Title

Teaching Organic Farming and Gardening: Resources for Instructors, 3rd Edition. Part 2 - Applied Soil Science

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PART 2

Applied Soil Science

2.1

Soils and Soil Physical Properties

Introduction: Soils & Soil Physical Properties

UNIT OVERVIEW

This unit introduces students to the components of soil and soil physical properties, and how each affects soil use and management in farms and gardens.

In two lectures. students will learn about soil-forming factors, the components of soil, and the way that soils are classified. Soil physical properties are then addressed, including texture, structure, organic matter, and permeability, with special attention to those properties that affect farming and gardening.

Through a series of demonstrations and hands-on exercises, students are taught how to determine soil texture by feel and are given the opportunity to examine other soil physical properties such as soil structure, color, depth, and pH. The demonstrations offer an opportunity to discuss how the observed soil properties might affect the use of the soil for farming and gardening.

MODES OF INSTRUCTION

> LECTURES (2 LECTURES, 1.5 HOURS EACH)

Lecture 1 introduces students to the formation, classification, and components of soil.

Lecture 2 addresses different concepts of soil and soil physical properties, with special attention to those properties that affect farming and gardening.

> DEMONSTRATION 1: SOIL TEXTURE DETERMINATION (1 HOUR)

Demonstration 1 teaches students how to determine soil texture by feel. Samples of many different soil textures are used to help them practice.

> DEMONSTRATION 2: SOIL PIT EXAMINATION (1 HOUR)

In Demonstration 2, students examine soil properties such as soil horizons, texture, structure, color, depth, and pH in a large soil pit. Students and the instructor discuss how the soil properties observed affect the use of the soil for farming, gardening, and other purposes.

> SUPPLEMENTAL DEMONSTRATIONS AND EXAMPLES (1 HOUR)

These simple demonstrations offer ideas for using objects, samples, or models to illustrate by way of analogy various soil physical properties.

> ASSESSMENT QUESTIONS (1 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- Soil formation
- Components of soil
- Soil physical properties: What are they?
- Factors that affect soil development and physical properties
- How soil physical properties affect their use for farming and gardening

SKILLS

- How to determine soil texture
- How to recognize different types of soil structure

REQUIRED READINGS (SEE RESOURCES SECTION)

Gershuny, Grace. 1993. *Start With the Soil,* Chapter 1; Chapter 2, pp. 27–38; Chapter 8, pp. 187–195; Chapter 9, pp. 200–205

Brady, Nyle C., and Ray R. Weil. 2008. *The Nature and Properties of Soils.* Chapter 1, 1.1–1.14

RECOMMENDED READINGS

Stell, Elizabeth P. 1998. *Secrets to Great Soil,* Chapter 1.

Lecture 1: Soils—An Introduction

Pre-Assessment Questions

1. What are some of the functions that soil serves?
2. What are some of the factors involved in soil formation?
3. What are the components that make up soil?

A. Introduction

1. What is soil?
   a) Definitions
      i. Different concepts = different definitions. How soil is defined depends on who is using the word.
         - Edaphological (in relation to plant growth)
           A mixture of mineral and organic material that is capable of supporting plant life
         - Engineering (in relation to supporting structures)
           Mixture of mineral material (sands, gravels, and fines [very small particles]) used as a base for construction
         - Pedological (looking at soil as a distinct entity)
           The unconsolidated mineral or organic material on the surface of the earth arising from a particular parent material that has been subjected to and shows the effects of climate macro- and microorganisms, the topography of its location in the landscape, and time. It is at the Geosphere-Biosphere-Hydrosphere-Atmosphere interface.
   b) Functions of soil
      i. Supports growth of higher plants
      ii. Primary factor controlling fate of water in hydrologic systems
      iii. Nature's recycling system for nutrients
      iv. Habitat for organisms
      v. Engineering medium

B. How Soil Is Made

1. Soil-forming factors

   At one time, people thought that soils were static. In the late 1800s, Russian soil scientists introduced the concept that soils are dynamic—that any one soil developed into the soil it is now and that it continues to evolve. The scientists came up with five soil-forming factors that influence how soils turn out the way they do. The idea is that if all five of the soil-forming factors are the same, then the soil will be the same. The technical term for soil formation is pedogenesis. The five soil-forming factors are:
   a) Climate: Temperature, precipitation, and how they are distributed across the seasons
   b) Biotic factors: Plants, animals, fungi, bacteria, and other microorganisms
   c) Topography: Slope position, aspect, and shape
   d) Parent material: Rock, alluvium (wind- or water-deposited material)
   e) Time: How long the soil has been forming

2. Weathering: The five factors above affect weathering, the breakdown of rock into smaller and smaller pieces. Two types of weathering are recognized: chemical and mechanical (physical).
   a) Mechanical weathering is the breakdown of rock due to physical factors such as temperature fluctuations and freeze/thaw cycles of water. An example would be quartz breaking down to fine sand-sized particles (since quartz is resistant to chemical weathering, it doesn't get much smaller than this).
   b) Chemical weathering refers to the breakdown of rock due to chemical reactions. For example, limestone ($CaCO_3$) and gypsum ($CaSO_4$) dissolve in water and become smaller and smaller compounds. Micas can lose potassium ions and become vermiculite. Vermiculite, in turn, can lose more potassium and become smectite. Feldspars lose potassium and become kaolinite. In these cases, rock weathers to a microscopic or even elemental state.

TABLE 2.1 | THE 12 MOST COMMON ELEMENTS IN THE EARTH'S CRUST

ELEMENT	% VOLUME	% WEIGHT
O^{2-}	90	47
Si^{4+}	2	27
Al^{3+}	1	7
Fe^{2+}	1	4
Mg^{2+}	1	2
Ca^{2+}	1	3
Na^{+}	1	2
K^{2+}	1	2
Ti^{4+}	trace	3
H^{+}	trace	1
Mn^{4+}	trace	1
$P5^{+}$	trace	1

C. Soil Profiles and Soil Development

1. Soil horizons

   Soils consist of one or more distinct layers called horizons. These layers are referred to as O, A, E, B, C and R depending on their position and nature

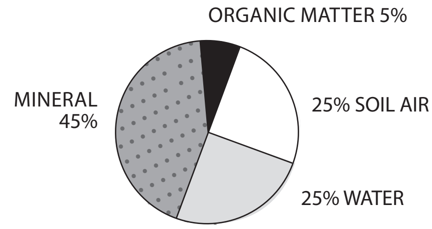
   - **O**: Top layer dominated by organic material
   - **A**: The mineral soil horizon that is usually at the surface or below an O horizon, generally called topsoil in agriculture. It has more organic carbon than underlying layers and is the best environment for plants and microbes to grow. Sometimes this layer is missing or reduced due to erosion or topsoil removal. Also, all surfaces resulting from plowing, pasturing, or similar disturbances are referred to as A horizons.
   - **E**: Horizon characterized by eluviation (removal of materials such as silicate clay, iron, aluminum, or organic matter), if distinct from the A horizon. Frequently not present. Usually more pale colored than the A horizon.
   - **B**: Horizon formed below an A, E, or O horizon that is dominated by loss of most or all of the original rock structure and shows evidence of soil formation such as illuviation (concentration of the silicate clay, iron, aluminum, or humus from higher horizons), development of soil color or structure, or brittleness.
   - **C**: Horizons or layers, excluding hard bedrock, that are little affected by soil-forming processes and thus lack characteristics of O, A, E or B horizons
   - **R**: The underlying bedrock

D. What Is in Soil?

1. 40–50% mineral. Generally almost half of the soil is made up of non-biological particles of different sizes. The sizes present depend on the history of the soil, including the forces that formed it, how long it has been forming, and the parent material.
   a) Rock particles too big to be soil: from gravel, to stones, to boulders
   b) Large soil particles: Sand (0.05–2.00 mm)
   c) Medium soil particles: Silt (0.002–0.05 mm)
   d) Small soil particles: Clay (< 0.002 mm)
2. 0–10% biological (See ▶ Table 2.2, Soil Fauna and their Eating Habits, and ▶ Table 2.3, Common Populations of Some Soil Microorganisms). A small fraction of the soil is made up of biological organisms, or parts of organisms. The percent present depends on similar factors from the history of the soil, including how long it has been forming and the parent material, and is strongly influenced by environmental conditions.
   a) Includes plants, animals, algae, bacteria, archaea, and fungi
   b) Organisms may be alive or dead (when dead they become "organic matter")
   c) This includes both macroscopic organisms (organisms you can see with the naked eye, such as plant roots, rodents, earthworms, insects) and microscopic organisms (organisms you can see only with assistance, such as some fungi, bacteria, archae)
3. ~50% pore space

   Pore space consists of the "empty" spaces in the soil. This is a critical part of the soil because it is filled with either:
   a) Air, which allows gas exchange for organisms (particularly CO_2 or O_2 for respiration)
   b) Water, which is key for organismal function, and is especially important for plants via uptake by roots

