nematodes) have a lower concentration of nitrogen in their cells than the bacteria they eat. (The ratio of carbon to nitrogen for protozoa is 10:1 or much more and 3:1 to 10:1 for bacteria.) Bacteria eaten by protozoa contain too much nitrogen for the amount of carbon protozoa need. They release the excess nitrogen in the form of ammonium (NH_4^+). This usually occurs near the root system of a plant. Bacteria and other organisms rapidly take up most of the ammonium, but some is used by the plant.

Another role that protozoa play is in regulating bacteria populations. When they graze on bacteria, protozoa stimulate growth of the bacterial population (and, in turn, decomposition rates and soil aggregation). Exactly why this happens is under some debate, but grazing can be thought of like pruning a tree — a small amount enhances growth, too much reduces growth or will modify the mix of species in the bacterial community.

Protozoa are also an important food source for other soil organisms and help to suppress disease by competing with or feeding on pathogens.

Where are the Protozoa?

Protozoa need bacteria to eat and water in which to move, so moisture plays a big role in determining which types of protozoa will be present and active. Like bacteria, protozoa are particularly active in the rhizosphere next to roots.

Typical numbers of protozoa in soil vary widely — from a thousand per teaspoon in low fertility soils to a million per teaspoon in some highly fertile soils. Fungal-dominated soils (e.g., forests) tend to have more testate amoebae and ciliates than other types. In bacterial-dominated soils, flagellates and naked amoebae predominate. In general, high clay-content soils contain a higher number of smaller protozoa (flagellates and naked amoebae), while coarser textured soils contain more large flagellates, amoebae of both varieties, and ciliates.

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NEMATODES

Nematodes are nonsegmented worms typically 1/500 of an inch (50 •m) in diameter and 1/20 of an inch (1 mm) in length. Those few species responsible for plant diseases have received a lot of attention, but far less is known about the majority of the nematode community that plays beneficial roles in soil.

An incredible variety of nematodes function at several trophic levels of the soil food web. Some feed on the plants and algae (first trophic level), others are grazers that feed on bacteria and fungi (second trophic level), and some feed on other nematodes (higher trophic levels).

Free-living nematodes can be divided into four broad groups based on their diet. Bacterial-feeders consume bacteria. Fungal-feeders feed by puncturing the cell wall of fungi and sucking out the internal contents. Predatory nematodes eat all types of nematodes and protozoa. They eat smaller organisms whole or attach themselves to the cuticle of larger nematodes, scraping away until the prey's internal body parts can be extracted. Omnivores eat a variety of organisms or may have a different diet at each life stage. Root-feeders are plant parasites and thus are not free-living in the soil.

What Do Nematodes Do?

Nutrient cycling. Like protozoa, nematodes are important in mineralizing, or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium (NH_4^+) is released because bacteria and fungi contain much more nitrogen than the nematodes require.

Grazing. At low nematode densities, feeding by nematodes stimulates the growth rate of prey populations. That is, bacterial-feeders stimulate bacterial growth, plant-feeders stimulate plant growth, and so on. At higher densities, nematodes will reduce the population of their prey. This may decrease plant productivity, may negatively impact mycorrhizal fungi, and can reduce decomposition and immobilization rates by bacteria and fungi. Predatory nematodes may regulate populations of bacterial- and fungal-feeding nematodes, thus preventing over-grazing by those groups. Nematode grazing may control the balance between bacteria and fungi and the species composition of the microbial community.

Dispersal of microbes. Nematodes help distribute bacteria and fungi through the soil and along roots by carrying live and dormant microbes on their surfaces and in their digestive systems.

Food source. Nematodes are food for higher level predators, including predatory nematodes, soil microarthropods, and soil insects. They are also parasitized by bacteria and fungi.

Disease suppression and development. Some nematodes cause disease. Others consume disease-causing organisms, such as root-feeding nematodes, or prevent their access to roots. These may be potential biocontrol agents.

Where Are the Nematodes?

Nematodes are concentrated near their prey groups. Bacterial-feeders abound near roots where bacteria congregate; fungal-feeders are near fungal biomass; root-feeders are concentrated around roots of stressed or susceptible plants. Predatory nematodes are more likely to be abundant in soils with high numbers of nematodes.

Because of their size, nematodes tend to be more common in coarser textured soils. Nematodes move in water films in large (>1/500 inch or 50 •m) pore spaces.

Agricultural soils generally support less than 100 nematodes in each teaspoon (dry gram) of soil. Grasslands may contain 50 to 500 nematodes, and forest soils generally hold several hundred per teaspoon. The proportion of bacterial-feeding and fungal-feeding nematodes is related to the amount of bacteria and fungi in the soil. Commonly, less disturbed soils contain more predatory nematodes, suggesting that predatory nematodes are highly sensitive to a wide range of disturbances.

Nematodes and Soil Quality

Nematodes may be useful indicators of soil quality because of their tremendous diversity and their participation in many functions at different levels of the soil food web. Several researchers have proposed approaches to assessing the status of soil quality by counting the number of nematodes in different families or trophic groups. In addition to their diversity, nematodes may be useful indicators because their populations are relatively stable in response to changes in moisture and temperature (in contrast to bacteria), yet nematode populations respond to land management changes in predictable ways. Because they are quite small and live in water films, changes in nematode populations reflect changes in soil microenvironments.

ANTHROPODS

Many bugs, known as arthropods, make their home in the soil. They get their name from their jointed (arthros) legs (podos). Arthropods are invertebrates, that is, they have no backbone and rely instead on an external covering called an exoskeleton.

Arthropods range in size from microscopic to several inches in length. They include insects, such as springtails, beetles, and ants; crustaceans such as sowbugs; arachnids such as spiders and mites; myriapods, such as centipedes and millipedes; and scorpions.

Nearly every soil is home to many different arthropod species. Certain row-crop soils contain several dozen species of arthropods in a square mile. Several thousand different species may live in a square mile of forest soil.

Arthropods can be grouped as shredders, predators, herbivores, and fungal-feeders, based on their functions in soil. Most soil-dwelling arthropods eat fungi, worms, or other arthropods. Root-feeders and dead-plant shredders are less abundant. As they feed, arthropods aerate and mix the soil, regulate the population size of other soil organisms, and shred organic material.

Shredders

Many large arthropods frequently seen on the soil surface are shredders. Shredders chew up dead plant matter as they eat bacteria and fungi on the surface of the plant matter. The most abundant shredders are millipedes and sowbugs, as well as termites, certain mites, and roaches. In agricultural soils, shredders can become pests by feeding on live roots if sufficient dead plant material is not present. Millipedes are also called diplopods because they possess two pairs of legs on each body segment. They are generally harmless to people, but most millipedes protect themselves from predators by spraying an offensive odor from their skunk glands. The desert-dwelling giant millipede is about 8 inches long. Sowbugs are relatives of crabs and lobsters. Their powerful mouthparts are used to fragment plant residue and leaf litter.

Predators

Predators and micropredators can be either generalists, feeding on many different prey types, or specialists, hunting only a single prey type. Predators include centipedes, spiders, ground beetles, scorpions, skunk-spiders, pseudoscorpions, ants, and some mites. Many predators eat crop pests, and some, such as beetles and parasitic wasps, have been developed for use as commercial biocontrols.

Long, slim centipedes crawl through spaces in the soil preying on earthworms and other soft-skinned animals. Centipede species with longer legs are familiar around homes and in leaf litter. Predatory mites prey on nematodes, springtails, other mites, and the larvae of insects. The powerful mouthparts on the tiger beetle (a carabid beetle) make it a swift and deadly ground-surface predator. Many species of carabid beetles are common in cropland. Rugose harvester ants are scavengers rather than predators. They eat dead insects and gather seeds in grasslands and deserts where they burrow 10 feet into the ground. Their sting is 100 times more powerful than a fire ant sting.

Herbivores

Numerous root-feeding insects, such as cicadas, mole crickets, and anthomyiid flies (root-maggots), live part or all of their life in the soil. Some herbivores, including rootworms and symphylans, can be crop pests where they occur in large numbers, feeding on roots or other plant parts. The symphylan, a relative of the centipede, feeds on plant roots and can become a major crop pest if its population is not controlled by other organisms.

Fungal Feeders

Arthropods that graze on fungi (and to some extent bacteria) include most springtails, some mites, and silverfish. They scrape and consume bacteria and fungi off root surfaces. A large fraction of the nutrients available to plants is a result of microbial-grazing and nutrient release by fauna.

A pale-colored and blind springtail is typical of fungal-feeding springtails that live deep in the surface layer of natural and agricultural soils throughout the world. Oribatid turtle-mites are among the most numerous of the microarthropods. This millimeter-long species feeds on fungi.

What Do Arthropods Do?

Although the plant feeders can become pests, most arthropods perform beneficial functions in the soil-plant system.

Shred organic material. Arthropods increase the surface area accessible to microbial attack by shredding dead plant residue and burrowing into coarse woody debris. Without shredders, a bacterium in leaf litter would be like a person in a pantry without a can-opener — eating would be a very slow process. The shredders act like can-openers and greatly increase the rate of decomposition. Arthropods ingest decaying plant material to eat the bacteria and fungi on the surface of the organic material.

Stimulate microbial activity. As arthropods graze on bacteria and fungi, they stimulate the growth of mycorrhizae and other fungi and the decomposition of organic matter. If grazer populations get too dense, the opposite effect can occur — populations of bacteria and fungi will decline. Predatory arthropods are important to keep grazer populations under control and to prevent them from over-grazing microbes.

Mix microbes with their food. From a bacterium's point of view, just a fraction of a millimeter is infinitely far away. Bacteria have limited mobility in soil and a competitor is likely to be closer to a nutrient treasure. Arthropods help out by distributing nutrients through the soil and by carrying bacteria on their exoskeleton and through their digestive system. By more thoroughly mixing microbes with their food, arthropods enhance organic matter decomposition.

Mineralize plant nutrients. As they graze, arthropods mineralize some of the nutrients in bacteria and fungi and excrete nutrients in plant-available forms.

Enhance soil aggregation. In most forested and grassland soils, every particle in the upper several inches of soil has been through the gut of numerous soil fauna. Each time soil passes through another arthropod or earthworm, it is thoroughly mixed with organic matter and mucus and deposited as fecal pellets. Fecal pellets are a highly concentrated nutrient resource, and are a mixture of the organic and inorganic substances required for growth of bacteria and fungi. In many soils, aggregates between 1/10,000 and 1/10 of an inch (0.0025mm and 2.5mm) are actually fecal pellets.

Burrow. Relatively few arthropod species burrow through the soil. Yet, within any soil community, burrowing arthropods and earthworms exert an enormous influence on the composition of the total fauna by shaping habitat. Burrowing changes the physical properties of soil, including porosity, water-infiltration rate, and bulk density.

Stimulate the succession of species. A dizzying array of natural bio-organic chemicals permeates the soil. Complete digestion of these chemicals requires a series of many types of bacteria, fungi, and other organisms with different enzymes. At any time, only a small subset of species is metabolically active — only those capable of using the resources currently available. Soil arthropods consume the dominant organisms and permit other species to move in and take their place, thus facilitating the progressive breakdown of soil organic matter.

Control pests. Some arthropods can be damaging to crop yields, but many others that are present in all soils eat or compete with various root- and foliage-feeders. Some (the specialists) feed on only a single type of prey species. Other arthropods (the generalists), such as many species of centipedes, spiders, ground-beetles, rove-beetles, and gamasid mites, feed on a broad range of prey. Where a healthy population of generalist predators is present, they will be available to deal with a variety of pest outbreaks. A population of predators can only be maintained between pest outbreaks if there is a constant source of non-pest prey to eat. That is, there must be a healthy and diverse food web.

A fundamental dilemma in pest control is that tillage and insecticide application have enormous effects on non-target species in the food web. Intense land use (especially monoculture, tillage, and pesticides) depletes soil diversity. As total soil diversity declines, predator populations drop sharply and the possibility for subsequent pest outbreaks increases.

The abundance and diversity of soil fauna diminishes significantly with soil depth. The great majority of all soil species are confined to the top 3 inches. Most of these creatures have limited mobility and are probably capable of "cryptobiosis," a state of "suspended animation" that helps them survive extremes of temperature, wetness, or dryness that would otherwise be lethal.

As a general rule, larger species are active on the soil surface, seeking temporary refuge under vegetation, plant residue, wood, or rocks. Many of these arthropods commute daily to forage within herbaceous vegetation above, or even high in, the canopy of trees. (For instance, one of these tree-climbers is the caterpillar-searcher used by foresters to control gypsy moth). Some large species capable of true burrowing live within the deeper layers of the soil.

Below about 2 inches in the soil, fauna are generally small — 1/250 to 1/10 of an inch; (25 of the smallest of these would fit in a period on this page). These species are usually blind and lack prominent coloration. They are capable of squeezing through minute pore spaces and along root channels. Sub-surface soil dwellers are associated primarily with the rhizosphere (the soil volume immediately adjacent to roots).

Abundance of Anthropods

A single square yard of soil will contain 500 to 200,000 individual arthropods, depending upon the soil type, plant community, and management system. Despite these large numbers, the biomass of arthropods in soil is far less than that of protozoa and nematodes.

In most environments, the most abundant soil dwellers are springtails and mites, though ants and termites predominate in certain situations, especially in desert and tropical soils. The largest number of arthropods are in natural plant communities with few earthworms (such as conifer forests). Natural communities with numerous earthworms (such as grassland soils) have the fewest arthropods. Apparently, earthworms out-compete arthropods, perhaps by excessively reworking their habitat or eating them incidentally. However, within pastures and farmlands, arthropod numbers and diversity are generally thought to increase as earthworm populations rise. Burrowing earthworms probably create habitat space for arthropods in agricultural soils.

EARTHWORMS

Of all the members of the soil food web, earthworms need the least introduction. Most people become familiar with these soft, slimy, invertebrates at a young age. Earthworms are hermaphrodites, meaning that they exhibit both male and female characteristics.

They are major decomposers of dead and decomposing organic matter and derive their nutrition from the bacteria and fungi that grow upon these materials. They fragment organic matter and make major contributions to recycling the nutrients it contains.

Earthworms occur in most temperate soils and many tropical soils. They are divided into 23 families, more than 700 genera, and more than 7,000 species. They range from an inch to 2 yards in length and are found seasonally at all depths in the soil. In terms of biomass and overall activity, earthworms dominate the world of soil invertebrates, including arthropods.

What Do Earthworms Do?

Earthworms dramatically alter soil structure, water movement, nutrient dynamics, and plant growth. They are not essential to all healthy soil systems, but their presence is usually an indicator of a healthy system. Earthworms perform several beneficial functions.

Stimulate microbial activity. Although earthworms derive their nutrition from microorganisms, many more microorganisms are present in their feces or casts than in the organic matter that they consume. As organic matter passes through their intestines, it is fragmented and inoculated with microorganisms. Increased microbial activity facilitates the cycling of nutrients from organic matter and their conversion into forms readily taken up by plants.

Mix and aggregate soil. As they consume organic matter and mineral particles, earthworms excrete wastes in the form of casts, a type of soil aggregate. Charles Darwin calculated that earthworms can move large amounts of soil from the lower strata to the surface and also carry organic matter down into deeper soil layers. A large proportion of soil passes through the guts of earthworms, and they can turn over the top 6 inches (15 cm) of soil in 10 to 20 years.

Increase infiltration. Earthworms enhance porosity as they move through the soil. Some species make permanent burrows deep into the soil. These burrows can persist long after the inhabitant has died and can be a major conduit for soil drainage, particularly under heavy rainfall. At the same time, the burrows minimize surface water erosion. The horizontal burrowing of other species in the top several inches of soil increases overall porosity and drainage.