◀ **FIGURE 2.1** | SOIL COMPOSITION: AN IDEALIZED SOIL



▶ **TABLE 2.2** | SOIL FAUNA AND THEIR EATING HABITS

MICROPHYTIC FEEDERS		**CARNIVORES SECONDARY CONSUMERS**		**CARNIVORES TERTIARY CONSUMERS**	
ORGANISM	**MICROFLORA CONSUMED**	**PREDATOR**	**PREY**	**PREDATOR**	**PREY**
Springtails	Algae* Bacteria* Fungi*	Mites	Springtails* Nematodes* Enchytraeids	Ants	Spiders Centipedes Mites* Scorpions
Mites	Fungi Algae Lichens	Centipedes	Springtails* Nematodes* Snails* Slugs* Aphids* Flies*	Centipedes	Spiders Mites Centipedes
Protozoa	Bacteria and other microflora			Beetles	Spiders Mites Beetles*
Nematodes	Bacteria Fungi	Moles	Earthworms* Insects		
Termites	Fungi				

*feed on live plants/plant residues, and/or soil organic matter

▶ **TABLE 2.3** | COMMON POPULATIONS OF SOME SOIL MICROORGANISMS

ORGANISM	NUMBER PER GRAM OF SOIL
Bacteria	$10^8 – 10^9$
Actinomycetes	$10^7 – 10^8$
Fungi	$10^5 – 10^6$
Algae	$10^4 – 10^5$
Protozoa	$10^4 – 10^5$
Nematoda	$10 – 10^2$

E. Soil Classification: 12 Orders

1. Soil scientists have come up with systems for classifying soils, in much the way plants and animals are classified. There are currently 4 main classification schemes: Russian, FAO, Canadian, and Soil Taxonomy (Euro-American in origin, but used worldwide). Soil taxonomy is similar to plant and animal classification in that the system is based on genesis—how it is thought the soil developed, similar to the evolutionary classification of plants and animals. Also, like plant and animal classification systems, soil taxonomy is not static. As more is learned, the system changes.
2. The highest category of this system is the Orders. There are 12 soil orders (see ▶ Table 2.4, 12 Orders in Soil Taxonomy).

▶ **TABLE 2.4** | 12 ORDERS IN SOIL TAXONOMY

Alfisols	form in areas with low rainfall, but wetter than deserts
Andisols	form in volcanic ash
Aridisols	form in deserts
Entisols	young soils (form in recently active areas, such as floodplains and mountains)
Gelisols	form in very cold climates, with permafrost near the surface
Histosols	soils very high in organic matter, common in wetlands
Inceptisols	fairly young soils, but with more soil development than Entisols
Mollisols	form in grasslands (such as the Midwestern prairies), have thick, dark, fertile soil
Oxisols	old soils formed in the tropics, have very low fertility
Spodosols	generally form in temperate coniferous forests, have very low fertility
Ultisols	form in humid temperate and tropical regions in older landscapes, are highly acidic with low fertility
Vertisols	soils rich in clay, which causes them to swell when wet and shrink (causing large cracks) when dry

Animals are classified first by kingdom, then phylum, then class, and so on down to species. Similarly, soils are classified first by order, then suborder, great group, and on down to series, the soil equivalent of species. Soils in a series have horizons that are similar in their key characteristics. Series names are usually taken from local geographic features or place names. There are over 20,000 recognized soil series in the U.S.

Lecture 2: Soil Properties

Pre-Assessment Questions

1. What are the mineral parts of the soil that create soil texture?
2. What are some of the factors affecting soil structure?
3. What makes up the organic matter component of soil?
4. What factors affect soil permeability and water holding capacity?

A. Soil Properties

1. Texture

   Non-technical definition: How the soil feels to the touch

   Technical definition: The proportions of sand, silt and clay in the soil

   a) Soil separates (mineral part of soil)

      i. Sand particles are the largest in the soil, ranging in size from 0.05 to 2.00 mm. Soil with high sand content feels gritty and doesn't hold well in a ball.

      ii. Silt particles are moderate size particles and range from 0.002 mm to 0.05. Soils high in silt feel floury when dry and greasy when wet.

      iii. Clay particles are the smallest in the soil, with sizes less than 0.02 mm

         - Morphology: Most clay minerals consist of microscopic layers (see **Baklava Demonstration** in Supplemental Demonstrations and Examples). These are called phyllosilicate minerals. (*Phyllo-* is from Greek for leaf, as in phyllo dough used to make baklava.) Different types of clay have different kinds of layers and different properties.
         - Properties of clays (see several demonstrations in Supplemental Demonstrations and Examples):

           Sticky (adhesion—sticks to other things) **(Target Demonstration)**

           Plastic (cohesion—sticks to itself) **(Ribbon Demonstration)**

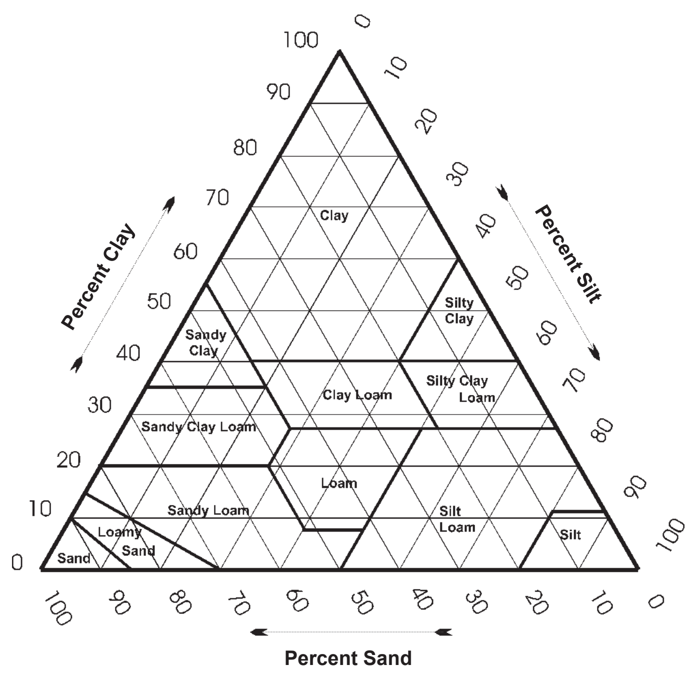
           Shrink-swell **(Slinky Demonstration)**

           Large surface area, due to layers and size **(Block Demonstration)**

         Cation Exchange Capacity (CEC): Clay particles have a net negative charge, and so can attract positive ions (cations), hold them, and then release them to the soil water when its cations have been lost through leaching or plant uptake. Cations such as potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), iron (Fe^{+2} and Fe^{+3}), and zinc (Zn^{+2}) are essential plant nutrients, so the ability of soil to hold and release these ions later is important for plant growth and reproduction.

   b) Texture Triangle (see ◀ Figure 2.2, Soil Texture Triangle)

◀ **FIGURE 2.2** | SOIL TEXTURE TRIANGLE



i. There are 12 soil textures (see ▶ Table 2.5, 12 Soil Textures Names and their Abbreviations), varying in percentages of sand, silt, and clay

2. Structure

Structure is the arrangement of soil particles into aggregates, and the pore space around them

a) Aggregates.

i. Aggregates can be natural or made by people (e.g., by tillage in wet soils; these aggregates are called clods)

ii. Types (shape) (See ◀ Figure 2.3, Soil Structure and Its Effects on Permeability)

- Granular
- Blocky (angular and sub-angular)
- Platy
- Columnar and prismatic
- Single grain (non-structure)
- Massive (non-structure)

iii. Size: Very fine, fine, medium, coarse, very coarse, thick, thin (see ▶ Table 2.6, Size Classes of Soil Structural Units)

iv. Aggregate stability is the ability to withstand wetting and drying, wind, and actions such as tillage. This is key for water infiltration, gas exchange, root growth, and long-term resistance to wind and water erosion, and is an indicator of soil health.

b) What causes soil aggregates to form?

i. Biological factors help bind soil particles together

- Bacterial exudates
- Root activity and exudates (sugars that act as glue)
- Fungal hyphae
- Macrofauna (especially earthworm) activity and waste
- High organic matter content

ii. Soils high in sand and silt do not form aggregates well. The type and quantity of clay particles greatly affects how well aggregates form and how they persist: Some types of clay form very stable aggregates, while other form weak aggregates.

iii. Calcium can help stabilize soils, although growers need to be aware of the type of calcium to apply depending on soil pH and the possibility of raising salinity. Overall, gypsum is an inexpensive and non-toxic source of calcium, although it should be used with care. See Resources and Unit 1.11, Reading and Interpreting Soil Test Reports for more specific information.

iv. Climate—especially the temperature and precipitation of an area—can affect soil aggregate formation. The physical action of freezing and thawing increases the likelihood of particles sticking together. Drying of soils can pull particles apart, as can the impact of raindrops.