Improve water-holding capacity. By fragmenting organic matter and increasing soil porosity and aggregation, earthworms can significantly increase the water-holding capacity of soils.

Provide channels for root growth. The channels made by deep-burrowing earthworms are lined with readily available nutrients and make it easier for roots to penetrate deep into the soil.

Bury and shred plant residue. Plant and crop residue are gradually buried by cast material deposited on the surface and as earthworms pull surface residue into their burrows.

Where Are Earthworms?

Different species of earthworms inhabit different parts of the soil and have distinct feeding strategies. They can be separated into three major ecological groups based on their feeding and burrowing habits. All three groups are common and important to soil structure.

Surface soil and litter species — Epigeic species. These species live in or near surface plant litter. They are typically small and are adapted to the highly variable moisture and temperature conditions at the soil surface. The worms found in compost piles are epigeic and are unlikely to survive in the low organic matter environment of soil.

Upper soil species — Endogeic species. Some species move and live in the upper soil strata and feed primarily on soil and associated organic matter (geophages). They do not have permanent burrows, and their temporary channels become filled with cast material as they move through the soil, progressively passing it through their intestines.

Deep-burrowing species — Anecic species. These earthworms, which are typified by the "night crawler," *Lumbricus terrestris*, inhabit more or less permanent burrow systems that may extend several meters into the soil. They feed mainly on surface litter that they pull into their burrows. They may leave plugs, organic matter, or cast (excreted soil and mineral particles) blocking the mouth of their burrows.

Looking for Earthworms?

It is easy to determine whether you have an adequate population of earthworms in your soil. Look for their casts in the forms of little piles of soil, mineral particles, or organic matter at the soil surface. They can be seen moving over the soil surface or even breeding, particularly on warm, damp nights. Dump a spadeful of moist soil into a bucket or onto a sheet of plastic, and sort through for earthworms. Can you identify different species? To find the deep burrowing species, pour a dilute mustard solution onto the soil. Many will quickly come to the soil surface in response to this irritant.

Abundance and Distribution of Earthworms

The majority of temperate and many tropical soils support significant earthworm populations. A square yard of cropland in the United States can contain from 50 to 300 earthworms, or even larger populations in highly organic soils. A similar area of grassland or temperate woodlands will have from 100 to 500 earthworms. Based on their total biomass, earthworms are the predominant group of soil invertebrates in most soils.

The family of earthworms that is most important in enhancing agricultural soil is Lumbricidae, which includes the genuses Lumbricus, Aporrectodea, and several others. Lumbricids originated in Europe and have been transported by human activities to many parts of the world. The United States has only one or two known native species of lumbricids. Others were brought to this country by settlers (probably in potted plants from Europe) and were distributed down the waterways.

Generally, lumbricids are much more common in the north and east than in the drier south and west of the United States. They tend to be more abundant in loam and clay loam and even in silty soil than in sandy soil and heavy clay. Populations also build up in irrigated soil. Earthworm populations tend to increase with soil organic matter levels and decrease with soil disturbances, such as tillage and potentially harmful chemicals.

Interaction of Earthworms With Other Members of the Food Web

The lives of earthworms and microbes are closely intertwined. Earthworms derive their nutrition from fungi, bacteria, and possibly protozoa and nematodes, and they promote the activity of these organisms by shredding and increasing the surface area of organic matter and making it more available to small organisms.

Earthworms also influence other soil-inhabiting invertebrates by changing the amount and distribution of organic matter and microbial populations. There is good evidence that earthworm activity affects the spatial distribution of soil microarthropod communities in the soil.

Earthworms have few invertebrate enemies other than flatworms and a species of parasitic fly. Their main predators are a wide range of birds and mammals that prey upon them at the soil surface.

Earthworms and Water Quality

Earthworms improve water infiltration and water-holding capacity because their shredding, mixing, and defecating enhances soil structure. In addition, burrows provide quick entry for water into and through soil. High infiltration rates help prevent pollution by minimizing runoff, erosion, and chemical transport to surface waters.

There is concern that burrows may increase the transport of pollutants, such as nitrates or pesticides, into groundwater. However, the movement of potential pollutants through soil is not a straightforward process and it is not clear when earthworm activity will or will not have a negative impact on groundwater quality.

Whether pollutants reach groundwater depends on a number of factors, including the location of pollutants on the surface or within soil, the quantity and intensity of rain, how well water moves into and through other parts of the soil, and characteristics of the burrows. The horizontal burrows of endogeic earthworms (such as *Aporrectodea tuberculata*, which are common in Midwestern fields) do not transport water and solutes as deeply as the vertical burrows of night crawlers (*L. terrestris*) and other anecic species. Even vertical burrows, however, are not direct channels for water movement. They have bends and turns and are lined with organic matter that adsorbs many potential pollutants from the water.

Although there is much more to learn about how earthworms affect water movement through soil, they clearly help minimize pollution of surface waters by improving infiltration rates and decreasing runoff.

Night Crawlers and Tillage

The substitution of conventional tillage by no-till or conservation tillage is increasingly common and widely adopted in the United States and elsewhere. In these situations, earthworms, particularly the "night crawler," *Lumbricus terrestris L.*, are especially important. Earthworms become the main agent for incorporating crop residue into the soil by pulling some into their burrows and by slowly burying the remainder under casts laid on the soil surface.

In reduced-tillage systems, surface residue builds up and triggers growth in earthworm populations. Earthworms need the food and habitat provided by surface residue, and they eat the fungi that become more common in no-till soils. As earthworm populations increase, they pull more and more residue into their burrows, helping to mix organic matter into the soil, improving soil structure and water infiltration.

Reference source:
The above text was taken from the Soil Biology Primer Web site Tugel, A.J., A.M. Lewandowski, eds. (February 2001 — last update). Soil Biology Primer [online]. Available at *www.statlab.iastate.edu/survey/SQI/soil_biology_primer.htm* [12/11/01].

SOIL VOCABULARY

ABC soil. A soil having an A, a B, and a C horizon.

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.

Alkali (sodic) soil. A soil having so high a degree of alkalinity (pH 8.5 or higher) or so high a percentage of exchangeable sodium (15% or more of the total exchangeable bases), or both, that plant growth is restricted.

Alluvium. Material, such as sand, silt, or clay, deposited on land by streams.

Aquic conditions. Current soil wetness characterized by saturation, reduction, and redoximorphic features.

Association, soil. A group of soils or miscellaneous areas geographically associated in a characteristic repeating pattern and defined and delineated as a single map unit.

Available water capacity (available moisture capacity). The capacity of soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field moisture capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil. The capacity, in inches, in a 60-inch profile or to a limiting layer is expressed as

Very low ....0 to 3
Low...3 to 6
Moderate ....6 to 9
High ....9 to 12
Very high................. more than 12

Bedding planes. Fine strata, less than 5 millimeters thick, in unconsolidated alluvial, eolian, lacustrine, or marine sediment.

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

Bottomland. The normal floodplain of a stream, subject to flooding.

Calcareous soil. A soil containing enough calcium carbonate (commonly combined with magnesium carbonate) to bubble visibly when treated with cold, dilute hydrochloric acid.

Cation. An ion carrying a positive charge of electricity.

Clay. Mineral soil particles less than 0.002 millimeter in diameter. As a soil textural classification, soil material that is 40% or more clay, less than 45% sand, and less than 40% silt.

Clay film. A thin coating of oriented clay on the surface of a soil aggregate or lining pores or root channels. Synonyms: clay coating, clay skin.

Complex, soil. A map unit of two or more kinds of soil in so small an area that it is not practical to map them separately at the selected scale of mapping. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas.

Concretions. Cemented bodies with crude internal symmetry organized around a point, a line, or a plane. They typically take the form of concentric layers visible to the naked eye. Calcium carbonate, iron oxide, and manganese oxide are common compounds making up concretions.

Conservation cropping system. Growing crops in combination with needed agricultural and management practices.

Conservation tillage. A tillage system that does not invert the soil and that leaves a protective amount of crop residue on the surface throughout the year.

Consistence, soil. Refers to the degree of cohesion and adhesion of soil material and its resistance to deformation when ruptured. Consistence includes resistance of soil material to rupture and to penetration; plasticity, toughness, and stickiness of puddled soil material, and the manner in which the soil material behaves when subject to compression.

Contour stripcropping. Growing crops in strips that follow the contour. Strips of grass or close-growing crops are alternated with strips of clean-tilled crops or summer fallow.

Control section. The part of the soil on which classification is based. The thickness varies among different kinds of soil, but for many it is that part of the soil profile between depths of 10 inches and 40 or 80 inches.

Corrosion. Soil-induced electrochemical or chemical action that dissolves or weakens concrete or uncoated steel.

Cover crop. A crop grown primarily to improve and protect the soil between periods of regular crop production, or a crop grown between trees and vines in orchards and vineyards.

Cropping system. Growing crops according to a planned system of rotation and management practices.

Crop residue management. Returning crop residue to the soil, which helps to maintain soil structure, organic matter content, and fertility and helps to control erosion.

Diversion (or diversion terrace). A ridge of earth, generally a terrace, built to protect downslope areas by diverting runoff from its natural course.

Drainage class (natural). Refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. 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.

Eluviation. The movement of material in true solution or colloidal suspension from one place to another within the soil. Soil horizons that have lost material through eluviation are *eluvial*; those that have received material are *illuvial*.

Endosaturation. A type of saturation of the soil in which all horizons between the upper boundary of saturation and a depth of 2 meters are saturated.

Episaturation. A type of saturation indicating a perched water table in a soil in which saturated layers are underlain by one or more unsaturated layers within 2 meters of the surface.

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 floodplains and coastal plains. Also called 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.

Excess fines (in tables). Excess silt and clay in the soil.

Excess sodium (in tables). Excess exchangeable sodium in the soil. The resulting poor physical properties restrict the growth of plants.

Fallow. Cropland left idle in order to restore productivity through accumulation of moisture. Summer fallow is common in regions of limited rainfall where cereal grain is grown.

Fast intake (in tables). The rapid movement of water into the soil.

Fine textured soil. Sandy clay, silty clay, or clay.

Floodplain. A nearly level alluvial plain that borders a stream and is subject to flooding unless protected artificially.

Fluvial. Of or pertaining to rivers; produced by river action, as a fluvial plain.

Fragipan. A loamy, brittle subsurface horizon low in porosity and content of organic matter and low or moderate in clay but high in silt or very fine sand. A fragipan appears cemented and restricts roots. When dry, it is hard or very hard and has a higher bulk density than the horizon or horizons above. When moist, it tends to rupture suddenly under pressure rather than to deform slowly.

Grassed waterway. A natural or constructed waterway, typically broad and shallow, seeded to grass as protection against erosion.

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.

Groundwater. Water filling all the unblocked pores of the material below the water table.

Gully. A miniature valley with steep sides cut by running water and through which water ordinarily runs after rainfall. The distinction between a gully and a rill is one of depth. A gully generally is an obstacle to farm machinery and is too deep to be obliterated by ordinary tillage; a rill is of lesser depth and can be smoothed over by ordinary tillage.

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

High-residue crops. Such crops as small grain and corn used for grain. If properly managed, residue from these crops can be used to control erosion until the next crop in the rotation is established. These crops return large amounts of organic matter to the soil.

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:

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.

Hydrologic soil groups. Refers to soils grouped according to their runoff potential. Runoff potential is affected by depth to a seasonal high water table, the infiltration rate and permeability after prolonged wetting, and depth to a very slowly permeable layer.

Illuviation. The movement of soil material from one horizon to another in the soil profile. Generally, material is removed from an upper horizon and deposited in a lower horizon.

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.

Intake rate. The average rate of water entering the soil under irrigation. Most soils have a fast initial rate; the rate decreases with application time. Therefore, intake rate for design purposes is not a constant but is a variable depending on the net irrigation application. The rate of water intake, in inches per hour, is expressed as follows:

Less than 0.2..........................very low
0.2 to 0.4..low
0.4 to 0.75...................moderately low
0.75 to 1.25...........................moderate
1.25 to 1.75............... moderately high
1.75 to 2.5...................................... high
More than 2.5...................... very high

Intermittent stream. A stream that carries water only part of the time, generally in response to periods of heavy runoff either from snowmelt or storms.

Irrigation. Application of water to soils. Methods of irrigation are

Border — Water is applied at the upper end of a strip in which the lateral flow of water is controlled by small earth ridges called border dikes, or borders.

Furrow — Water is applied in small ditches made by cultivation implements. Furrows are used for tree and row crops.

Sprinkler — Water is sprayed over the soil surface through pipes or nozzles from a pressure system.

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

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

Mineral soil. Soil that is mainly mineral material and low in organic material.

Minimum tillage. Only the tillage essential to crop production and prevention of soil damage.

Morphology, soil. The physical makeup of the soil, including the texture, structure, porosity, consistence, color, and other physical, mineral, and biological properties of the various horizons, and the thickness and arrangement of those horizons in the soil profile.

Munsell notation. A designation of color by degrees of three simple variables — hue, value, and chroma. For example, a notation of 10YR 6/4 is a color with hue of 10YR, value of 6, and chroma of 4.

Nodules. Cemented bodies lacking visible internal structure. Calcium carbonate, iron oxide, and manganese oxide are common compounds making up nodules.

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. The content of organic matter in the surface layer is described as follows:

Very low ....less than 0.5%
Low.......................................0.5 to 1.0%
Moderately low ....1.0 to 2.0%
Moderate ....2.0 to 4.0%
High ....4.0 to 8.0%
Very high....................more than 8.0%

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

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 line with conventional usage in the engineering profession and with traditional usage in published soil surveys, this rate of flow continues to be expressed as “permeability.” Terms describing permeability, measured in inches per hour, are as follows:

Extremely slow ....0.0–0.01 inch
Very slow.............................0.01–0.06 inch
Slow..0.06–0.2 inch
Moderately slow.....................0.2–0.6 inch
Moderate ....0.6 inch–2.0 inches
Moderately rapid .... 2.0–6.0 inches

Rapid .... 6.0–20 inches
Very rapid .... more than 20 inches

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

Piping (in tables). Formation of subsurface tunnels or pipe-like cavities by water moving through the soil.

Ponding. Standing water on soils in closed depressions. Unless the soils are artificially drained, the water can be removed only by percolation or evapotranspiration.

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. The degrees of acidity or alkalinity, expressed as pH values, are
Ultra acidic .... less than 3.5
Extremely acidic 3.5–4.4
Very strongly acidic.............................4.5–5.0
Strongly acidic 5.1–5.5
Moderately acidic.................................5.6–6.0
Slightly acidic..6.1–6.5
Neutral...6.6–7.3
Slightly alkaline 7.4–7.8
Moderately alkaline.............................7.9–8.4
Strongly alkaline 8.5–9.0
Very strongly alkaline .... 9.1 and higher

Residuum (residual soil material). Unconsolidated, weathered or partly weathered mineral material that accumulated as consolidated rock disintegrated in place.

Root zone. The part of the soil that can be penetrated by plant 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 groundwater runoff or seepage flow from groundwater.

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

Saturation. Wetness characterized by zero or positive pressure of the soil water. Under conditions of saturation, the water will flow from the soil matrix into an unlined auger hole.

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.

Sheet erosion. The removal of a fairly uniform layer of soil material from the land surface by the action of rainfall and surface runoff.

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% or more silt and less than 12% clay.

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% is a drop of 20 feet in 100 feet of horizontal distance. In this survey, classes for simple slopes are as follows:

Level.................................. 0–1%
Nearly level...................... 1–3%
Gently sloping 3–8%

Sodic (alkali) soil. A soil having so high a degree of alkalinity (pH 8.5 or higher) or so high a percentage of exchangeable sodium (15% or more of the total exchangeable bases), or both, that plant growth is restricted.

Soil. A natural three-dimensional body at the earth’s surface. It is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time.

Soil separates. Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes, in millimeters, of separates recognized in the United States are as follows:

Very coarse sand 2.0–1.0
Coarse sand..........................1.0–0.5
Medium sand.....................0.5–0.25
Fine sand 0.25–0.10
Very fine sand..................0.10–0.05
Silt....................................0.05–0.002
Clay .... less than 0.002

Solum. The upper part of a soil profile, above the C horizon, in which the processes of soil formation are active. The solum in soil consists of the A, E, and B horizons. Generally, the characteristics of the material in these horizons are unlike those of the material below the solum. The living roots and the plant and animal activities are largely confined to the solum.

Stripcropping. Growing crops in a systematic arrangement of strips or bands that provide vegetative barriers to wind erosion and water erosion.

Structure, soil. The arrangement of primary soil particles into compound particles or aggregates.

Subsoil. Technically, the B horizon; roughly, the part of the solum below plow depth.

Substratum. The part of the soil below the solum.

Subsurface layer. Any surface soil horizon (A, E, AB, or EB) below the surface layer.

Surface layer. The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, ranging in depth from 4 to 10 inches (10 to 25 centimeters). Frequently designated as the "plow layer" or the "Ap horizon."

Terrace. An embankment, or ridge, constructed across sloping soils on the contour or at a slight angle to the contour. The terrace intercepts surface runoff so that water soaks into the soil or flows slowly to a prepared outlet. A terrace in a field generally is built so that the field can be farmed. A terrace intended mainly for drainage has a deep channel that is maintained in permanent sod.

Terrace (geologic). An old alluvial plain, ordinarily flat or undulating, bordering a river, lake, or sea.

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."

Tilth, soil. The physical condition of the soil as related to tillage, seedbed preparation, seedling emergence, and root penetration.

Topsoil. The upper part of the soil, which is the most favorable material for plant growth. It is ordinarily rich in organic matter and is used to topdress roadbanks, lawns, and land affected by mining.

Weathering. All physical and chemical changes produced in rocks or other deposits at or near the earth's surface by atmospheric agents. These changes result in disintegration and decomposition of the material.

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Key to Soil Orders in Florida[1]

M.E. Collins[2]

This fact sheet is intended for anyone who has some understanding of Soil Taxonomy but who needs a simplified key to help distinguish one soil order from another. There are 12 soil orders: Andisols, Gelosols, Entisols, Inceptisols, Alfisols, Ultisols, Spodosols, Histosols, Mollisols, Aridisols, Vertisols, and Oxisols. Only seven of these soil orders are present in Florida. The soil orders not recognized in Florida are the Aridisols, Vertisols, Andisols, Gelosols, and Oxisols. The distribution of dominant soil orders in Florida is shown in Figure 1. Alfisols, Inceptisols, and Mollisols are not shown because: Alfisols are widely interspersed throughout the state; and the aerial extent of Inceptisols and Mollisols is too small to be shown at this scale of map (source: Carlisle and Brown, 1982).

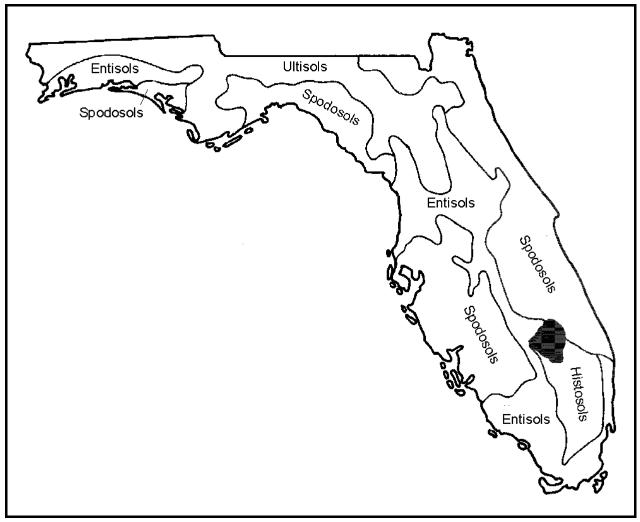

Figure 1. Soil orders in Florida. Alfisols, Inceptisols and Mollisols are not shown.

To determine the order to which a soil belongs, you must follow the "Keys to Soil Taxonomy" (Soil Survey Staff, 1996). But before you can use the key, you must know which diagnostic horizon(s) is present in the soil that you are classifying. These diagnostic horizons are particular kinds of horizons in the soil that indicate the degree and kind of dominant sets of soil-forming processes that have occurred. Therefore, you must know the epipedon (diagnostic surface horizon) and what, if any, diagnostic subsurface horizons exist.

The soil order is the highest category in Soil Taxonomy. At this hierarchical level, soils are distinguished in relation to the five soil-forming factors: (1) climate and (2) living organisms acting on (3) parent materials over (4) time as conditioned by (5) relief.

The seven soil orders recognized in Florida and the major properties that differentiate them are discussed next. Complete definitions for the soil orders and diagnostic horizons are available in "Keys to Soil Taxonomy" (Soil Survey Staff, 1996).

1. This document is SL-43, one of a series of fact sheets of the Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. First published: August 1985. Revised: October 1997. Please visit the FAIRS Web site at **http://hammock.ifas.ufl.edu**.

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ALFISOLS

Soils in the Alfisol order are characterized by having undergone processes that translocate silicate clays to form an argillic horizon. Clay translocation in Alfisols takes place without the depletion of bases. The unique properties of Alfisols in Florida are a combination of an argillic horizon, a medium to high amount of bases in the soil, water generally available to plants during the growing season, and an ochric epipedon. In general, these soils are intensively cropped. An example of a generalized profile description of an Alfisol is shown in Figure 2. Presently, Alfisols have been mapped on approximately 4.6 million acres in Florida.

ENTISOLS

A soil that does not reflect any major set of soil-forming processes belongs to the Entisol order. Entisols are able to support any vegetation and occur in any climate. Commonly, they form in inert parent materials such as quartz sand (Central Ridge of Florida) or slowly soluble rock such as limestone (South Florida). There also may have been insufficient time, as in recent alluvial deposits, for diagnostic horizons to have formed. Entisols could occur on steep slopes, where the rate of erosion exceeds the rate of formation of pedogenic horizons. The properties unique to Florida Entisols are a dominance of mineral soil and an absence of distinct pedogenic horizons except for an ochric epipedon, an albic horizon, and a spodic or argillic diagnostic subsurface horizon that is below 80 inches.

An example of a generalized profile description of an Entisol is shown in Figure 2. Presently, Entisols have been mapped on approximately 7.5 million acres in Florida.

HISTOSOLS

Soils that belong to the Histosol order have a very high content of organic carbon (more than half of the soil's thickness is organic) in the upper 32 inches of the soil. These soils are considered to be organic rather than mineral soils. The amount of organic carbon required for Histosols depends on the amount of clay. Most Florida Histosols formed from partially decomposed plant remains that accumulated in water. More common names for Histosols are peats or mucks.

An example of a generalized profile description of a Histosol is shown in Figure 2. Presently, Histosols have been mapped on approximately 4.0 million acres in Florida.

INCEPTISOLS

Soils of the Inceptisol order have a unique combination of properties that include water available to plants during the growing season, one or more pedogenic horizons of alteration or concentration with little accumulation of translocated materials, some unweathered minerals, a moderate to high cation exchange capacity in the clay fraction, and usually textures finer than loamy sand. Even though most Inceptisols in Florida have loamy sand or coarser (more sandy) textures, these soils are classified as Inceptisols because of a dark, thick, and low base saturation ($<35\%$) surface horizon (umbric epipedon). Inceptisols in Florida are of minor extent.

An example of a generalized profile description of an Inceptisol is shown in Figure 2. Presently, Inceptisols have been mapped on approximately 1.0 million acres in Florida.

MOLLISOLS

Soils that belong to the Mollisol order have a very dark brown to black surface horizon (mollic epipedon), a high amount of calcium versus other extractable cations present in the soil, and clay minerals of moderate or high cation-exchange capacity. The mollic epipedon forms mainly from the decomposition of organic matter in a soil that has a considerable amount of divalent cations, especially calcium. Soil properties associated with a mollic epipedon are a reasonable reserve of plant nutrients (Ca, Mg, K, and sometimes N), soil structure that allows movement of air and water when the soil is not saturated, and good permeability. The vast majority of Mollisols presently recognized in Florida are poorly to very poorly drained.

An example of a generalized profile description of a Mollisol is shown in Figure 2. Presently, Mollisols have been mapped on approximately 1.0 million acres in Florida.

SPODOSOLS

Spodosols are characterized by having undergone soil processes that translocate organic matter and aluminum, or organic matter, aluminum, and iron, as amorphous materials. The most striking property Spodosols have is a horizon that has resulted from accumulation of black or reddish amorphous materials having a high cation-exchange capacity. This horizon is called a spodic horizon. In some Spodosols a leached horizon, which can range from white to gray, overlies the spodic horizon. Many Spodosols in Florida are poorly to very poorly drained, and all Spodosols in Florida have developed in sandy, acid parent materials.

An example of a generalized profile description of a Spodosol is shown in Figure 2. Approximately 8.4 million acres in Florida have been mapped as Spodosols.

ULTISOLS

Ultisols are like Alfisols in that they have a horizon in which clay has accumulated to a significant extent (argillic horizon). Ultisols, however, are more developed and more leached than Alfisols. The soil properties associated with Ultisols are an argillic horizon, enough moisture for crops in most years, and a low supply of bases. They exist in relatively warm and moist climates, like northwest Florida, and therefore can be highly productive if managed properly.

An example of a gene profile description of an Ultisol is shown in Figure 2. There are approximately 6.9 million known acres of Ultisols in Florida.

KEY TO SOIL ORDERS IN FLORIDA

In this gene key the soil orders are listed in the same sequence as in Soil Taxonomy. This key is an abbreviated guide.

A. Soils that are organic in more than half the thickness of the upper 32 inches.
Histosols

B. Other soils that are mineral with an illuvial horizon of amorphous aluminum and organic matter with or without iron (a spodic horizon) within 80 inches of the surface.
Spodosols

C. Other mineral soils with an illuvial horizon of clay (an argillic horizon), relatively low base saturation (< 35 %), and enough moisture for crops in most years.
Ultisols

D. Other mineral soils that have a thick, dark surface horizon which is relatively rich in organic matter (a mollic epipedon), have a high base saturation (> 50 %) throughout the soil, and do not have deep, wide cracks.
Mollisols

E. Other mineral soils with an illuvial horizon of clay (an argillic horizon), relatively high base saturation (> 35 %), and enough moisture for crops in most years.
Alfisols

F. Other mineral soils that have no horizon of illuvial clays, relatively little organic matter or base saturation or both, some diagnostic horizons and weatherable minerals, and enough moisture for a crop in most years.
Inceptisols

G. Mineral soils with weak or no diagnostic horizons.
Entisols

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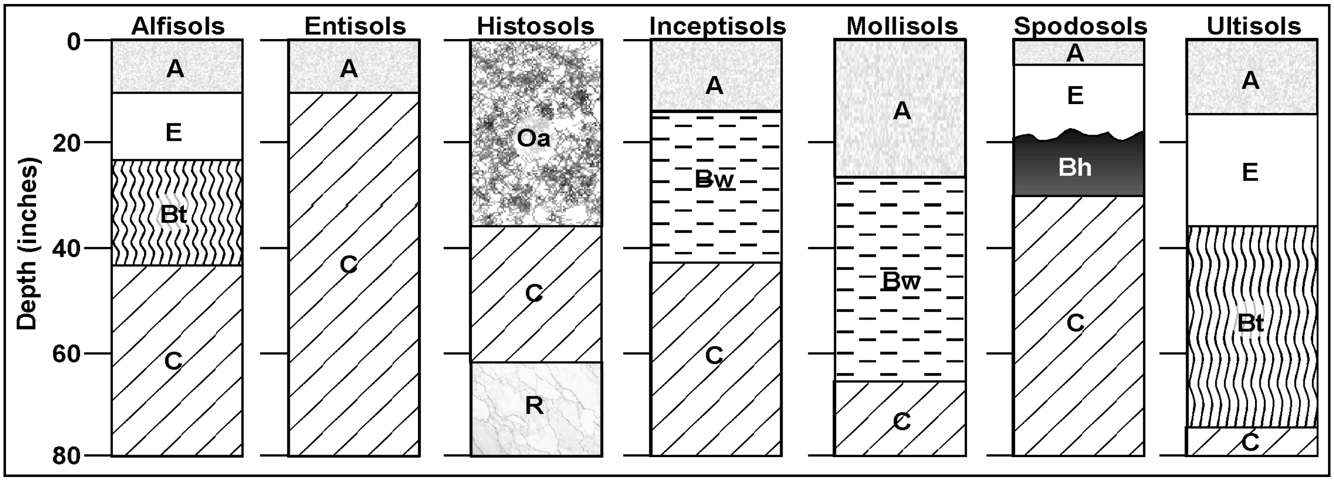

Figure 2. Generalized profile description of the soil orders in Florida.

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Soil Texture[1]

R.B. Brown[2]

Soil texture is a term commonly used to designate the proportionate distribution of the different sizes of mineral particles in a soil. It does not include any organic matter. These mineral particles vary in size from those easily seen with the unaided eye to those below the range of a high-powered microscope. According to their size, these mineral particles are grouped into “separates."

A soil separate is a group of mineral particles that fit within definite size limits expressed as diameter in millimeters. Sizes of the separates used in the USDA system of nomenclature for soil texture are shown in Table 1.

Since various sizes of particle have quite different physical characteristics, the nature of mineral soils is determined to a remarkable degree by the particular separate that is present in larger amounts. Thus, a soil possessing a large amount of clay has quite different physical properties from one made up mostly of sand and/or silt. The analytical procedure by which the percentages of the various soil separates are obtained is called a mechanical analysis.

Mineral soils (that is, those soils consisting mainly of rock and mineral fragments, rather than plant remains and other accumulated organic materials) are a mixture of soil separates, and it is on the basis of the proportion of these various separates that the textural class names of soils are determined.

There are twelve major textural classes. Their compositions are defined by the USDA textural triangle (Figure 1).

How to Use the USDA Textural Triangle

After a mechanical analysis has been completed in the laboratory and a percentage obtained for each of the soil separates (as in the examples of soil samples from various soil horizons shown in Table 2), add up the amounts of sand from the very coarse sand through the very fine sand, to determine the total sand content. Total sand is used, along with silt and clay contents, to determine the soil textural name from the USDA textural triangle.

For example, Sample No. 3, the Bt (subsoil) horizon of soil S1 (Table 2), has an analysis of 72% sand, 3% silt, and 25% clay. Look at the USDA textural triangle (Figure 1) and notice the percent sand" arrow pointing from right to left on the bottom of the triangle. Find the 72% sand point and mentally sketch a line from that point parallel to the side opposite the 100% sand corner of the triangle. Such a line will pass through all points on the triangle that correspond to a soil having 72% sand. Now locate the 3% silt point on the upper right side of the triangle, and visualize a line from this point parallel to the side opposite the 100% silt corner of the triangle. This line intersects the sand line at a single point inside the area labeled as sandy clay loam.