▶ **TABLE 2.5** | 12 SOIL TEXTURES NAMES AND THEIR ABBREVIATIONS

clay	C	sandy loam	SL
sandy clay	SC	loam	L
silty clay	SIC	silt loam	SIL
clay loam	CL	loamy sand	LS
sandy clay loam	SCL	sand	S
silty clay loam	SICL	silt	SI

◀ **FIGURE 2.3** | SOIL STRUCTURE AND ITS EFFECTS ON PERMEABILITY

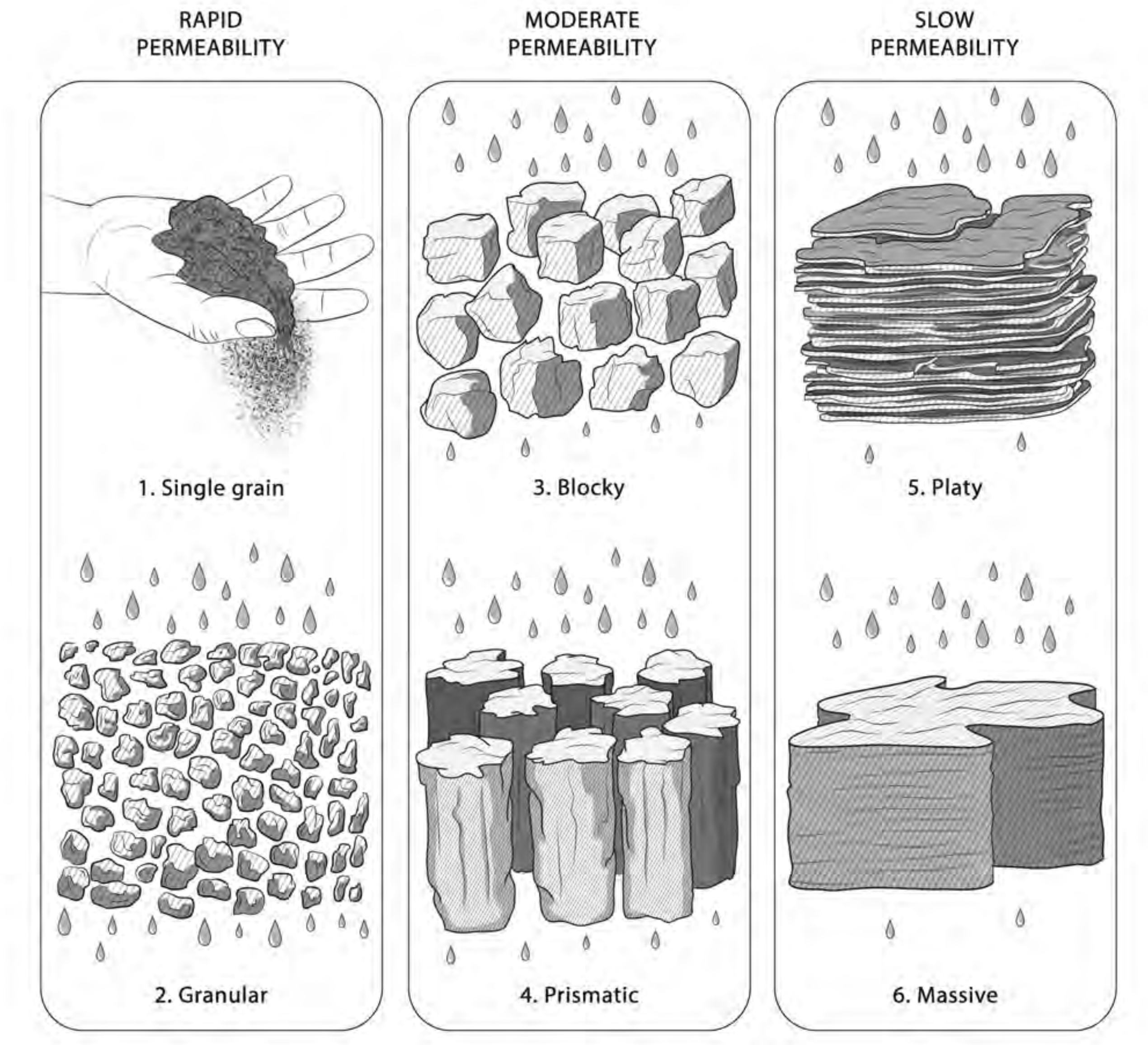


Illustration by José Miguel Mayo

▶ **TABLE 2.6** | SIZE CLASSES OF SOIL STRUCTURAL UNITS. THIN AND THICK, RATHER THAN FINE AND COARSE, ARE USED FOR PLATY STRUCTURES.

SIZE CLASS	PLATY	COLUMNAR/ PRISMATIC	BLOCKY	GRANULAR
very fine (thin)	<1 mm	<10 mm	<5 mm	<1 mm
fine (thin)	1 – 2 mm	10 – 20 mm	5 –10 mm	1 – 2 mm
medium	2 – 5 mm	20 – 50 mm	10 – 20 mm	2 – 5 mm
coarse (thick)	5 –10 mm	50 –100 mm	20 –50 mm	5 –10 mm
very coarse (thick)	>10 mm	>100 mm	>50 mm	>10 mm

3. Pores

   Pores are the spaces between soil particles or aggregates. They are important because they allow air and water to move through the soil and also to be stored there. Without air, roots, macroorganisms, and most microorganisms cannot live.

   a) Types of pores include:

      i. Interstitial pores: Small spaces between soil particles or aggregates

      ii. Tubular pores: Pores made by roots or animals

   b) Sizes of pores: Pores are generally broken up into two size classes, although there is not a particular size limit between them

      i. Macropores: Allow free movement of air and water

      ii. Micropores: Air movement is greatly impeded, water movement is restricted to capillary flow

4. Bulk density

   The bulk density of the soil is the weight of a given volume of oven-dried soil divided by the volume, and reflects the amount of pore space in the soil. It is an indicator of soil health (e.g., see Unit 1.2, Garden and Field Tillage and Cultivation for a discussion of tillage's effect on bulk density).

> **Bulk density is expressed in grams per cubic centimeter. The formula is usually written like this:**
>
> $D_b = Ms/Vt$
>
> Where Db = bulk density
>
> Ms = mass of solids
>
> Vt = total volume
>
> Soil bulk density values range from 0.5 to 3.0 but most values are between 0.8 and 1.8. Anything denser than about 1.8 is root limiting.

   a) Factors that affect bulk density

      i. Types of minerals that make up the soil particles: Some minerals are heavier than others

      ii. Soil texture: Clays are lighter than silts and sands

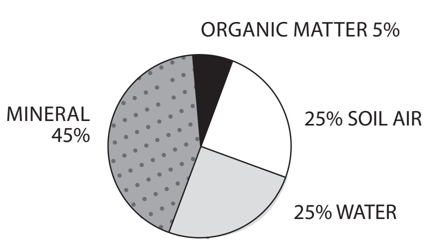
      iii. Organic matter content: Organic matter has a really low bulk density compared to mineral particles

      iv. Soil compaction: Compacted soils have higher bulk densities than non-compacted soils

   b) How bulk density informs cropping

      High bulk density indicates compacted soils that restrict root growth. Such soils need to be improved with practices such as cover cropping, incorporating crop residues, and using crops with various rooting depths to increase organic matter content.

FIGURE 2.4 | SOIL COMPOSITION: AN IDEALIZED SOIL



5. Organic matter

   Organic matter consists of dead plants, animal, microbes and fungi or their parts, as well as animal and microbial waste products in various stages of decomposition. Eventually, all of these break down into humus, which is relatively stable in the soil.

   a) Forms of organic matter

   b) Importance of organic matter: Although organic matter makes up a minor part of the soil, it has a very strong impact on a number of factors

i. Structure

Organic matter acts like glue that helps hold soil aggregates together. These will hold even upon wetting.

ii. Available Water Capacity (AWC)

Organic matter helps bind water to the soil, keeping it from being lost through percolation and making it available to plants for uptake. This is especially important in sandy soils.

iii. Cation Exchange Capacity (CEC) (see description of CEC under Texture)

Like clay particles, organic matter particles have a negative charge and thus attract, hold, and release cations necessary for plant growth and reproduction

iv. Binding plant toxins

Organic molecules can bind up dome ions that are toxic to plants

c) Relationship to climate

i. The amount of organic matter soil can hold is really in equilibrium, like a bathtub that is receiving water at the same rate that water is going down the drain—the water molecules are moving in and out of the bathtub but the total volume in the tub stays constant. Organic matter added beyond a soil's equilibrium is "overflow," and is broken down to carbon dioxide and water.

ii. There is a maximum amount of organic matter that any particular soil can hold, and that amount is inversely proportional to soil temperature and moisture: wetter and colder soils can hold higher quantities of organic matter than warmer and drier soils. For example, peat soils of northern Canada and Europe have very high organic matter while soils of the Southwest U.S. tend to be very low in organic matter.

iii. Some researchers and growers are looking at the potential of organic and conservation tillage practices to increase soil OM. Increasing the total C content of the soil through high C inputs and minimal soil disturbance may increase the amount of OM in equilibrium, sequestering the C and offsetting emissions of CO_2.

6. Color

Soil color varies with parent material, how long the soil has been forming, and the environment itself

a) Describing soil color

Soil color is described using Munsell Color Notation (show *Munsell Soil Color Book)*. The notation breaks soil color into hue (the particular color), value (how light or dark the color is), and chroma (how washed out or intense it is). The Munsell Soil books have color chips that allow scientists to precisely describe and compare soils.

b) Meaning of soil color

i. Drainage and wetness (also called "redoximorphic features") (show samples)

Greenish, bluish, and gray colors in the soil indicate wetness. These colors may occur as the dominant color (the matrix) or in patches (mottles). The colors are caused by the reduction of iron by bacteria in anaerobic conditions, when the bacteria get the electrons they need for energy from iron rather than from oxygen. These colors will persist even if the area is drained.

Bright colors (reds and yellows), indicate well-drained soils. However, color shouldn't be your sole indicator for determining the soil's suitability for crops. It is possible for a soil with bright colors to still have excess free water at points in the growing season if the groundwater is moving quickly and has sufficient oxygen or if it is too cold for biological activity.

ii. Organic matter

Dark colors in the soil usually indicate organic matter. However, they may also indicate wetness (remember, wetter soils can accumulate more organic matter). Sometimes dark colors may be derived from the parent material. This is often the case in soils that formed from dark-colored igneous rock.

7. Soil depth

Soil depth determines how far the roots can grow and how much water the soil can hold. Depth is measured to the shallowest root-limiting layer.

a) Factors that can limit soil depth:

i. Bedrock

ii. Hardpans

- Densely compacted material (tillage pan or plow pan): Can form when farm implements repeatedly pass through the soil at the same depth. This causes soil particles to be pressed closer together, reducing the amount of pore space and the size of the pores. Consequently, these pans have permeability rates lower than those of the soil above and below them.
- Natural hardpans: Can form when certain minerals, such as iron, lime (calcium carbonate), and silica, bind to soil particles and create a cemented layer in the soil
- On a field scale, growers may choose to plow or rip a soil to break up natural or tillage pans and to increase the pore space in the soil. Another option is to use deep-rooted cover crops (see Unit 1.6, Selecting and Using Cover Crops). In a gardening context, growers can use double digging (see Unit 1. 2).

  However, the benefits of using tillage to break up soil compaction are temporary, especially in coarser soils. In a coarse-textured soil, such as a sandy loam, most of the pore space added by plowing or ripping will be lost by the end of one cropping season. While it is more difficult to break up compaction in a finer textured soil, the benefits will last longer than they will in a coarse textured soil.

iii. Strongly contrasting textures

If the area of cultivation is very different from the surrounding soil, water or roots can be trapped in the cultivated area. This makes it similar to having a flower pot holding the water in or inhibiting root growth (sometimes called the "pot effect"), and can be potentially damaging to the crop. On a small scale, this can happen if a hole dug for planting is filled with soil amendments and the lighter soil, but not mixed well into the surrounding soil. On a larger scale, this can happen with sandy floodplain soils adjacent to denser soils.

iv. Water tables

8. Soil temperature

Soil temperature is important to growers, especially for spring planting. Many seeds need a certain minimum temperature for germination (see Unit 1.3, Propagating Crops from Seed, and Greenhouse Management).

a) Factors influencing soil temperature

i. Local climate: Soil temperature is highly correlated to air temperature

ii. Slope steepness and aspect: In the Northern Hemisphere, north-facing aspects tend to be cooler than south-facing aspects. The effect is more pronounced with steeper slopes and lower relative humidity.

iii. Topography: Topography strongly influences microclimates. For example, cool air flows down from mountaintops along drainages and settles in low parts of valleys. Soil and air temperature in these drainages and low areas may be lower than the elevated areas adjacent to them. This is readily apparent in the "citrus belt" in the San Joaquin Valley.

iv. Cover: Plants shade the soil, reducing the temperature. In addition, growing plants cool the surrounding air temperature through transpiration.

v. Soil color: Dark-colored soils absorb heat more readily than light-colored soils

vi. Horticultural practices: Mulching reduces heat by reducing insolation— the absorption of heat when it's sunny—and can also act as an insulator, holding in heat in cold weather

b) Soil temperature influences on soil properties

i. Biological activity: Lower temperature = lower biological activity. Below about 40°F there is little biological activity.

ii. Organic matter accumulation: Lower temperature = higher organic matter accumulation (see "Relationship to climate" under "Organic matter," above)

iii. Weathering of parent materials: Fluctuating temperatures help the physical breaking down of rock and mineral grains (the rock part of sand, silt, and clay). Warmer temperatures = higher rates of chemical weathering.

iv. Nutrient availability: Many nutrients are unavailable or poorly available at low temperatures, especially phosphorus. This is primarily related to low biological activity at those temperatures.

9. Drainage

Soil drainage is a way of expressing the frequency and duration of periods in which the soil is saturated (has free water or water in excess of field capacity). Excess free water in the root zone can kill plants or keep them from becoming established.

a) Drainage classes: The U.S. Department of Agriculture recognizes seven natural drainage classes ranging from "excessively drained," where the water moves out of the soil very rapidly, to "very poorly drained," where water moves out of the soil so slowly that water remains at or near the soil surface through much of the growing season

b) Factors that affect drainage

i. Soil texture (coarser soils tend to drain more rapidly)

ii. Soil depth (shallow soils tend to drain more rapidly)

iii. Precipitation (areas with greater rainfall may drain more slowly)

iv. Topography (soils on level ground may drain more slowly)

10. Odor

a) Indicator of wetness

When soils are waterlogged, bacteria obtain oxygen for respiration from other compounds, including sulfate (SO_4^{-2}). This releases hydrogen sulfide gas, which has a "rotten eggs" odor. This accounts for the sulfur smell prevalent around some marshes, but can be smelled even in overwatered potted plants.

11. Permeability and infiltration

a) Rate at which water moves through the soil

Permeability is the rate at which water moves down through the soil. It is usually measured in inches per hour. Infiltration is the rate at which water enters the soil. It is similar to permeability, except that it also takes into account surface conditions such as soil crusting. Permeability and infiltration affect the rate at which you can safely apply water to the field or garden bed. Applying water at rates higher than the permeability and infiltration can break apart soil aggregates and lead to sealing of the soil surface with the smaller particles (crusting). The soil sealing further decreases infiltration rates. Applying water at rates greater than the soil can take it in can also cause ponding, which increases the possibility of diseases, as well as runoff, which causes soil erosion and possible fertilizer loss.

The permeability of a soil can be no faster than the permeability of the slowest layer. For example, sandy loam has a permeability of 2.0 to 6.0 inches per hour. Sandy clay loam has a permeability of 0.2 to 0.6 inches per hour. A soil that has a sandy loam surface over a sandy clay loam subsoil will have a permeability of 0.2 to 0.6 inches per hour.

b) Measurement

Permeability is normally measured in inches per hour

c) Properties influencing permeability and infiltration

i. Texture

Soil texture is usually the dominant soil property affecting infiltration. Soils that are high in clay content tend to have a lower permeability, while soils that are high in sand content tend to have a higher permeability (see ▶ Table 2.7, Soil Permeability Chart).

▶ **TABLE 2.7** | SOIL PERMEABILITY CHART
THESE ARE NORMAL VALUES FOR NON-COMPACTED SOILS, SUCH AS IN GRASSLAND SITUATIONS

TEXTURE CLASS	TEXTURE	PERMEABILITY RATE	PERMEABILITY CLASS
Coarse	gravel, coarse sand sand, loamy sand	> 20 inches/hour 6 – 20 inches/hour	very rapid rapid
Moderately Coarse	coarse sandy loam sandy loam fine sandy loam	2 – 6 inches/hour	moderately rapid
Medium	very fine sandy loam loam silt loam silt	0.60 – 2 inches/hour	moderate
Moderately fine	clay loam sandy clay loam silty clay loam	0.20 – 0.60 inches/hour	moderately slow
Fine	sandy clay silty clay clay (<60%)	0.06 – 0.20 inches/hour	slow
Very fine	clay (>60%) clay pan	< 0.06 inches/hour	very slow

Soil texture not only affects how fast water moves through the soil, it also affects the pattern of movement. Water will move almost straight down through a sandy soil whereas it will have more lateral movement in a soil with higher clay content. (See ◀ Figure 2.5, Movement of Water through Sandy and Clay Soils)

◀ **FIGURE 2.5** | MOVEMENT OF WATER THROUGH SANDY AND CLAY SOILS

m = minutes, hr = hours

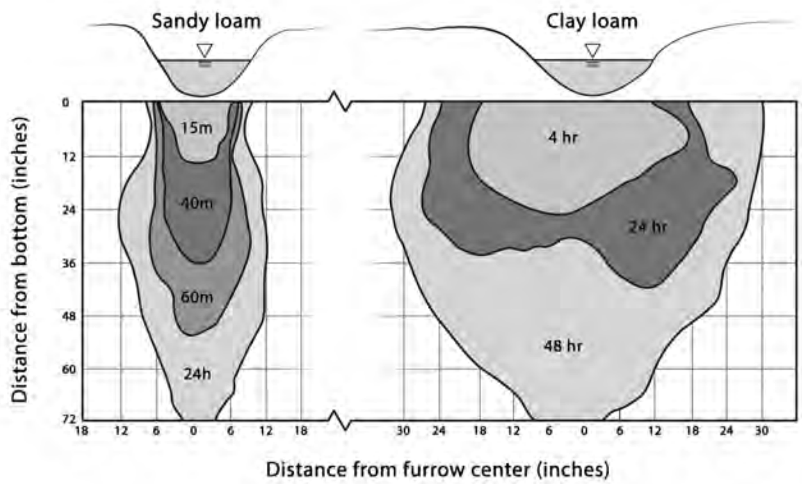


Illustration by José Miguel Mayo

ii. Structure

Soil structure has perhaps the greatest effect on permeability, especially as it relates to pores between soil particles. As we saw earlier, these pores allow for the movement of air and water through the soil.