Two properly sketched lines (sand and silt, sand and clay, or silt and clay) will correctly indicate the textural class name of a mineral soil. Notice that, in the case of Sample No.3, the 25% clay line sketched by drawing a line through that point and parallel to the base of the triangle (which is the side opposite the 100% clay corner) intersects the 72% sand and 3% silt lines at exactly the same point (shown with

1. This document is Fact Sheet SL-29, one of a series of fact sheets of the Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Date first printed: April 1990. Reviewed: April 1998. Please visit the FAIRS Web site at **http://hammock.ifas.ufl.edu**.

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a dot on Figure 1) where the sand and silt lines intersect each other. Any three percentages of sand, silt, and clay that add up to 100 will always define a single point on the triangle.

In the cases of sands, loamy sands, and sandy loams, the proportion of individual sand separates (very coarse sand, coarse sand, etc.) must be considered in assigning a textural name to a sample. The total sand fraction of Sample No.2 (Table 2), for example, is not dominated by any one sand separate, so it is called, simply, sand. In contrast, Sample No.4 (Table 2), the A horizon (topsoil) of Soil S2, is dominated by sand particles that are in the 0.10-0.25 mm (fine sand) size range. This soil is designated fine sand to reflect that dominance.

The paragraphs that follow contain more information on the characteristics of the various sands, loamy sands, and sandy loams.

Determination of Soil Texture in the Field

In the field, the percentages of sand, silt, and clay particles in a soil are estimated by feel. The soil is rubbed between the fingers and the thumb and an estimate of the amount of the various separates present is made based on the degree to which the characteristic properties of each are expressed. This process of estimation requires skill and experience, but accuracy can be improved by frequent checks of such estimates against the findings of experienced field soil scientists in the region, and against determinations obtained by laboratory analysis of the samples.

Dry soil feels different from moist soil, due in part to the fact that soil particles tend to aggregate together upon drying. It is best to moisten dry soil when making field estimates of soil texture. The more important characteristics of the various textural classes of soils which are of value and which can be recognized by feel and/or determined by laboratory analysis are as follows.

Sands

Sands are loose and single-grained (that is, not aggregated together). They feel gritty to the touch and are not sticky. Each individual sand grain is of sufficient size that it can easily be seen and felt. Sands cannot be formed into a cast by squeezing when dry. When moist, sands will form a very weak cast, as if molded by the hand, that crumbles when touched. Soil materials classified as sands must contain 85-100% sand-sized particles, 0-15% silt-sized particles, and 0-10% clay-sized particles. These percentages are given by the boundaries of the sand portion of the USDA textural triangle (Figure 1).

The reason that sands are referred to in the plural is that there are several USDA textures within this group. All of these textures fit the “sand” portion of the textural triangle, but they differ from each other in their relative proportions of the various sizes of sand grains.

Coarse Sand: This is the sand that looks and feels most coarse and gritty. It must contain 25% or more very coarse sand and coarse sand, and less than 50% any other single grade of sand.

Sand: This is the normal sort of sand that contains a more or less even distribution of the different sizes of sand grain. It is not dominated by a particular size of sand particle. It contains 25% or more very coarse, coarse, and medium sand (but less than 25% very coarse plus coarse sand), and less than 50% either fine sand or very fine sand.

Fine Sand: This class of sand is dominated by the finer sizes of sand particle, and as such feels rather uniform in texture and somewhat less coarse than either sand or coarse sand. It must contain 50% or more fine sand; or less than 25% very coarse, coarse, and medium sand, and less than 50% very fine sand.

Very Fine Sand: This soil is dominated by the very finest of sand grains. Its grittiness seems almost to grade into the smoothness that one would expect in a silty soil. It is 50% or more very fine sand.

Remember, the term "sand" has more than one meaning in the USDA system. Sand can mean a group of soil separates (very coarse sand, coarse sand, medium sand, fine sand, and very fine sand) that collectively range in diameter from 2 to 0.05 mm (Table 1). Sands, in the plural, are a major textural grouping on the USDA textural triangle (Figure 1; Table 2). This major grouping (sands) includes four individual USDA textures (coarse sand, sand, fine sand, and very fine sand), depending on the proportions of the individual separates in a particular soil.

Loamy Sands

Loamy sands consist of soil materials containing 70-90% sand, 0-30% silt, and 0-15% clay. As such, they resemble sands in that they are loose and single-grained, and most individual grains can be seen and felt. Because they do contain slightly higher percentages of silt and clay than do the sands, however, the loamy sands are slightly cohesive when moist, and fragile casts can more readily be formed with them than with sands.

As with sands, the loamy sands are dealt with in the plural because there are several USDA textures within this group. The name assigned to a soil material in the loamy sands depends on the proportions of the different sand separates.

Loamy Coarse Sand: This is the coarsest and grittiest sort of loamy sand. It must contain 25% or more very coarse and coarse sand, and less than 50% any other single grade of sand.

Loamy Sand: This class includes any loamy sand whose sand fraction is not dominated by a particular size of sand particle. It consists of 25% or more very coarse, coarse, and medium sand (but less than 25% very coarse plus coarse sand), and less than 50% either fine sand or very fine sand.

Loamy Fine Sand: The sand grains in this class of loamy sand are dominantly in the finer size range. Loamy fine sand contains 50% or more fine sand; or less than 50% very fine sand and less than 25% very coarse, coarse, and medium sand.

Loamy Very Fine Sand: This soil material is so dominated by very fine sand that it almost takes on a smooth, silty quality. It consists of 50% or more very fine sand.

Sandy Loams

Sandy loams consist of soil materials containing somewhat less sand, and more silt plus clay, than loamy sands. As such, they possess characteristics which fall between the finer-textured sandy clay loam and the coarser-textured loamy sands. Many of the individual sand grains can still be seen and felt, but there is sufficient silt and/or clay to give coherence to the soil so that casts can be formed that will bear careful handling without breaking.

As with sands and loamy sands, the sandy loams comprise four different USDA textures. All four textures fit within the sandy loam section of the textural triangle, but they differ in proportions of the various sizes of sand grain.

Coarse Sandy Loam: This is the coarsest and grittiest sandy loam. It must consist of 25% or more very coarse and coarse sand, and less than 50% any other single grade of sand.

Sandy Loam: Sandy loam is not dominated by any particular size of sand particle. It contains 30% or more very coarse, coarse, and medium sand (but less than 25% very coarse and coarse sand), and less than 30% either fine sand or very fine sand.

Fine Sandy Loam: The grains in fine sandy loam are dominantly in the finer size range. It must contain 30% or more fine, and less than 30% very fine sand; or between 15 and 30% very coarse, coarse, and medium sand; or more than 40% fine and very fine sand, at least half of which is fine, and less than 15 percent very coarse, coarse, and medium sand.

Very Fine Sandy Loam: This soil material is sandy loam that is particularly influenced by the presence of large amounts of very fine sand, giving it a relatively smooth quality in comparison with the other sandy loams. Specifically, it has 30% or more very fine sand; or more than 40% fine and very fine sand, at least half of which is very fine sand, and less than 15% very coarse, coarse, and medium sand.

Loam

Loam is soil material that is medium-textured. It feels as though it contains a relatively even mixture of sand, silt, and clay because clay particles, with their small size, high surface areas, and high physical and chemical activities, exert a greater influence on soil properties than does sand or silt.

Loam tends to be rather soft and friable. It has a slightly gritty feel, yet is fairly smooth and slightly sticky and plastic when moist. Casts formed from such soils can be handled quite freely without breaking.

Sandy Clay Loam

Soil having this texture consists of materials whose behavior is dominated by sand and clay. It most nearly resembles the sandy loams in that it has considerable amounts of sand, which can be most easily detected by moistening the soil and smoothing it out between the fingers. However, as the name implies, sandy clay loam has more clay than the sandy loams and thus possesses greater cohesive properties (such as stickiness and plasticity) when moistened. Casts made from these materials are quite firm, can be handled roughly without breaking; and tend to become hard when dry. The moist soil will form a thin ribbon that will barely sustain its own weight when squeezed carefully between the thumb and fingers.

Clay Loam

Clay loam consists of soil material having the most even distribution of sand, silt, and clay of any of the soil textural grades. But it feels as though it possesses more clay than sand or silt. Sticky and plastic when wet, it forms casts that are firm when moist and hard when dry. The moist soil will form a thin ribbon that will barely sustain its own weight when squeezed carefully between the thumb and fingers.

Silt

Silt is similar to silt loam but contains even less sand and clay. Sand-sized particles, if present, are generally so small (either fine or very fine sand) that they are nondetectable to the fingers. Clay particles are present in such low percentages that little or no stickiness is imparted to the soil when moistened, but it instead feels smooth and rather silky. Silt-sized particles are somewhat plastic, and casts can be formed that will bear careful handling.

Silt Loam

Silt loam has rather small amounts of sand and clay and is composed mostly of silt-sized particles. When dry, it is often rather cloddy in the field; but the lumps are easily broken between the fingers, and the soil then feels soft and floury. Either moist or dry, casts can be formed which can be handled somewhat freely without breaking. When moistened and squeezed between the fingers it feels soft and smooth. It will not "ribbon out"; it will break into small bits.

Silty Clay Loam

This soil material resembles clay loam in cohesive properties, but possesses more silt and less sand and thus has a rather smooth feel. The small amounts of sand particles which are present are generally quite fine and are very difficult to detect. Silty clay loam is also intermediate in characteristics between the silty clay and the silt loam; it is sticky and plastic when wet, firm when moist, and forms casts that are hard when dry.

Silty Clay

Silty clay is quite smooth, nongritty, very sticky and very plastic when wet, and forms very hard aggregates when dry.

Sandy Clay

Sandy clay is somewhat similar to silty clay, but it contains much more sand and less silt.

Clay

Clay is the finest textured of all the soil classes. Clay usually forms extremely hard clods or lumps when dry and is extremely sticky and plastic when wet. When containing the proper amount of moisture, it can be "ribboned out" to a remarkable degree by squeezing between thumb and forefinger, and may be rolled into a long, very thin wire.

Organic Soils

Organic soils are made up of plant and animal remains that have accumulated, in varying stages of decomposition, in an environment that does not allow decay of the materials to take place rapidly. Such an environment may be found in some swamps, marshes, and lakes, and rarely in drier, more upland environments where the ecosystem is so productive that plant remains accumulate at extremely high rates. Muck, peaty muck, mucky peat, and peat are terms used in place of textural class names for organic soils. Muck consists of highly decomposed remains of plants and other organisms. Peat consists of relatively raw, less well-decomposed organic materials. Peaty muck and mucky peat are intermediate in decomposition. Mineral soils, as described in earlier paragraphs, are not dominated by organic materials, but consist primarily of sand-, silt-, and/or clay-sized particles of minerals or rock fragments. If you encounter a soil material that has been designated mucky sand or other such mixed name, it indicates that the soil is a mineral soil having a higher than ordinary content of organic matter (say, 10% or so by weight), but not high enough to treat the soil as an organic soil (muck, peaty muck, etc.).

Coarse Fragments and Rock Outcrops

Mineral particles in the soil that are larger than 2 mm in diameter are not soil separates, but are classified as pebbles (or, collectively, gravel), cobblestones, stones, or boulders, depending on their sizes and shapes. Collectively, they are called coarse fragments and are regarded as part of the soil mass due to their influence on water retention, infiltration, and runoff. When present in significant amounts, coarse fragments up to 25 cm (10 inches) in diameter are recognized by use of an appropriate adjective in the textural soil class name. For example, a sandy loam surface soil containing sufficient gravelly material to affect tillage could be designated as "gravelly sandy loam" or as "sandy loam, gravel phase."

Rock fragments larger than 25 cm (10 inches) in diameter (if somewhat equally dimensioned) or more than 38 cm (15 inches) in the longest dimension (if length and width differ greatly) are called stones and boulders. Stones range up to 60 cm (2 feet), and boulders are rocks that are larger than that with no upper size limit. The larger coarse fragments and rock outcrops are described in relation to their number, size, and spacing at the soil surface. Descriptive terminology is used as a phase of a textural soil class name, such as "loamy sand, bouldery phase," or "silt loam, rock outcrop phase."

Significance of Soil Texture

Of soil characteristics, texture is one of the most important. It influences many other properties of great significance to land use and management. Some terms often used to describe the various textural class names follow to discuss this relationship adequately: sandy or coarse-textured soils (for sands and loamy sands); loamy or medium-textured soils (for sandy loams, loam, silt, silt loam, sandy clay loam, clay loam, and silty clay loam); and clayey or fine textured soils (for sandy clay, silty clay, and clay).

Generally speaking, sandy soils tend to be low in organic matter content and native fertility, low in ability to retain moisture and nutrients, low in cation exchange and buffer capacities, and rapidly permeable (i.e., they permit rapid movement of water and air). Thick, upland deposits of such soil materials (common in the central ridge section of Florida, but also in other sand hill areas) are often quite droughty, need irrigation at times during dry seasons, 7 and are best adapted to deep-rooted crops (such as citrus where temperatures permit).

Sandy soils usually have high bulk densities and are therefore well-suited for road foundations and building sites. They do require good water management (generally including more frequent irrigations and/or artificial drainage to fit the needs of a specific crop) and proper fertilization (meaning more frequent but lower quantities of nutrients per application). Total amounts of fertilizer per crop are usually quite high.

As the relative percentages of silt and/or clay particles become greater, properties of soils are increasingly affected. Finer-textured soils generally are more fertile, contain more organic matter, have higher cation exchange and buffer capacities, are better able to retain moisture and nutrients, and permit less rapid movement of air and water. All of this is good up to a point. When soils are so fine-textured as to be classified as clayey, however, they are likely to exhibit properties which are somewhat difficult to manage or overcome. Such soils are often too sticky when wet and too hard when dry to cultivate. They also may have shrink-swell characteristics that affect their suitability adversely for use as building sites and for road construction.

The question is sometimes asked, "What is the best soil?" The answer can only properly be given by another question, "Best for what?" It is generally thought that (with all other factors being equal) soils having sandy loam, or loam-textured surface soils, are better suited for a wider variety of crops, and will produce higher yields more economically than most other soils in Florida. Such soils are more common in the northwest portion of the state.

Some Things Texture Does Not Tell Us

It is very important to realize that texture alone does not tell us all we need to know about soils as we try to understand and predict their behavior and their suitability for different uses.

Cementation is an example of one soil attribute that can alter the effect of soil texture. A soil may be sandy throughout its depth, but the coating of sand grains by naturally-occurring materials such as organic matter and iron/aluminum oxides may lead to the cementation of sand grains to each other and even to the plugging of the pores between sand grains. This phenomenon happens commonly in subsoils of the flatwoods. The resulting stained layer (called a spodic horizon by soil scientists and a hardpan by many others) can reduce the permeability of the subsoil, depending on the degree of cementation and plugging that has occurred, and can significantly alter the behavior of a soil relative to the behavior that it would have if there were no staining, cementation, or plugging.

Human activities can affect permeability of soils. Plowpans and other types of compaction can reduce soil permeability radically, even in sandy soils. Conversely, subsoiling or other kinds of ripping/ breaking of slowly permeable soil horizons can increase soil permeability.

The water table can have an important impact on soil behavior. Sandy soils of the flatwoods, for example, are likely to be saturated with water for extended periods during most years. The sandy soils of higher, sand hill landscapes are unlikely to have high water tables even for short periods.

Comparison with Engineering Classification Systems

The system for determining USDA texture is significantly different from the Unified and the American Association of State Highway and Transportation Officials

(AASHTO) systems that are traditionally used by engineers. One major difference is that the cutoffs between particle sizes are different among the three systems.