Practices that improve soil structure also improve permeability. For example, heavy overhead irrigation or flood irrigation breaks down soil structure, which can lead to a sealing of the soil surface. This in turn makes it more difficult for any further water to enter the soil. Tillage can help break up a soil that has become sealed, particularly if it is done when the soil is not too wet (see Unit 1.2).

Other properties that relate to soil structure, permeability, and infiltration include:

- Salts: Sodium salts cause soil particles to disperse and clog pores, which has a negative effect on soil structure. Such soils tend to seal when wet, which drastically lowers both infiltration and permeability.
- Organic matter: As described above, organic matter improves soil structure, improving permeability and infiltration
- Compaction and pores: Fine-textured soils (soils with high clay content) contain more total pore space than coarse-textured soils (soils with high sand content), however the pore spaces are smaller. Because of this, water moves more slowly through a fine-textured soil, leading to lower permeability and infiltration.
- Calcium: Calcium improves soil structure by encouraging aggregation and increasing pore size. As a result it increases permeability and infiltration.
- Soil organisms: Microorganisms (e.g., bacteria and fungi) and macroorganisms (e.g., insects and earthworms) in the soil increase permeability and infiltration by encouraging the formation of soil aggregates and creating macropores in the soil

d) Additional properties influencing infiltration

i. Dryness: Frequently, dry soils will repel water until they become moistened to some degree. This is especially true of soils that have high amounts of organic matter. **(See Peat Moss Demonstration in Supplemental Demonstrations and Examples.)**

ii. Slope: Slope may cause water to run off rather than enter the soil

12. Water holding capacity
    a) Water holding capacity: The maximum amount of water that the soil can hold that is available for plant growth. It is the difference between the amount of water in the soil at field capacity and the amount of water in the soil at wilting point. It is also referred to as Available Water Capacity (AWC) and as Plant Available Water (PAW). These ideas are further discussed in Unit 1.5, Irrigation—Principles and Practices. **(See Sponge Demonstration in Supplemental Demonstrations and Examples)**
    b) Field capacity: The amount of water the soil can hold against the flow of gravity, that is, the water left after saturated soil has finished draining. This is the upper limit of water storage.
    c) Wilting point: The soil moisture content at which the soil can no longer provide moisture for growth of most agronomic plants. This is the lower practical limit of water storage and results in non-recoverable wilting of the crop. The permanent wilting point varies by crop.
    d) Measurement

       Water holding capacity is measured in inches/foot or inches/inch. If it takes the addition of two inches of water to wet a dry soil (at permanent wilting point) to a depth of 1 foot, then the water holding capacity is 2 inches per foot (0.16 inches per inch). The water holding capacity is then expanded to the number of inches of water the soil can hold within the rooting depth of the crop—usually ranging from 4–60 inches—or up to a root-restricting layer, whichever is shallower. Researchers generally use the metric system, and for water holding capacity this means m^3/m^3.
    e) Properties influencing water holding capacity
       i. Texture

          Soils that have a high sand content tend to have a lower water holding capacity, while soils high in clay content tend to have a higher water holding capacity (see examples in ▶ Table 2.8, Typical Available Water Capacity). However, if the clay content is too high or the clay particles are too fine, then the water holding capacity may be reduced because the tiny pores between the particles may hold the water so tightly that the plants can't access it.

▶ **TABLE 2.8** | TYPICAL AVAILABLE WATER CAPACITY (AWC) FOR VARIOUS SOIL TEXTURES FOR SOILS HIGH IN 2:1 MINERALS (SOILS HIGH IN KAOLINITE OR GIBBSITE ARE ABOUT 20% LOWER)

SOIL TEXTURE	**AVAILABLE MOISTURE**	
	RANGE inches/foot	AVERAGE inches/foot
Very Coarse to Coarse Textured (sands and loamy sands)	0.50 – 1.25	0.90
Moderately Coarse Textured (coarse sandy loam, sandy loam and fine sandy loam)	1.25 – 1.75	1.50
Medium Textured (very fine sandy loam, silt, silt loam, loam, sandy clay loam, clay loam and silty clay loam)	1.50 – 2.30	1.90
Fine and Very Fine Textured (silty clay, sandy clay and clay)	1.60 – 2.50	2.10
Organic Soils (peats and mucks)	2.00 – 3.00	2.50

ii. Structure

Key factors influencing the structural effects on water holding capacity include:

- Organic matter: Organic matter improves the water holding capacity
- Compaction: A compacted soil has reduced pore space and thus less space for the water to occupy
- Soil depth: The presence of a root-restricting layer reduces the water holding capacity. In addition, the natural rooting depth of a plant limits the water available to it, and this varies by crop. If a crop's roots will only go to a depth of two feet in a well-cultivated soil with no root restrictions, then soil below two feet should not be considered when determining water holding capacity for that crop.
- Coarse fragments: "Coarse fragments" refers to gravel, cobbles, stones, and boulders in the soil—anything larger than 2 mm. Since coarse fragments do not hold water, their presence in the soil reduces its water holding capacity (see ▶ Table 2.9, Reduction in Water Holding Capacity for Coarse Fragments).

▶ **TABLE 2.9** | REDUCTION IN WATER HOLDING CAPACITY FOR COARSE FRAGMENTS

TEXTURE MODIFIER	% COARSE FRAGMENTS	% AWC REDUCTION
No modifier	0-15%	0-15%
Gravelly, cobbly, stony, bouldery	15-35%	15-35%
Very (gravelly, cobbly, stony, bouldery)	35-60%	35-60%
Extremely (gravelly, cobbly, stony, bouldery)	60-90%	60-90%

iii. Salts

Salts reduce the soil's water holding capacity. A soil that is salty can be wet and yet not have any water available for plant growth. This is because the salts have such a strong attraction for the water that the roots cannot overcome it (see ▶ Table 2.10, Reduction in AWC for Salts).

▶ **TABLE 2.10** | REDUCTION IN AWC FOR SALTS

EC of soil	4	6	12	16	18	20	22	25	30
% Reduction AWC	10	20	30	40	50	60	70	80	90

iv. Estimating total available water

You can estimate approximate total available water by hand using the methods in ▼ Example 1, Calculation of Total Available Water Capacity in the Root Zone.

You can obtain a more precise estimate by using soil moisture sensors to monitor the wetting and dry-down of the soil following irrigation events or precipitation. This requires electronic sensors that are installed at several depths within the rooting zone for a given crop at several locations in a field, the total number of which would depend on the budget available. While these methods have in the past been used primarily by researchers, some commercial growers are moving to this kind of monitoring to better understand the water holding capacity and total available water for their fields and crops, leading to more precise watering. This is of particular importance for areas that experience regular or periodic droughts or water rationing. As technology improves and prices of electronic monitoring come down, these methods are becoming available to more growers; see Supplement 3, Soil Moisture Sensing Instruments Commonly Used for Irrigation Schedules, in Unit 1.5.

▼ **EXAMPLE 1** | CALCULATION OF TOTAL AVAILABLE WATER CAPACITY IN THE ROOT ZONE

ESTIMATING AVAILABLE WATER CAPACITY

Determine AWC for each layer soil texture.

Reduce AWC for each layer for gravel.

Reduce AWC for each layer for salts.

Calculate AWC for entire soil.

(In this example we assume no salts or coarse fragments)

DEPTH	**TEXTURE**	**LAYER THICKNESS** (FOOT)		**AWC PER FOOT** (INCHES/FOOT)		**AVAILABLE MOISTURE** (INCHES)
0 to 8 inches	sandy loam	8/12	x	1.5	=	1.0
8 to 20 inches	sandy clay loam	12/12	x	1.9	=	1.9
20 to 48 inches	loamy sand	28/12	x	0.9	=	2.1
48 inches	rock (rooting depth)					
TOTAL AVAILABLE MOISTURE						5.0 inches

If you wanted to irrigate at 50% depletion, which is often the case, then in this case you would irrigate with 2.5 inches of water when the available water reached 2.5 inches (50% of 5 inches)

Demonstration 1: Soil Texture Determination

for the instructor

INSTRUCTOR OVERVIEW

The following demonstration outline covers the resources and skills used to determine the texture of a given soil sample by feel and to determine the approximate percentages of sand, silt, and clay in that sample. First demonstrate how to use the Soil Texture Decision Chart to identify the texture of a given sample. Following this, give students the opportunity to identify the approximate soil textural classification of several additional soil samples. The Soil Texture Triangle is used to help students determine the approximate percent of sand, silt, and clay in their samples. The Soil Texture Descriptions are included to help confirm the accuracy of the determination by providing descriptions of how the soil feels and performs under several tests.

MATERIALS

- Multiple samples of different kinds of soil textures
- Handouts (see below)
  1. The Soil Texture Decision Chart: How soil texture is determined
  2. The Soil Texture Triangle: The percentatges of sand, silt, and clay in each textural classification
  3. The Soil Texture Descriptions: How the soil feels and performs under several tests

DEMONSTRATION TIME

About 1 hour

DEMONSTRATION OUTLINE

A. Demonstrate how to determine the soil texture of a given sample by feel using the Soil Texture Decision Chart (next page)

B. Determine the percentage of sand, silt, and clay in the soil sample using the Soil Texture Triangle (page 2-25)

C. Use the Soil Texture Descriptions (pages 2-26–27) to confirm the accuracy of the textural determination

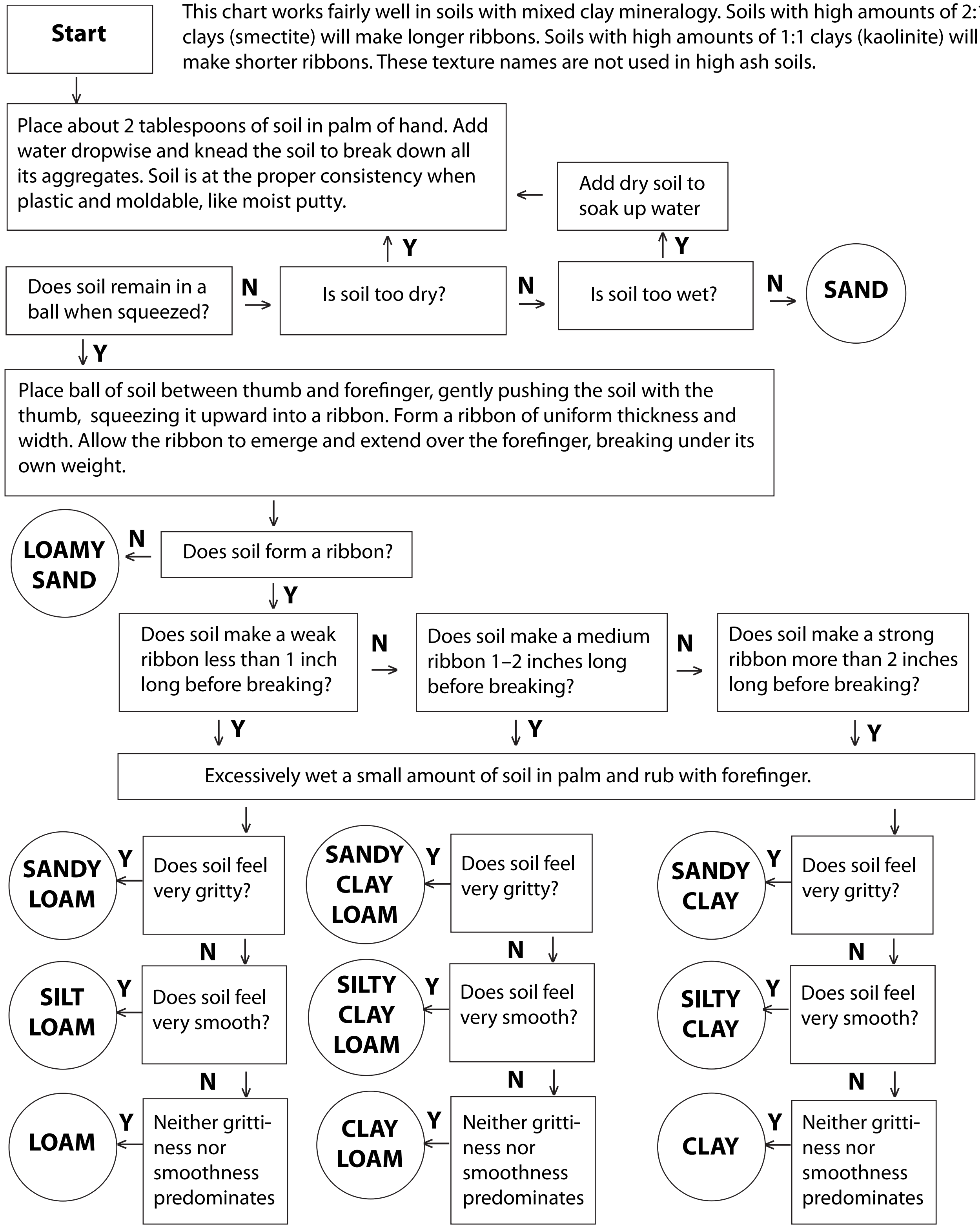
D. Students practice determining soil texture following the same steps

E. Once a texture has been determined, describe/discuss the characteristics of each of the soils:

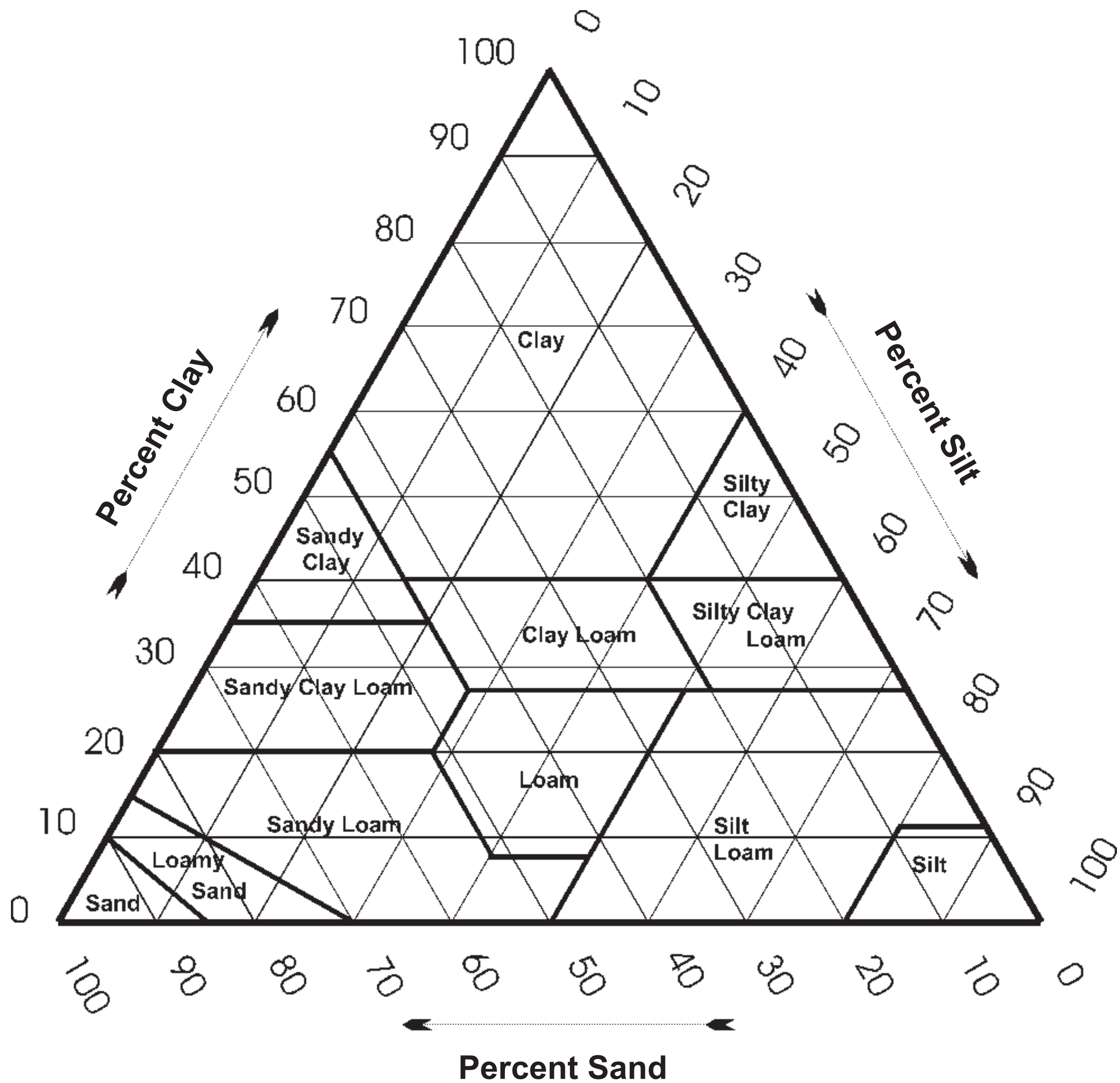
1. Drainage
2. Water availability
3. Cation exchange capacity (CEC)
4. How it may be improved using organic farming practices

Soil Texture Decision Chart

This chart works fairly well in soils with mixed clay mineralogy. Soils with high amounts of 2:1 clays (smectite) will make longer ribbons. Soils with high amounts of 1:1 clays (kaolinite) will make shorter ribbons. These texture names are not used in high ash soils.