Another important difference is that USDA texture depends entirely on particle size; the Unified and AASHTO designations depend not only on particle sizes but also on other properties such as Atterberg limits (liquid limit and plasticity index).

There is, unfortunately, no way to translate directly from the USDA system to the other systems and back. Sandy clay loam in the USDA system, for example, may be either SC or CL in the Unified system, depending on the percentages of different sizes of particles; similarly, it may be A-6 or A-2-6 in the AASHTO system. Conversely, CL from the Unified system may be clay, silty clay, silty clay loam, clay loam, loam, silt loam, sandy clay, or sandy clay loam in the USDA system, depending on the results of a mechanical analysis done using USDA standards; a soil designated A-6 in the AASHTO system may be clay loam, loam, silt loam, or sandy clay loam in the USDA system.

For more information on the Unified and AASHTO systems, consult with your local office of the USDA Natural Resources Conservation Service, a modern soil survey report, or a textbook in soil mechanics.

Table 1. Size limits (diameter in millimeters) of soil separates in the USDA soil textural classification system

Name of soil separate	Diameter limits (mm)
Very coarse sand*	2.00 - 1.00
Coarse sand	1.00 - 0.50
Medium sand	0.50 - 0.25
Fine sand	0.25 - 0.10
Very fine sand	0.10 - 0.05
Silt	0.05 - 0.002
Clay	less than 0.002

* Note that the sand separate is split into five sizes (very coarse sand, coarse sand, etc.). The size range for sands, considered broadly, comprises the entire range from very coarse sand to very fine sand, i.e., 2.00-0.05 mm.

Where to Get More Information

For additional information on the availability of soil survey reports and other soil-related information assistance in your region, contact your local County Extension Service, Soil and Water Conservation District, and USDA Natural Resources Conservation Service offices.

Acknowledgment

This fact sheet is a major revision of "Soil Texture" (Soil Science Fact Sheet SL-29), by R. E. Caldwell. It has been modified as part of a project entitled “Determining Soil-Water Seasonal Movement." Partial support for this project has been provided by the U.S. Geological Survey, Department of the Interior, through the Florida Water Resources Research Center, as authorized by the Water Resources Research Act of 1984. Additional support has come from the Soil Characterization Program of Florida's Accelerated Soil Survey, funded by the Florida Legislature through the Bureau of Soil and Water Conservation, Florida Department of Agriculture and Consumer services.

Table 2. Distribution of particle sizes and USDA textural names for soil samples from three different depths in each of two contrasting Florida soils, designated “S1" and “S2".

Sample No.	Soil	Soil Horizon*	VCS+	CS	MS	FS	VFS	Total Sand #	Silt	Clay	USDA Textural Name
1	S1	A (Topsoil)	2	13	36	37	5	93	5	2	Sand
2		E (Subsurface)	3	14	36	38	4	95	3	2	Sand
3		Bt (Subsoil)	2	8	26	32	4	72	3	25	Sandy clay loam
4	S2	A (Topsoil)	0	1	7	80	5	93	6	1	Fine sand
5		E (Subsurface)	<1	1	7	85	4	97	2	1	Fine sand
6		Bh (Subsoil)	0	1	7	77	4	89	6	5	Fine sand

* The A horizon, or topsoil, is the upper part of the soil, ordinarily somewhat enriched in, and darkened by, organic matter. The E horizon, or subsurface layer, is a leached layer, lighter in color and lower in organic matter than the overlying topsoil. The B horizon, or subsoil, is the soil beneath the A and E horizons; it may be enriched relative to overlying horizons by clay particles, in which case it is designated a Bt horizon, or by organic material that gives it a black or dark brown appearance, in which case it is designated a Bh horizon.

\+ VCS = very coarse sand; CS = coarse sand; MS = medium sand; FS = fine sand; VFS = very fine sand. See Table 1 for size limits of the various soil separates.

\# Note that the percent total sand is obtained by adding the percentages of the five sand separates (very coarse sand, coarse sand, etc.). The percentages of sand, silt, and clay (which total 100%) are used with the USDA textural triangle (Figure 1) to determine the textural name of a sample. If the sand fraction of a sample is dominated by a particular size separate, however, a further modifier must be attached to the textural name (e.g., fine sand, or loamy coarse sand), as discussed in the text.

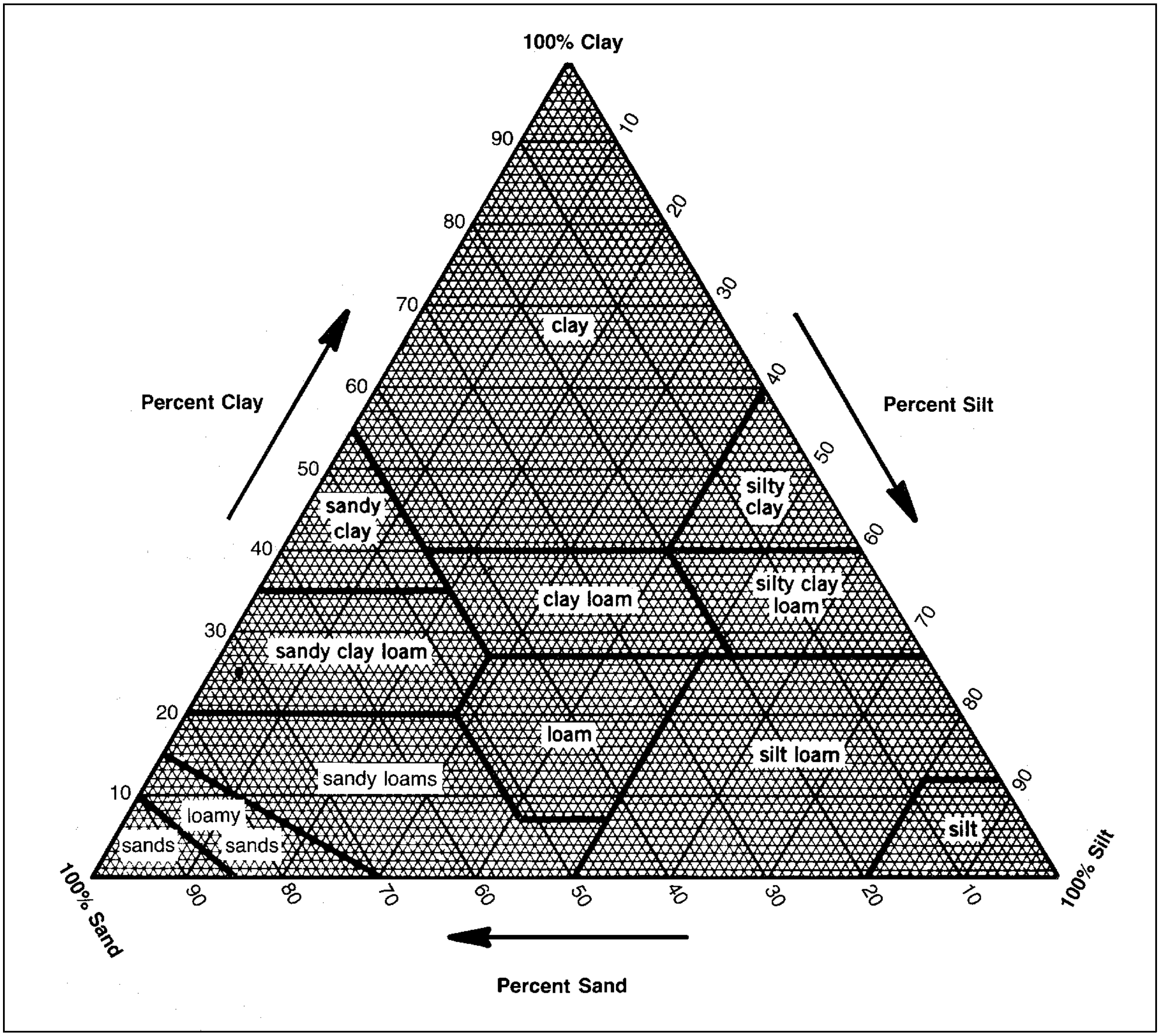


Figure 1. The USDA textural triangle, showing the twelve major textural classes in the USDA system. Within the sands, loamy sands, and sandy loams, the proportions of the various separates of sand (very coarse sand, coarse sand, medium sand, fine sand, and very fine sand) must be considered in determining which textural name to assign. If the sand fraction of a sample is dominated by a particular sand separate, a modifier must be attached to the major textural name (e.g., coarse sand, loamy very fine sand, or fine sandy loam), as discussed in the text of this fact sheet.

Soil Quality Information Sheet

Soil Quality - Introduction

USDA Natural Resources Conservation Service **Revised June 2001**

What is soil?

Soil is a dynamic resource that supports plant life. It is made up of different sized mineral particles (sand, silt, and clay), organic matter, and numerous species of living organisms. Thus, soil has biological, chemical, and physical properties, some of which are dynamic and can change in response to how the soil is managed.

What does soil do for us?

Soil provides several essential services or functions:

Soil supports the growth and diversity of plants and animals by providing a physical, chemical, and biological environment for the exchange of water, nutrients, energy and air.

Soil regulates the distribution of rain or irrigation water between infiltration and runoff, and regulates the flow and storage of water and solutes, including nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water.

Soil stores, moderates the release of, and cycles plant nutrients and other elements.

Soil acts as a filter to protect the quality of water, air, and other resources.

Soil supports structures and protects archeological treasures.

What is soil quality?

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Changes in the capacity of soil to function are reflected in soil properties that change in response to management or climate.

Why is soil quality important?

Management that enhances soil quality will benefit cropland, rangeland, and woodland productivity. Enhanced soil quality can help to reduce the onsite and offsite costs of soil erosion, improve water and nutrient use efficiencies, and ensure that the resource is sustained for future use. It also benefits water quality, air quality, and wildlife habitat.

How is soil quality evaluated?

Soil quality is evaluated separately for each individual soil using soil quality indicators that reflect changes in the capacity of the soil to function. Useful indicators are those that are sensitive to change, and change in response to management. The type and number of indicators used depends on the scale of the evaluation (i.e., field, farm, watershed, or region) and the soil functions of interest. For example, infiltration rate and aggregate stability help indicate the capacity of the soil to intake water and resist runoff and erosion. Changes in soil organic matter, including active organic carbon or particulate soil organic matter, may indicate changes in productivity. Increased bulk density may reflect limits to root growth, seedling emergence, and water infiltration. Measurements of indicators can be made with simple to somewhat complex field tests, or sophisticated laboratory analyses.

To evaluate soil quality, indicators can be assessed at one point in time or monitored over time to establish trends.

An **assessment** provides information about the current functional status or quality of the soil. The assessment must start with an understanding of the standard, baseline value, or reference value to be used for comparison. Assessments can be made to help identify areas where problems occur, to identify areas of special interest, or to compare fields under different management systems. Land managers can use this information, along with data from soil surveys, fertility tests, and other resource inventory and monitoring data, to make management decisions.

Monitoring of soil quality indicators over time identifies changes or trends in the functional status or quality of the soil. Monitoring can be used to determine the success of management practices or the need for additional management changes or adjustments.

What concerns relate to soil quality?

Evaluating soil quality can improve the response to many resource concerns, including those listed below. For further information, refer to other Soil Quality Information Sheets.

- Loss of soil by erosion
- Deposition of sediment by wind or floodwaters
- Compaction of layers near the surface
- Degradation of soil aggregates or soil structure
- Reduced infiltration and increased runoff
- Crusting of the soil surface
- Nutrient loss or imbalance
- Pesticide carryover
- Buildup of salts
- An unfavorable change in pH
- Loss of organic matter
- Reduced biological activity
- Poor residue breakdown
- Infestation by weeds or pathogens
- Excessive wetness
- Increased water-repellency of soils due to fire
- Reduced water quality
- Greenhouse gas emissions

The full series of Soil Quality Information Sheets is available at www.statlab.iastate.edu/survey/SQI.

This Sheet was prepared by the Soil Quality Institute in cooperation with the National Soil Survey Center, NRCS, USDA; and the National Soil Tilth Laboratory, Agricultural Research Service, USDA

Soil Quality Information Sheet

Indicators for Soil Quality Evaluation

USDA Natural Resources Conservation Service **April 1996**

What are indicators?

Soil quality indicators are physical, chemical, and biological properties, processes, and characteristics that can be measured to monitor changes in the soil.

The types of indicators that are the most useful depend on the function of soil for which soil quality is being evaluated. These functions include:
- providing a physical, chemical, and biological setting for living organisms;
- regulating and partitioning water flow, storing and cycling nutrients and other elements;
- supporting biological activity and diversity for plant and animal productivity;
- filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials; and
- providing mechanical support for living organisms and their structures.

Why are indicators important?

Soil quality indicators are important to:
- focus conservation efforts on maintaining and improving the condition of the soil;
- evaluate soil management practices and techniques;
- relate soil quality to that of other resources;
- collect the necessary information to determine trends;
- determine trends in the health of the Nation's soils;
- guide land manager decisions.

What are some indicators?

Indicators of soil quality can be categorized into four general groups: visual, physical, chemical, and biological.

Visual indicators may be obtained from observation or photographic interpretation. Exposure of subsoil, change in soil color, ephemeral gullies, ponding, runoff, plant response, weed species, blowing soil, and deposition are only a few examples of potential locally determined indicators. Visual evidence can be a clear indication that soil quality is threatened or changing.

Physical indicators are related to the arrangement of solid particles and pores. Examples include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile.

Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed for plant growth and development. The soil's chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants, and some physical conditions, such as the tendency for crust to form.

Biological indicators include measurements of micro- and macro-organisms, their activity, or byproducts. Earthworm, nematode, or termite populations have been suggested for use in some parts of the country. Respiration rate can be used to detect microbial activity, specifically microbial decomposition of organic matter in the soil. Ergosterol, a fungal byproduct, has been used to measure the activity of organisms that play an important role in the formation and stability of soil aggregates. Measurement of decomposition rates of plant residue in bags or measurements of weed seed numbers, or pathogen populations can also serve as biological indicators of soil quality.

How are indicators selected?

Soil quality is estimated by observing or measuring several different properties or processes. No single property can be used as an index of soil quality.

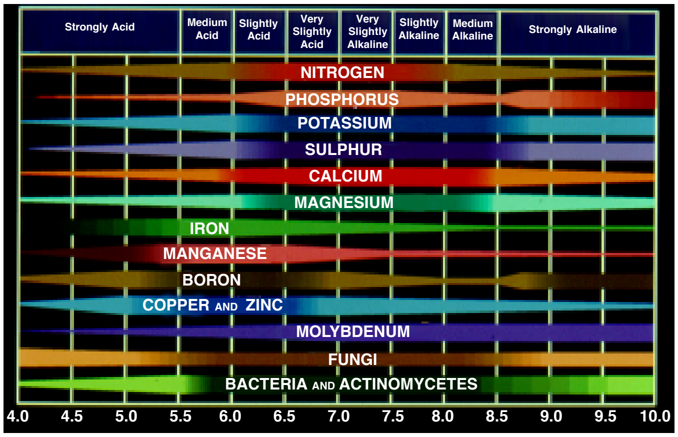
The selection of indicators should be based on:
- the land use;
- the relationship between an indicator and the soil function being assessed;
- the ease and reliability of the measurement;
- variation between sampling times and variation across the sampling area;
- the sensitivity of the measurement to changes in soil management;
- compatibility with routine sampling and monitoring;
- the skills required for use and interpretation.

When and where to measure?

The optimum time and location for observing or sampling soil quality indicators depends on the function for which the assessment is being made. The frequency of measurement also varies according to climate and land use.

Soil variation across a field, pasture, forest, or rangeland can greatly affect the choice of indicators. Depending on the function, such factors as the landscape unit, soil map unit, or crop growth stage may be critical. Wheel tracks can dramatically affect many properties measured for plant productivity. Management history and current inputs should also be recorded to ensure a valid interpretation of the information.

Monitoring soil quality should be directed primarily toward the detection of trend changes that are measurable over a 1- to 10-year period. The detected changes must be real, but at the same time they must change rapidly enough so that land managers can correct problems before undesired and perhaps irreversible loss of soil quality occurs.



Soil reaction influence on availability of plant nutrients.

What does the value mean?

Interpreting indicator measurements to separate soil quality trends from periodic or random changes is currently providing a major challenge for researchers and soil managers. Soils and their indicator values vary because of differences in parent material, climatic condition, topographic or landscape position, soil organisms, and type of vegetation. For example, cationexchange capacity may relate to organic matter, but it may also relate to the kind and amount of clay.

Establishing acceptable ranges, examining trends and rates of change over time, and including estimates of the variance associated with the measurements are important in interpreting indicators. Changes need to be evaluated as a group, with a change in any one indicator being evaluated only in relation to changes in others. Evaluations before and after, or with and without intervention, are also needed to develop appropriate and meaningful relationships for various kinds of soils and the functions that are expected of them.

The overall goal should be to maintain or improve soil quality without adversely affecting other resources.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Indicators: Aggregate Stability

USDA Natural Resources Conservation Service **April 1996**

What are soil aggregates?

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The space between the aggregates provide pore space for retention and exchange of air and water.

What is aggregate stability?

Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied.

Aggregate stability is not the same as *dry aggregate stability*, which is used for wind erosion prediction. The latter term is a size evaluation.

Why is aggregate stability important?

Aggregation affects erosion, movement of water, and plant root growth. Desirable aggregates are stable against rainfall and water movement. Aggregates that break down in water or fall apart when struck by raindrops release individual soil particles that can seal the soil surface and clog pores. This breakdown creates crusts that close pores and other pathways for water and air entry into a soil and also restrict emergence of seedlings from a soil.

Optimum conditions have a large range in pore size distribution. This includes large pores between the aggregates and smaller pores within the aggregates. The pore space between aggregates is essential for water and air entry and exchange. This pore space provides zones of weakness through which plant roots can grow. If the soil mass has a low bulk density or large pore spaces, aggregation is less important. For example, sandy soils have low aggregation, but roots and water can move readily.

How is aggregate stability measured?

Numerous methods measure aggregate stability. The standard method of the NRCS Soil Survey Laboratory can be used in a field office or in a simple laboratory. This procedure involves repeated agitation of the aggregates in distilled water.

An alternative procedure described here does not require weighing. The measurements are made on air-dry soil that has passed through a sieve with 2-millimeter mesh and retained by a sieve with a 1-millimeter mesh. A quantity of these 2-1 millimeter aggregates is placed in a small open container with a fine screen at the bottom. This container is placed in distilled water. After a period of time, the container is removed from the water and its contents are allowed to dry. The content is then removed and visually examined for the breakdown from the original aggregate size. Those materials that have the least change from the original aggregates have the greatest aggregate stability.

Soils that have a high percentage of silt often show lower aggregate stability if measured air-dry than the field behavior would suggest, because water entry destroys the aggregate structure.

What influences aggregate stability?

The stability of aggregates is affected by soil texture, the predominant type of clay, extractable iron, and extractable cations, the amount and type of organic matter present, and the type and size of the microbial population.

Some clays expand like an accordion as they absorb water. Expansion and contraction of clay particles can shift and crack the soil mass and create or break apart aggregates.

Calcium ions associated with clay generally promote aggregation, whereas sodium ions promote dispersion.

Soils with over about five percent iron oxides, expressed as elemental iron, tend to have greater aggregate stability.

Soils that have a high content of organic matter have greater aggregate stability. Additions of organic matter increase aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products or mycelia have formed.

Soil microorganisms produce many different kinds of organic compounds, some of which help to hold the aggregates together. The type and species of microorganisms are important. Fungal mycelial growth binds soil particles together more effectively than smaller organisms, such as bacteria.

Aggregate stability declines rapidly in soil planted to a clean-tilled crop. It increases while the soil is in sod and crops, such as alfalfa.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

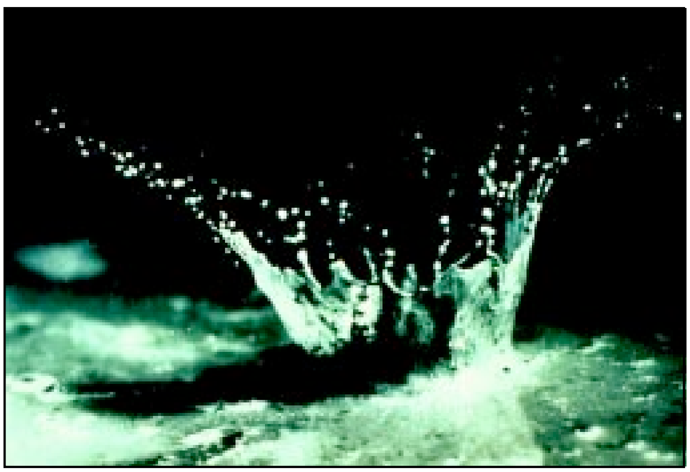
Soil Quality Information Sheet

Soil Quality Indicators: Infiltration

USDA Natural Resouces Conservation Service **January 1998**

What is Infiltration?

Infiltration is the process of water entering the soil. The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores.



Why is infiltration a concern?

Soil can be a excellent temporary storage medium for water, depending on the type and condition of the soil. Proper management of the soil can help maximize infiltration and capture as much water as allowed by a specific soil type.

If water infiltration is restricted or blocked, water does not enter the soil, and it either ponds on the surface or runs off the land. Thus, less water is stored in the soil profile for use by plants. Runoff can carry soil particles and surface applied fertilizers and pesticides off the field. These materials can end up in streams and lakes or in other places where they are not wanted.

Soils that have reduced infiltration have an increase in the overall amount of runoff water. This excess water can contribute to local and regional flooding of streams and rivers or results in accelerated soil erosion of fields or streambanks.

In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources.

Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions.

Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions which reduce biological activity and fertilizer use efficiencies.

What factors influence infiltration?

A number of factors impact soil infiltration. Some of these are:

- **Texture**: The type of soil (sandy, silty, clayey) can control the rate of infiltration. For example, a sandy surface soil normally has a higher infiltration rate than a clayey surface soil. A soil survey is a recorded map of soil types on the landscape.

- **Crust**: Soils that have many large surface connected pores have higher intake rates than soils that have few such pores. A crust on the soil surface can seal the pores and restrict the entry of water into the soil.

- **Compaction**: A compacted zone (plowpan) or an impervious layer close to the surface restricts the entry of water into the soil and tends to result in ponding on the surface.

- **Aggregation and Structure**: Soils that have stable strong aggregates as granular or blocky soil structure have a higher infiltration rate than soils that have weak, massive, or platelike structure. Soils that have a smaller structural size have higher infiltration rates than soils that have a larger structural size.

- **Water Content**: The content or amount of water in the soil affects the infiltration rate of the soil. The infiltration rate is generally higher when the soil is initially dry and decreases as the soil becomes wet. Pores and cracks are open in a dry soil, and many of them are filled in by water or swelled shut when the soil becomes wet. As they become wet, the infiltration rate slows to the rate of permeability of the most restrictive layer.

- **Frozen Surface**: A frozen soil greatly slows or completely prevents water entry.

- **Organic Matter**: An increased amount of plant material, dead or alive, generally assists the process of infiltration. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event.

- **Pores**: Continuous pores that are connected to the surface are excellent conduits for the entry of water into the soil. Discontinuous pores may retard the flow of water because of the entrapment of air bubbles. Organisms such as earthworms increase the amount of pores and also assists the process of aggregation that enhances water infiltration.

How can infiltration be increased?

A number of management options can help increase soil infiltration:

- Decrease compaction by reducing tillage and by avoiding the use of machinery when the soils are wet. Keep the number of trips across a field to a minimum and follow the same wheel tracks for all operations, if posssible.
- Decrease the formation of crusts by maintaining plant cover or by practicing residue management to reduce the impact of raindrops. Use a rotary hoe or row cultivator to shatter crust.
- Increase the amount of organic materials added to the soil to increase the stability of soil aggregates.
- Decrease or eliminate tillage operations to help maintain surface connected pores and encourage biological activity.

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(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Information Sheet

Soil Quality Indicators: Organic Matter

USDA Natural Resources Conservation Service **April 1996**

What is soil organic matter?

Soil organic matter is that fraction of the soil composed of anything that once lived. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Well-decomposed organic matter forms *humus*, a dark brown, porous, spongy material that has a pleasant, earthy smell. In most soils, the organic matter accounts for less than about 5% of the volume.

What does organic matter do?

Organic matter is an essential component of soils because it:

- provides a carbon and energy source for soil microbes;
- stabilizes and holds soil particles together, thus reducing the hazard of erosion;
- aids the growth of crops by improving the soil's ability to store and transmit air and water;
- stores and supplies such nutrients as nitrogen, phosphorus, and sulfur, which are needed for the growth of plants and soil organisms;
- retains nutrients by providing cation-exchange and anion-exchange capacities;
- maintains soil in an uncompacted condition with lower bulk density;
- makes soil more friable, less sticky, and easier to work;
- retains carbon from the atmosphere and other sources;
- reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants.

Soil organic matter also improves tilth in the surface horizons, reduces crusting, increases the rate of water infiltration, reduces runoff, and facilitates penetration of plant roots.

Where does it come from?

Plants produce organic compounds by using the energy of sunlight to combine carbon dioxide from the atmosphere with water from the soil. Soil organic matter is created by the cycling of these organic compounds in plants, animals, and microorganisms into the soil.

What happens to soil organic matter?

Soil organic matter can be lost through erosion. This process selectively detaches and transports particles on the soil surface that have the highest content of organic matter.

Soil organic matter is also utilized by soil microorganisms as energy and nutrients to support their own life processes. Some of the material is incorporated into the microbes, but most is released as carbon dioxide and water. Some nitrogen is released in gaseous form, but some is retained, along with most of the phosphorus and sulfur.

When soils are tilled, organic matter is decomposed faster because of changes in water, aeration, and temperature conditions. The amount of organic matter lost after clearing a wooded area or tilling native grassland varies according to the kind of soil, but most organic matter is lost within the first 10 years.

Rates of decomposition are very low at temperatures below 38 °F (4 °C) but rise steadily with increasing temperature to at least 102°F (40°C) and with water content until air becomes limiting. Losses are higher with aerobic decomposition (with oxygen) than with anaerobic decomposition (in excessively wet soils). Available nitrogen also promotes organic matter decomposition.

What controls the amount?

The amount of soil organic matter is controlled by a balance between additions of plant and animal materials and losses by decomposition. Both additions and losses are very strongly controlled by management activities.

The amount of water available for plant growth is the primary factor controlling the production of plant materials. Other major controls are air temperature and soil fertility. Salinity and chemical toxicities can also limit the production of plant biomass. Other controls are the intensity of sunlight, the content of carbon dioxide in the atmosphere, and relative humidity.

The proportion of the total plant biomass that reaches the soil as a source of organic matter depends largely on the amounts consumed by mammals and insects, destroyed by fire, or produced and harvested for human use.

Practices decreasing soil organic matter include those that:

1. Decrease the production of plant materials by
- replacing perennial vegetation with short-season vegetation,
- replacing mixed vegetation with monoculture crops,
- introducing more aggressive but less productive species,
- using cultivars with high harvest indices,
- increasing the use of bare fallow.

2. Decrease the supply of organic materials by
- burning forest, range, or crop residue,
- grazing,
- removing plant products.

3. Increase decomposition by
- tillage,
- drainage,
- fertilization (especially with nitrogen).

Practices increasing soil organic matter include those that:

1. Increase the production of plant materials by
- irrigation,
- fertilization to increase plant biomass production,
- use of cover crops
- improved vegetative stands,
- introduction of plants that produce more biomass,
- reforestation,
- restoration of grasslands.

2. Increase supply of organic materials by
- protecting from fire,
- using forage by grazing rather than by harvesting,
- controlling insects and rodents,
- applying animal manure or other carbon-rich wastes,
- applying plant materials from other areas.

3. Decrease decomposition by
- reducing or eliminating tillage,
- keeping the soil saturated with water (although this may cause other problems),
- keeping the soil cool with vegetative cover.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Animal waste photo courtesy University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources

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Soil Quality Information Sheet

Soil Quality Indicators: pH

USDA Natural Resources Conservation Service **January 1998**

What is pH?

Soil pH is a measure of the acidity or alkalinity in the soil. It is also called soil reaction.

The most common classes of soil pH are:

Extremely acid	3.5 – 4.4
Very strongly acid	4.5 – 5.0
Strongly acid	5.1 – 5.5
Moderately acid	5.6 – 6.0
Slightly acid	6.1 – 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0

What is the significance of pH?

Availability of Nutrients

Soil pH influences the solubility of nutrients. It also affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil. Soil pH thus affects the availability of several plant nutrients.

A pH range of 6 to 7 is generally most favorable for plant growth because most plant nutrients are readily available in this range. However, some plants have soil pH requirements above or below this range.

Soils that have a pH below 5.5 generally have a low availability of calcium, magnesium, and phosphorus. At these low pH's, the solubility of aluminum, iron, and boron is high; and low for molybdenum.

At pH 7.8 or more, calcium and magnesium are abundant. Molybdenum is also available if it is present in the soil minerals. High pH soils may have an inadequate availability of iron, manganese, copper, zinc, and especially of phosphorus and boron.

Micro-organisms

Soil pH affects many micro-organisms. The type and population densities change with pH. A pH of 6.6 to 7.3 is favorable for microbial activities that contribute to the availability of nitrogen, sulfur, and phosphorus in soils.

Pesticide Interaction

Most pesticides are labeled for specific soil conditions. If soils have a pH outside the allowed range, the pesticides may become ineffective, changed to an undesirable form, or may not degrade as expected, which results in problems for the next crop period.

Mobility of heavy metals

Many heavy metals become more water soluble under acid conditions and can move downward with water through the soil, and in some cases move to aquifers, surface streams, or lakes.

Corrosivity

Soil pH is one of several properties used as a general indicator of soil corrosivity. Generally, soils that are either highly alkaline or highly acid are likely to be corrosive to steel. Soils that have pH of 5.5 or lower are likely to be highly corrosive to concrete.

What controls soil pH?

The acidity or alkalinity in soils have several different sources. In natural systems, the pH is affected by the mineralogy, climate, and weathering. Management of soils often alters the natural pH because of acid-forming nitrogen fertilizers, or removal of bases (potassium, calcium, and magnesium). Soils that have sulfur-forming minerals can produce very acid soil conditions when they are exposed to air. These conditions often occur in tidal flats or near recent mining activity where the soil is drained.

The pH of a soil should always be tested before making management decisions that depend on the soil pH.

How is pH measured?

A variety of kits and devices are available to determine the pH in the field. The methods include:

- dyes
- paper strips
- glass electrodes.

Soil pH can change during the year. It depends on temperature and moisture conditions, and can vary to as much as a whole pH unit during the growing season. Since pH is a measure of the hydrogen ion activity $[H^+]$, many different chemical reactions can affect it. Temperature changes the chemical activity, so most measurements of pH include a temperature correction to a standard temperature of 25 degrees C (77°F). The soil pH generally is recorded as a range in values for the soil depth selected.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

How is soil pH modified?