Soil Texture Triangle



Soil Texture Descriptions

Edd Russell, Soil Scientist, USDA, Natural Resources Conservation Service

The mineral particles in the soil are divided into the following size classes:

Coarse fragments (gravel, cobbles, stones)	larger than 2 mm
Sand	0.05 to 2 mm
Silt	0.002 to 0.05 mm
Clay	smaller than 0.002 mm

To put these in perspective, if a particle of clay were the size of a BB, then a particle of silt would be about the size of a golf ball, and a grain of sand would be about the size of a chair.

Sand is gritty when wet or dry. Sands are the smallest soil particles you can see with the naked eye. Silt is smooth and floury when dry and feels greasy when wet. Clay is hard when dry and it is sticky and plastic when wet. Clay exhibits both cohesion (it sticks to itself) and adhesion (it sticks to other things).

Texture is a word used to describe how something feels. Soil texture refers to the relative proportion of sand, silt, and clay in a specific soil or horizon (layer) in the soil, because this determines how a soil feels. The texture class of a soil is determined with the texture triangle, shown on page 2-25.

Following is a description of some of the texture classes. There is also a chart at the back of this section that shows you how to determine soil texture.

SAND

Sand is loose and single grained. The individual grains can readily be seen and felt. Squeezed in the hand when dry, it will fall apart when the pressure is released. Squeezed when moist, it will form a cast (a mass that holds together), but will crumble when touched.

LOAMY SAND

When dry, loamy sand is loose and single grained. When wet it is gritty, it does not ribbon and lacks stickiness, but it may show faint clay stainings. Squeezed when moist, it forms a cast that does not break with very careful handling. Individual grains of sand can be readily seen or felt.

SANDY LOAM

A sandy loam soil forms weak aggregates, it contains 45%–85% sand, but has enough silt and up to 20% clay, which makes it somewhat coherent. Individual sand grains can be seen and felt. Squeezed when dry it will form a cast that will readily fall apart, but when moist it will form a cast that will bear careful handling without breaking. It will definitely stain fingers. When placed in water it turns the water cloudy.

LOAM

Loam is a soil having a relatively even mixture of different grades of sand, silt, and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly sticky and slightly plastic. Dry aggregates are slightly hard or hard to break. When moist it will form a cast that can be handled without breaking. It stains fingers. When placed in water it turns the water cloudy.

SILT LOAM

A silt loam is a soil having moderate amounts of the fine grades of sand and less then 27% clay; over half of the particles are silt sized. When dry, aggregates break with some difficulty. When moist it forms a firm ball and ribbons fairly well. Either dry or moist it will form casts that can be freely handled without breaking.

SILT

Silt is a rare textural class that is not easy to find in nature. Silt feels quite floury and soft when dry. When moist it is greasy feeling and is neither sticky nor plastic.

SANDY CLAY LOAM

A sandy clay loam is a soil with 45%–80% sand, 20%–35% clay, and 0%–28% silt. Dry aggregates are hard and break with difficulty. When moist it forms a firm ball and can be squeezed into a ribbon and may show a fingerprint. It is sticky and plastic; it stains fingers and it turns water cloudy.

CLAY LOAM

A clay loam is a moderately fine-textured soil that usually breaks into aggregates or lumps that are hard when dry and friable or firm when moist. The soil ribbons well when moist and shows a good fingerprint; is sticky and plastic and will form a cast that can bear much handling. It stains fingers.

SILTY CLAY LOAM

A silty clay loam handles like silt loam but it is sticky, plastic, and friable or firm when moist. Also, when moist the soil shows a good fingerprint and, like clay loam, will form a cast that can bear good handling. It stains fingers. When the soil is pulverized, it feels floury.

SANDY CLAY

A sandy clay is a fine texture soil with 45%–65% sand, 35%–55% clay and 0%–20% silt. Dry, it is very hard—aggregates can only be broken with extreme pressure. Moist, it is sticky or very sticky and plastic and shows a good fingerprint; it ribbons well and stains fingers.

SILTY CLAY

A silty clay soil is a fine-textured soil with 40%–60% silt, up to 20% sand and 40%–60% clay. Dry, it is extremely hard and it feels quite floury when crushed. It is very sticky and very plastic when moist and it shows a good fingerprint. It forms a cast that can bear much handling and ribbons very well, and clouds water and stains fingers.

CLAY

Clay is also a fine-textured soil that usually forms very hard or extremely hard blocks or prisms. It is very sticky and very plastic when moist, it ribbons very well and forms a very good fingerprint. Some clays are very firm or extremely firm when moist.

Demonstration 2: Soil Pit Examination

for the instructor

INSTRUCTOR OVERVIEW

In this demonstration, students examine the soil profile and various soil properties exposed in a shallow soil excavation. Discuss the soil profile and how the soil properties observed affect the use of the soil for farming, gardening, and other purposes.

MATERIALS

- Shovel and Pic mattock (to dig pit)
- Munsell soil color book
- Water bottle for moistening soil
- pH kit

SITE PREPARATION

Several hours before the demonstration dig a pit approximately 2–4 feet deep (or until distinct soil horizons are observed). For ease, the pit may be triangular in shape and stepped. Plan to have the soil profile in full sun at the time of the demonstration.

PREPARATION TIME

Approximately 1 hour

DEMONSTRATION TIME

1 hour

DEMONSTRATION OUTLINE

A. Determine Approximate Textural Classification of Soil by Feel

B. Identify Distinct Soil Horizons

1. A Horizon and what defines it
2. B Horizon and what defines it
3. C Horizon and what defines it
4. Identify indicators of soil disturbance (e.g., tillage)

C. Describe/Define the Type(s) of Soil Structure Observed

1. Describe general soil structure and how it is created
2. Identify and provide examples of soil aggregates and how they form

Supplemental Demonstrations & Examples

for the instructor

INSTRUCTOR OVERVIEW

These demonstrations and examples use analogy and models to illustrate various soil physical properties. Note the references to sections of the detailed lecture for specific topics.

SOIL EXAMPLES

Lecture Reference: Throughout

PURPOSE

To show examples of certain soil physical properties

MATERIALS: EXAMPLES OF SOIL TO SHOW

- Texture (sand, silt, clay, loam, etc.)
- Structure
- Hard pans
- Color (dark = high organic matter, bright = well drained, redoximorphic features = wetness)

BAKLAVA DEMONSTRATION

Lecture 2 Reference: A 1 a) iii

PURPOSE

To show layering akin to what is found in phyllosilicate (layer-lattice) clays

MATERIALS

- Baklava, preferably enough so that each student can have a piece

METHODS

Point out that many clay minerals are layered at the microscopic level much the way that baklava is and that cations are adsorbed to the sides of clay particles much the same as the nuts are stuck to the sides of the baklava.

TARGET DEMONSTRATION

Lecture 2 Reference: A 1 a) iii

PURPOSE

To show that clay is sticky (adhesion)

MATERIALS

- Moist clay, moistened enough so that it adheres to most surfaces
- A flipchart or blackboard with a target drawn on it
- Moist sandy loam (optional, for contrast)

METHODS

Form the clay into a ball, and throw it at the target (test the surface first to make sure that the clay will actually stick to it). Optionally, you can repeat the process with sandy loam or similar to show that it is not as sticky.

RIBBON DEMONSTRATION

Lecture 2 Reference: A 1 a) iii

PURPOSE

To show that clay is plastic (cohesion)

MATERIALS

- Moist clay
- Moist sandy loam (optional, for contrast)

METHODS

Squeeze the clay through your thumb and forefinger to create a ribbon. Optionally, repeat the process with sandy loam to show that it does not ribbon as well.

SLINKY DEMONSTRATION

Lecture 2 Reference: A 1 a) iii

PURPOSE

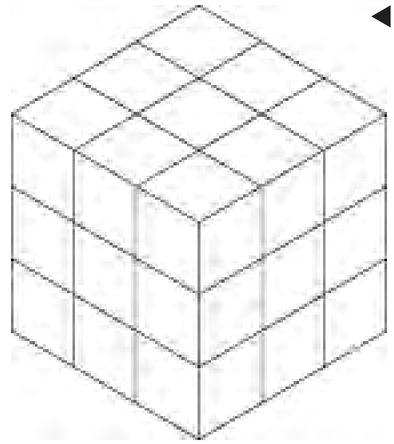
To show how clays shrink and swell by layers becoming separated

MATERIALS

- Slinky

METHODS

Stretch and compress a slinky in your hand while explaining that some clays can shrink and swell as layers get separated when water gets between them



◀ Figure 2.6

BLOCK DEMONSTRATION

Lecture 2 Reference: A 1 a) iii (See ◀ Figure 2.6)

PURPOSE

To show that smaller particles have a larger surface area than a single large particle occupying the same space.