A soil pH below about 5.6 is considered low for most crops. Generally, the ideal pH range is between 6.0 and 7.0. Liming is a common method to increase the pH. It involves adding finely ground limestone to the soil. The reaction rate for limestone increases when soil temperatures are warm and soil moisture is high. If the limestone is more finely ground, the reaction is faster.

The amount of limestone to apply depends on the amount of organic matter and clay as well as the pH. Fertility testing laboratories that have local experience make this determination.

A soil pH that is more than about 8.0 is considered high for most crops. Soils that have a pH in this range are often also calcareous.

Calcareous soils have a high content of calcium carbonate. The pH of these soils does not change until most of the calcium carbonate is removed. Acids that are added to the soil dissolve the carbonates and lower the soil pH. Treatments with acid generally are uneconomical for soils that have a content of calcium carbonate of more than about 5%. Because phosphorus, iron, copper, and zinc are less available to plants in calcareous soils, nutrient deficiencies are often apparent. Applications of these nutrients are commonly more efficient than trying to lower the pH.

When the soil pH is above 8.6, sodium often is present. These soils generally do not have gypsum or calcium carbonates, at least not in the affected soil horizons. Addition of gypsum followed by leaching using irrigation is a common reclamation practice. However, salts flushed into drainage water may contaminate downstream waters and soils.

The application of anhydrous ammonia as a nitrogen fertilizer contributes to lowering the soil pH. In some parts of the country, applications of ammonia lower the surface soil pH from ranges of 6.6 to 7.3 to below 5.6. This reduction can be easily overlooked in areas of no-till cropping unless the pH is measured in the upper 2 inches.

Chemical amendments that contain sulfur generally form an acid, which lowers the soil pH.

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Soil Quality Indicators: Soil Crusts

USDA Natural Resources Conservation Service **April 1996**

Soil crusts are relatively thin, somewhat continuous layers of the soil surface that often restrict water movement, air entry, and seedling emergence from the soil. They generally are less than 2 inches thick and are massive.

Crusts are created by the breakdown of structural units by flowing water, or raindrops, or through freeze-thaw action. Soil crusts are generally only a temporary condition. Typically, the soil immediately below the surface layer is loose.

Why are soil crusts a concern?

Crusts reduce infiltration and increase runoff. Rainfall and sprinkler irrigation water impart a large amount of impact energy onto the soil surface. If the soil is not protected by a cover of growing plants, crop residue or other material, and if soil aggregates are weak, the energy can cause a soil crust to form.

If a crust forms, individual soil particles fill the pore space near the surface and prevent the water from entering (infiltrating) the soil. If the infiltration is limited, water accumulates and flows down slope, causing movement of soil particles. Thus water erosion is initiated.

Crusts restrict seedling emergence. The physical emergence of seedlings through a soil crust depends on the:

- thickness of the crust,
- strength of the crust,
- size of the broken crust pieces,
- water content, and
- type of plant species. Non-grass plant species, such as soybeans or alfalfa, exert less pressure under identical conditions than grasses such as corn.

Crusts reduce oxygen diffusion to seedlings. Seed germination depends on the diffusion of oxygen from the air through the soil. If soil crusts are wet, oxygen diffusion is reduced as much as 50 percent.

Crusts reduce surface water evaporation. The reflectance of a crusted surface is higher than that for an uncrusted surface. Higher reflectance results in less absorption of energy from the sun. This results in a cooler soil surface and decreases the rate of evaporation.

Crusts decrease water loss because less of their surface area is exposed to the air than a tilled soil. When crusts become dry, they become barriers to evaporation by retarding capillary movement of water to the soil surface.

Crusts affect wind erosion. Crusts increase wind erosion in those soils that have an appreciable amount of sand. Rainfall produces clean sand grains that are not attached to the soil surface. These clean sand grains are subject to movement by air along the smooth surface of the crust. The sand breaks down the crust as it moves across the soil surface. Cultivation to break the crust and increase the surface roughness reduces wind erosion on sandy soils.

For soils that have a small amount of sand, crusts protect the soil surface and generally decrease the hazard of wind erosion.

How do crusts form?

Soil crusts and associated cracks form by raindrop impact or freeze-thaw processes.

Raindrop impact breaks soil aggregates, moves clay downward a short distance leaving a concentration of sand and silt particles on the soil surface.

Raindrop-impact crusts break down to a granular condition in many soils that have a high shrink-swell potential and experience frequent wetting and drying cycles.

Freeze-thaw crusts are formed by the puddling effect as ice forms, melts, and reforms. The temperature and water regimes and parent material control freeze-thaw crust formation. These crusts are generally 3/8- to 5/8-inch thick, compared to 1/4-inch commonly for raindrop-impact crusts.

The size and behavior on wetting of cracks associated with raindrop-impact and freeze-thaw crust differ. Both extend to the base of the crust. The cracks in raindrop-impact crust are 1/4 inch wide. They close on wetting and hence are ineffective in increasing infiltration. The cracks in freeze-thaw crust are 1/4- to 3/4-inch wide. They do not close on wetting and hence increase infiltration.

How are soil crusts measured?

Soil crusts are characterized by their thickness and strength (air dry rupture resistance). Crust air dry rupture resistance can be measured by taking a dry piece about 1/2 inch on edge and applying a force on the edge until the crust breaks. In general, more force is required for crusts that are thick and have a high clay content. Other means of measurement, such as a penetrometer, may be used.

How can the problem be corrected?

- Maintain plant cover or crop residues on the soil surface to reduce the impact of raindrops.

- Adopt management practices that increase aggregate stability.

- Use practices that increase soil organic matter content or reduce concentrations of sodium ions.

- Use a rotary hoe or row cultivator to shatter crusts and thus increase seedling emergence and weed control.

- Employ sprinkler water to reduce restriction of seedling emergence.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Soil crust photo courtesy of University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources.

Soil Quality Information Sheet

Soil Quality Resource Concerns:

Available Water Capacity

USDA Natural Resources Conservation Service **January 1998**

What is available water capacity?

Available water capacity is the amount of water that a soil can store that is available for use by plants.

It is the water held between field capacity and the wilting point adjusted downward for rock fragments and for salts in solution. Field capacity is the water retained in a freely drained soil about 2 days after thorough wetting. The wilting point is the water content at which sunflower seedlings wilt irreversibly.

Why be concerned?

In areas where drizzle falls daily and supplies the soils with as much or more water than is removed by plants, available water capacity is of little importance. In areas where plants remove more water than the amount supplied by precipitation, the amount of available water that the soil can supply may be critical. This water is necessary to sustain the plants between rainfall events or periods of irrigation. The soil effectively buffers the plant root environment against periods of water deficit.

How is available water expressed?

Available water is expressed as a volume fraction (0.20), as a percentage (20%), or as an amount (in inches). An example of a volume fraction is water in inches per inch of soil. If a soil has an available water fraction of 0.20, a 10 inch zone then contains 2 inches of available water.

Available water capacity is often stated for a common depth of rooting (where 80 percent of the roots occur). This depth is at 60 inches or more in areas of the western United States that are irrigated and at 40 inches in the higher rainfall areas of the eastern United States. Some publications use classes of available water capacity. These classes are specific to the area in which they are used. Classes use such terms as very high, high, medium, and low.

Soil properties affect available water

Rock fragments reduce the available water capacity in direct proportion to their volume unless the rocks are porous.

Organic matter increases the available water capacity. Each 1 percent of organic matter adds about 1.5 percent to available water capacity.

Bulk density plays a role through its control of the pore space that retains available water. High bulk densities for for agiven soil tend to lower the available water capacity.

Osmotic pressure exerted by the soil solution is 0.3 - 0.4 times the electrical conductivity in mmhos/cm. A significant reduction in available water capacity requires an electrical conductivity of more than 8 mmhos/cm.

Texture has a significant effect. Some guidelines follow, assuming intermediate bulk density and no rock fragments.

Textures	Fraction Available Water
Sands, and loamy sands and sandy loams in which the sand is not dominated by very fine sand	Less than 0.10
Loamy sands and sandy loams in which very fine sand is the dominant sand fraction, and loams, clay loam, sandy clay loam, and sandy clay	0.10 - 0.15
Silty clay, and clay	0.10 - 0.20
Silt, silt loam, and silty clay loam	0.15 - 0.25

The **rooting depth** affects the total available water capacity in the soil. A soil that has a root barrier at 20 inches and an available water fraction of 0.20 has 4 inches of available water capacity. Another soil, that has a lower available water fraction of 0.10, would, if the roots extended to a depth of 60 inches, have 6 inches of available water capacity. For shallow rooting crops, like onions, the available water below 1-2 feet has little significance. For deeper rooting crops, like corn, the available water at the greater depth is very important.

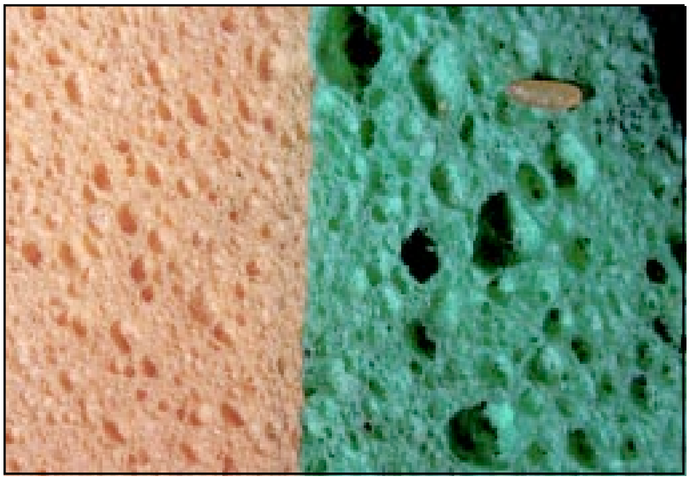

Figure 1: Pore size varies greatly between sponges.

Soil quality and available water

First, consider the difference between precipitation and evapotranspiration during the growing season. Second, decide what plants are involved. As indicated, some plants root less deeply than others.

Compare two soils that have different internal properties and climates selecting a crop that will extract water to a depth of 60 inches, unless there is a shallower root barrier.

Quantity		Soil Locations OK	ME
Rooting depth (in.)		30	60
Available water fraction	x	0.10	0.15
Available water amount (in.)	=	3.0	9.0
Evapotranspiration deficit (in./day)	÷	0.17	0.04
Time available water satisfies deficit (days)	=	18	222

* Evapotranspiration deficit is the monthly precipitation subtracted from monthly evapotranspiration. Calculate the average daily deficit for the month with the largest deficit.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil quality with respect to available water is better for the soil from Maine (ME), because of both the internal properties and the lower evapotranspiration deficit.

Figure 2: Available water capacity is greater with small pore size.

Improving the available water

Apply organic matter to the surface or mix into the upper few inches to increase the available water fraction near the surface. Available water near the surface is especially important at the seedling stage while roots are very shallow.

Maintain salts below the root zone. Keep infiltration high, reduce evaporation with a residue cover, minimize tillage, avoid mixing the lower soil layers with the surface, and plant seeds and seedlings on the furrow edges.

Minimize compaction by reducing the weight of vehicles and the amount of traffic, especially when the soil is moist or wet. Break up compacted layers when needed by ripping, and effectively expand the depth of the soil and increase the available water capacity.

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Soil Quality Resource Concerns: Soil Erosion

USDA Natural Resources Conservation Service **April 1996**

What is erosion?

Wind or water erosion is the physical wearing of the earth's surface. Surface soil material is removed in the process.

Why should we be concerned?

Erosion removes topsoil, reduces levels of soil organic matter, and contributes to the breakdown of soil structure. This creates a less favorable environment for plant growth.

In soils that have restrictions to root growth, erosion decreases rooting depth, which decreases the amount of water, air, and nutrients available to plants.

Erosion removes surface soil, which often has the highest biological activity and greatest amount of soil organic matter. This causes a loss in nutrients and often creates a less favorable environment for plant growth.

Nutrients removed by erosion are no longer available to support plant growth onsite, but can accumulate in water where such problems as algal blooms and lake eutrophication may occur.

Deposition of eroded materials can obstruct roadways and fill drainage channels. Sediment can damage fish habitat and degrade water quality in streams, rivers, and lakes.

Blowing dust can affect human health and create public safety hazards.

What are some signs of erosion?

Wind erosion:

- dust clouds,
- soil accumulation along fencelines or snowbanks,
- a drifted appearance of the soil surface.

Water erosion:

- small rills and channels on the soil surface,
- soil deposited at the base of slopes,
- sediment in streams, lakes, and reservoirs,
- pedestals of soil supporting pebbles and plant material.

Water erosion is most obvious on steep, convex landscape positions. However, erosion is not always readily visible on cropland because farming operations may cover up its signs. Loss of only 1/32 of an inch can represent a 5 ton per acre soil loss.

Long-term soil erosion results in:

- persistent and large gullies,
- exposure of lighter colored subsoil at the surface,
- poorer plant growth.

How can soil erosion be measured?

Visual, physical, chemical, and biological indicators can be used to estimate soil surface stability or loss.

Visual indicators

- comparisons of aerial photographs taken over time,
- presence of moss and algae (crypotogams) crusts in desert or arid soils,
- changes in soil horizon thickness,
- deposition of soil at field boundaries.

Physical indicators

- measurements of aggregate stability,
- increasing depth of channels and gullies.

Chemical indicators

- decreases in soil organic matter content,
- increases in calcium carbonate content at the surface, provided greater content exists in subsurface layers,
- changes in cation-exchange capacity (CEC).

Biological indicators

- decreased microbial biomass,
- lower rate of respiration,
- slower decomposition of plant residues.

What causes the problem?

Water erosion

- lack of protection against raindrop impact,
- decreased aggregate stability,
- long and steep slopes,
- intense rainfall or irrigation events when plant or residue cover is at a minimum,
- decreased infiltration by compaction or other means.

Mechanical erosion

- removal by harvest of root crops,
- tillage and cultivation practices that move soil downslope.

Wind erosion

- exposed surface soil during critical periods of the year,
- occurrence of wind velocities that are sufficient to lift individual soil particles,
- long, unsheltered, smooth soil surfaces.

How can soil erosion be avoided?

Soil erosion can be avoided by:

- maintaining a protective cover on the soil,
- creating a barrier to the erosive agent,
- modifying the landscape to control runoff amounts and rates.

Specific practices to avoid water erosion:

- growing forage crops in rotation or as permanent cover,
- growing winter cover crops
- interseeding,
- protecting the surface with crop residue,
- shortening the length and steepness of slopes,
- increasing water infiltration rates,
- improving aggregate stability.

Specific practices to avoid wind erosion:

- maintaining a cover of plants or residue,
- planting shelterbelts,
- stripcropping,
- increase surface roughness,
- cultivating on the contour,
- maintaining soil aggregates at a size less likely to be carried by wind.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

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Agricultural Management Effects on Earthworm Populations

Introduction: Earthworm habits and their effects on soil

Many people consider earthworms to be an indicator of soil quality because they respond to and contribute to healthy soil. For earthworms to be abundant, a field must meet several conditions that are also associated with soil quality and agricultural sustainability: moderate pH, surface residue for food and protection, and soil that is not waterlogged, compacted, droughty, or excessively sandy. Not all healthy soils will have earthworms. Worms are not common in sandy soils, in drier regions of the southern and western United States, and in local areas where earthworms have not yet migrated or been introduced by human activities.

Earthworm species vary in how they get food, and thus inhabit different parts of the soil, and have somewhat different effects on the soil environment. They fall into three distinct ecological groups based on feeding and burrowing habits. Epigeic (litter dwelling) earthworms live and feed in surface litter. They move horizontally through leaf litter or compost with little ingestion of or burrowing into the soil. These worms are characteristically small and are not found in low organic matter soils. *Lumbricus rubellus* is an example of epigeic species. Endogeic (shallow dwelling) earthworms are active in mineral topsoil layers and associated organic matter. They create a three-dimensional maze of burrows while consuming large quantities of soil. The genuses *Diplocardia* and *Aporrectodea* have endogeic life habits. Anecic (deep burrowing) earthworms live in permanent, nearly vertical burrows that may extend several feet into the soil. They feed on surface residues and pull them into their burrows. *Lumbricus terrestris* is an example of an anecic species (Coleman and Crossley, 1996). Once established, earthworms contribute to soil function. They:

- Shred residues, stimulating microbial decomposition and nutrient release;
- Produce casts rich in N, P, K, and other nutrients;
- Improve soil stability, air porosity and moisture holding capacity by burrowing and aggregating soil;
- Turn soil over and may reduce the incidence of disease by bringing deeper soil to the surface and burying organic matter;
- Improve water infiltration by forming channels and promoting soil aggregation; and
- Improve root growth by creating channels lined with nutrients for plant roots to follow.

Technical
Note No. 11

June 2001

This is the eleventh note in a series of Soil Quality-Agronomy technical notes on the effects of land management on soil quality.

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Both endogeic and anecic species are important in contributing to these functions in agricultural systems. The shallow dwellers improve topsoil porosity and the deep burrowing earthworms improve infiltration and drainage.

Earthworms may have undesirable impacts if they remove too much surface residue and leave the soil surface unprotected, or if their burrows open into surface irrigation furrows. There is also some concern that earthworms may enhance the "preferential flow" of herbicides and other pollutants down burrows and into groundwater, causing water to pass too rapidly through the soil matrix. When their total effect is considered, however, earthworms are unlikely to have a significant negative impact on water quality. Where they are active, earthworms may bury herbicide-tainted residue before it has a chance to leach down through burrows. Earthworms may act as plugs in their own burrows, and, in the case of the herbicide atrazine, earthworm-feeding activity may actually change the chemical to reduce its mobility (Farenhorst et al., 2000). In addition, earthworm activity improves soil structure and therefore reduces runoff of chemicals into surface water. Another concern is that fresh earthworm casts on the surface are unstable and may lead to higher soil erosion and nutrients in runoff. Earthworm casts stabilize as they age so that the risk of erosion is greatly reduced. In summary, earthworms affect soil function in multiple ways. In specific situations they may have undesirable effects, but predominately they contribute to improved soil quality and are a sign of a healthy, properly functioning soil.

What determines earthworm abundance?

The number of earthworms in an agricultural field is influenced by the intensity and number of soil disturbance events like tillage and traffic, the abundance and quality of food sources, the chemical environment of the soil, and the soil microclimate. Important factors of the soil environment include:

- *Organic matter (food sources)* – Higher inputs of fresh organic matter are associated with greater earthworm populations.
- *Soil type* – Populations are highest in medium textured soil.
- *Depth to a restrictive layer* – Earthworms prefer deeper soil.
- *Soil pH* – In general, earthworms will not thrive in a soil with a pH below 5 (Edwards and Lofty, 1977).
- *Moisture holding capacity and internal drainage* – Earthworms need moist but well-aerated soil.
- *Rainfall and temperature* – Climate affects the soil environment and food sources (plant biomass) for earthworms.
- *Predation and parasitism*.
- *Earthworm introduction* – Even where environmental factors are favorable, earthworms may not have migrated and established populations.

When all other factors are equal, the availability of plant litter and organic matter is usually the most important in determining earthworm abundance, but any of the other factors may override the influence of organic matter.

Many management practices affect earthworm populations because they change one or more of the environmental factors listed above. This technical note will examine the effects of six components of management: (1) tillage, (2) crop rotations and cover crops, (3) fertilizers, (4) pesticides, (5) irrigation and drainage, and (6) worm seeding (inoculation).

Tillage

As the number and intensity of tillage operations increase, so does the physical destruction of burrows, cocoons, and the earthworm bodies themselves. Less intensive tillage systems that leave residues on the surface throughout the year improve the environment for earthworms. The residues provide food, insulate earthworms from weather conditions, provide cover to protect them from birds and other surface predators, and protect their burrows. Decreased tillage disturbances particularly benefit night crawlers (*L. terrestris*), which move in the same burrow between deeper soil layers and the soil surface in search of food. When tillage destroys the burrow, some earthworms will not have the energy reserve to form a new burrow to their food source. Endogeic (shallow dwelling) earthworms will tolerate annual tillage because they continually form new burrows and acquire a greater proportion of their food from the soil rather than surface litter. No-till and other methods of conservation tillage such as chisel plowing and ridge tillage can increase populations of both types of earthworms (Edwards and Bohlen, 1996) (Table 1).

Although a single tillage event will not drastically reduce earthworm populations, repeated tillage over time will cause a decline in earthworm populations.

Research has found the following:

- Earthworms were reduced by 70% compared to previously undisturbed sod after five years of plowing (Edwards and Bohlen, 1996).
- After 25 years of conventional tillage crop production earthworm populations were only 11-16% of what existed in the original grass field (Edwards and Bohlen, 1996).
- Edwards et al. (1995) reported up to 30 times more earthworms in no-till systems compared to plowed fields.
- In Nigeria, researchers found 2400 earthworm casts/m^2 in no-till plots compared to 100 casts/m^2 under conventional tillage (Edwards and Lofty, 1977).
- In a Georgia experiment, no-till fields had an average of 967 earthworms/m2 compared to 149 /m2 in conventionally tilled fields (Coleman and Crossley, 1996).

Table 1. Earthworm Populations (No./yd^2) as influenced by amount of surface residues at Langdon Research and Extension Center, ND (Deibert and Utter, 1994).

	40 - 45% Residue	80 – 90% Residue
Earthworms	71	106
Cocoons	204	514
Total	275	620

Crop Rotations and Cover Crops

Tillage affects decomposition and availability of surface residue, while choice of crop determines the quantity and quality of the residue as a food source for earthworms. Earthworm populations will decrease to very low numbers under an exhaustive cropping system of plowing, crop residue removal, and no additions of manure or other organic inputs.

There is a strong correlation between earthworm numbers and the amount and quality of residue returned to the soil. (Table 3.) Generally, cereal crops such as wheat (especially if straw is returned to the soil) encourage earthworms more than crops which leave less residue such as soybean. Studies in the 1940's showed the following ranking in order of earthworm population (all are conventionally tilled cropping systems): pasture = small grains followed with legume hay grown in the summer > small grains with summer fallow > drilled soybeans for grain > soybeans for hay > corn (Hopp and Hopkins, 1946). At the Rothamsted Experimental Station in England where crops have been studied since 1843, the largest earthworm populations occur under continuous cereals, were lower under root crops such as turnip, and were the lowest under fallow (Edwards and Bohlen, 1996).

Despite its high residue production, continuous corn supports fewer earthworms than when in rotation with soybeans, whether under no-till or conventional tillage. Earthworms seem to prefer legumes (Table 2). Although probably less important, other factors that may discourage earthworms in corn could be soil application of insecticides to control rootworms and anhydrous ammonia fertilizer (Kladivko, 1993).

Crop rotations with pasture or hay greatly increase earthworm numbers. There is a strong correlation between earthworm numbers and years in grass and legumes. For example, a crop every third year in grass rotations will have greater earthworm numbers than a crop every two years or annual cropping. Dick Thompson (Boone, Iowa) followed a 6-year rotation of corn, soybeans, oats, and 3 years of pasture (alfalfa, red clover, grasses, and other forages). He reduced tillage and used livestock manure. Researchers from the Agricultural Research Service National Soil Tilth Laboratory (Ames, Iowa) found more earthworms in Thompson's fields compared to an adjacent neighbor's conventionally tilled field in corn-soybean rotation (Ernst, 1995). The larger earthworm populations were attributed to more food from grass-legume hay crops, manure, and reduced tillage.

Alfalfa and clover in rotations benefit earthworm numbers because of the absence of tillage and the high protein content in their residues. Rotations with alfalfa and grass contain more earthworms than lespedeza and grass, and orchard grass contains more earthworm numbers than timothy grass alone (Hopp and Hopkins, 1946).

Using cover crops helps to increase earthworm populations by increasing their food supply (organic residue) and by giving them a longer season to eat and reproduce. Cover crops insulate worms from cold weather in the fall and from warm weather in southern climates. The extra food and ground cover provided by cover crops are especially important where earthworms are removing a high percentage of crop residue. University of Wisconsin has reported residue cover being reduced from 30% to 15% by earthworms at planting time in no-till fields (Ernst, 1995).

Table 2. Earthworm populations (No./yd^2) under different no-till rotations at Brecker Farm, Havana, ND (Deibert and Utter, 1994).

	Wheat-Corn	Corn-Soybeans	Wheat-Soybeans
Earthworms	257	346	443
Cocoons	27	71	35
Total	284	417	478

Table 3. Earthworm populations affected by crop and tillage (Kladivko, 1993).

Crop	Management	Earthworms/m^2
Continuous corn	Plow	10
Continuous corn	No-till	20
Continuous soybean	Plow	60
Continuous soybean	No-till	140
Bluegrass-Clover	Alleyway	400
Dairy pasture	Manure	340
Dairy pasture	Heavy manure	1300

Fertilizers

Nearly all organic fertilizers benefit earthworms. The addition of animal manure, sewage wastes, and spent malt from breweries, paper pulp, or potato processing waste all showed a positive effect on earthworm numbers (Edwards et al., 1995). Additions of organic material can double or triple earthworm numbers in a single year. The ammonia and salt content of some liquid manure can have an adverse effect on earthworms, but populations usually recover quickly and henceforth increase (Edwards and Bohlen, 1996).

Normally, the use of inorganic fertilizers also has a positive impact on earthworm numbers. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues (Edwards and Bohlen, 1996; Edwards et al., 1995). Hendrix et al. (1992) reported that earthworm numbers in meadows receiving inorganic fertilizer averaged nearly twice the earthworms in unfertilized meadows on the Georgia piedmont.

Ammonia and ammonia-based fertilizers can adversely affect earthworms. Annual use of ammonium sulfate, anhydrous ammonia, and sulfur-coated urea has been shown to decrease earthworm populations (Edwards et al., 1995). Research at Park Grass (Rothamsted) since 1856 showed that after extremely long exposure to several levels of ammonium sulfate (0, 48, 97, and 145 kg/ha), the populations of earthworms were inversely proportional to the dose of nitrogen applied (Edwards and Lofty, 1977). This is probably due to the effect these fertilizers have on lowering soil pH. Direct exposure to anhydrous ammonia during application will kill up to 10% of the population. However, farmers report increased numbers in the long run due to higher yields and more food for earthworms to feed upon (Ernst, 1995). Still, some farmers have switched from anhydrous ammonia to 28% nitrogen to avoid killing earthworms during nitrogen application. Others have converted to using manures in order to protect and increase earthworms (Ernst, 1995).

Lime seems to benefit earthworm populations in otherwise acid soils because most species of earthworms favor neutral pH levels and require calcium for growth. Lime may indirectly benefit earthworms by increasing plant growth and therefore plant residues. A study in New Zealand showed a 50% increase in surface feeding earthworm species by adding one ton of lime per acre (Edwards et al., 1995).

Pesticides

In general, most herbicides are harmless to earthworms. The triazine class of herbicides has a moderate impact on earthworm numbers. Herbicides used prior to World War II, including lead arsenate and copper sulfate, are moderately toxic to earthworms. The main threat of toxicity to earthworms is from long-term buildup of these compounds in the soil (Edwards and Bohlen, 1996).

The majority of the carbamate class of insecticides are toxic to earthworms. The toxic effects of carbofuran (Furadan) have been studied extensively. Other insecticides in the carbamate class that have proved highly toxic to earthworms are aldicarb (Temik), aminocarb, bufencarb, carbaryl (Sevin), methiocarb (Measural), methomyl (Lannate), oxamyl (Vydate), promecarb, propoxur (Baygon), and thiofanox. Generally, insecticides in the organophosphate class are less toxic to earthworms. However, organophosphate insecticides that are extremely or highly toxic are phorate (Thimet), chloropyrifos (Dursban, Equity, Tenure, etc.), ethoprophos (Mocap), ethyl-parathion, and isazophos. Aromatic organochlorine insecticides (used predominantly in the 1950's-1970's) are generally not very toxic. Exceptions are chlordane, endrin, heptachlor, and izobenzan. Carbamate fungicides (carbendazim and benomyl) have shown toxic effects to earthworms. Other broad-spectrum fumigants (fungicides and nematicides) are very toxic to earthworms. (Ernst, 1995; Edwards and Bohlen, 1996.)

Irrigation and Drainage

Irrigated soil can support high levels of earthworm activity where moisture levels would otherwise be too dry. Irrigation also increases crop production, resulting in more food and increased earthworm populations. Irrigation waters that carry earthworms and their cocoons may act as a source of inoculum for certain species (Edwards et al., 1995). Draining poorly drained soils will potentially provide a more favorable environment for earthworm activity by aerating the soil.

Seeding Worms

Shallow dwelling earthworms are generally present in agricultural fields, so their populations dramatically increase within one to two years of switching to earthworm friendly practices. However, the deep dwelling night crawlers take longer to increase. Even when favorable conditions have been established, night crawlers must move into unoccupied areas by slow overland migration. Night crawlers are also slow to breed. If left to their own devices, it may take seven to eight years, or longer, for populations to grow (Ernst, 1995).

Seeding earthworms or their eggs may be an option to increase populations in favorable environments. Although some soils, such as extremely coarse sands or heavy clays with a high water table, will not support night crawlers due to inherently adverse soil properties. If a farmer wants to try seeding night crawlers, it is recommended to begin with a low cost, small-scale trial to be sure they survive at a particular site (Kladivko, 1993). Farmers in Indiana and Illinois have seeded 10,000 – 100,000 night crawlers to their farms at a cost of four to five cents per worm from local bait shops and Canadian sources (Ernst, 1995). If seeding is an option, drop 4-5 under mulch every 30-40 feet, preferably on a cloudy wet cool day. In one case, a farmer used an earth auger attached to a cordless drill and put a handful of worms per hole every 30 feet (Ernst, 1995). Even with seeding, however, populations will still take five years or more to grow significantly, if they survive at all (Kladivko, personal communication.)

The Netherlands has reported the addition of earthworms on once flooded soils that have been drained (polder soils). Natural earthworm densities have increased over 26 years following reclamation. However, much higher population densities have been found where earthworms were seeded (Edwards and Bohlen, 1996).

Summary

Earthworms benefit soil quality by shredding residues stimulating microbial decomposition, improving soil fertility, and improving soil physical properties such as soil aggregation and infiltration. Food availability is the major factor limiting earthworm numbers. Producing food through crop residues and cover crops and leaving them on the soil surface through the use of conservation tillage practices provides food to increase earthworm numbers. Generally, fertilizers increase earthworm numbers by increasing crop residues, especially when pH is maintained near neutral. Herbicides are generally harmless to earthworms. However, some insecticides, nematicides, fungicides are very toxic to earthworms. In some situations, earthworm inoculation may be desirable to introduce certain species to an area once earthworm friendly practices are in place.

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