MATERIALS

- 27 wooden blocks

METHODS

1. Form the blocks into a cube: 3 blocks by 3 blocks by 3 blocks. Assume the blocks each have a dimension of 1 on each side. Have the students calculate the surface area of the cube:

   Each side is 3 x 3 = 9 There are 6 sides, 6 x 9 = 54
2. Have the students then calculate the total surface area of the individual blocks in the cube:

   The side of each block has and area of 1 x 1 = 1

   Each block has 6 sides, and therefore a surface area of 6 x 1 = 6

   There are 27 blocks, so the total surface area is 6 x 27 = 162

COLOR BOOK EXAMPLE

Lecture 2 Reference: A 6 a)

PURPOSE

To show how soil color is described

MATERIALS

Munsell or Earth Colors soil color charts

METHODS

Show how the color charts and Munsell color notation are used.

PERMEABILITY DEMONSTRATION

Lecture 2 Reference: A 11 c) i (See ◀ Figure 2.7)

MATERIALS

- 4 jars or beakers, about 2 cup size
- 2 2-liter plastic soda bottles
- Coarse gravel, rounded is better, 1/2–1 inch, about 1 cup
- Fine gravel, < 1/4 inch, about 2 cups
- Sand, about 2 cups
- Clay, dry and ground, about 2 cups
- Water

METHODS

1. Cut the bottoms out of the soda bottles.
2. Invert the bottles into two of the jars to make funnels. Label one "Sand" and the other "Clay".
3. Place the coarse gravel into the bottom of the funnels, enough to plug the holes so that the fine gravel won't go through.
4. Cover the coarse gravel with about a 1 inch thick layer of fine gravel.
5. Place the sand and clay into the appropriate funnels. You want a layer about 2–3 inches thick.
6. Fill the other jars with about 3/4 to 1 cup of water each.
7. Using both hands, pour the water into the funnels at the same time and rate.
8. See which soil the water passes through faster.

◀ Figure 2.7, Permeability Demonstration

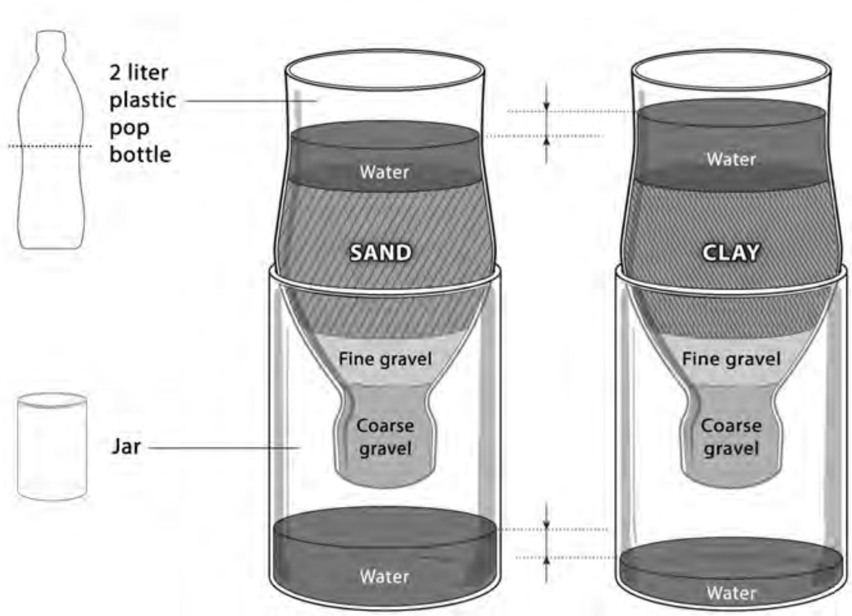


Illustration by José Miguel Mayo

PEAT MOSS DEMONSTRATION

Lecture 2 Reference: A 11 d) i.

PURPOSE

To show how dry organic matter repels water

MATERIALS

- Dry peat moss (a handful)
- Water

METHODS

Hold up a handful of dry peat moss and pour the water over it, showing how the water runs off rather than soaking in.

SPONGE DEMONSTRATION

Lecture 2 Reference: A 12

PURPOSE

To provide a conceptual model of available water capacity and field capacity

MATERIALS

- Sponge
- Water in a bowl or pan

METHODS

1. Soak the sponge in water until it is saturated.
2. Hold up the sponge until most of the water stops dripping. Explain that the sponge is analogous to soil. When the water has finished draining from the soil 24 hours after saturation, the soil is said to be at field capacity.
3. Squeeze the sponge to remove as much water as you can. Mention that this water would be analogous to what can be removed by plants and is the water available at the soil's water holding capacity. After squeezing the sponge, there is still some moisture left in it and that is analogous to the water that is held so tightly in the soil that plants cannot remove it, which is the water content at the permanent wilting point.

Assessment Questions

TRUE OR FALSE

1. Climate affects how a soil forms.
   True False
2. Air is not an important part of soil.
   True False
3. Clay holds more water than sand.
   True False
4. Platy structure on the surface of the soil is desirable.
   True False
5. Organic matter is not particularly beneficial to the physical condition of the soil.
   True False

MULTIPLE CHOICE

1. Which of the following is not a soil-forming factor?
   a. Time
   b. Parent material
   c. Soil color
   d. Topography
2. Of the soil separates listed below, which has the smallest particle size?
   a. Sand
   b. Silt
   c. Clay
3. Which one of the following is not considered one of the major constituents of soil?
   a. Chemical
   b. Mineral
   c. Organic matter
   d. Pore space
4. Which of the following foods has a structure similar to silicate clays?
   a. Ice cream
   b. Cheese
   c. Cake
   d. Baklava
5. A soil that has a balanced amount of sand, silt and clay has which one of the following for a texture?
   a. Platy
   b. Loam
   c. Silt
   d. Granular
6. Of the following, which is the best to add to a clay soil to help offset the negative effects of the clay?
   a. Sand
   b. Silt
   c. Organic matter
   d. Sodium salts
7. Which one of the following does not contribute to the formation of soil structure?
   a. Biological factors
   b. Amount and type of clay
   c. Iron
   d. Climate
8. Gray or mottled colors in the soil indicate past or present:
   a. Wormholes
   b. Wetness
   c. Drought
   d. Texture
9. The rate at which water moves through the soil is called:
   a. Porosity
   b. Hydraulic speed
   c. Permeability
   d. Saturation potential

10. Which of the following influence the available water-holding capacity of the soil?
    a. Texture
    b. Structure
    c. Organic matter
    d. Salts
    e. a, b and c
    f. a, b, c, and d
    g. a, c and d

ESSAY QUESTIONS

1. Why are the "empty" places in the soil so important?

2. Clay contributes many good characteristics to soil, but if there is too much it can cause problems. What are some of the negative effects of too much clay in the soil and how can these effects be overcome?

3. What are some of the negative effects of too much sand in the soil and how can these effects be overcome?

4. Use a soil texture triangle to calculate the soil texture for the following combinations of sand, silt and clay:
    a. 25% sand, 30% silt, 45% clay
    b. 40% sand, 30% silt, 30% clay
    c. 60% sand, 10% silt, 30% clay
    d. 70% sand, 12% silt, 18% clay
    e. 90% sand, 5% silt, 5% clay
    f. 80% sand, 15% silt, 5% clay
    g. 10% sand, 85% silt, 5% clay
    h. 5% sand, 75% silt, 20% clay
    i. 40% sand, 40% silt, 20% clay
    j. 55% sand, 5% silt, 40% clay
    k. 10% sand, 60% silt, 40% clay
    l. 5% sand, 45% silt, 50% clay

5. What surface structure is most desirable for gardening? What can you do to help develop this structure and maintain it?

Assessment Questions Key

TRUE – FALSE

1. Climate affects how a soil forms.

   True *False*

2. Air is not an important part of soil.

   True **False**

3. Clay holds more water than sand.

   True *False*

4. Platy structure on the surface of the soil is desirable.

   True **False**

5. Organic matter is not particularly beneficial to the physical condition of the soil.

   True **False**

MULTIPLE CHOICE

1. Which of the following is not a soil-forming factor?
   a. Time
   b. Parent Material
   c. Soil Color
   d. Topography

2. Of the soil separates listed below, which has the smallest particle size?
   a. Sand
   b. Silt
   c. Clay

3. Which one of the following is not considered one of the major constituents of soil?
   a. Chemical
   b. Mineral
   c. Organic matter
   d. Pore space

4. Which of the following foods has a structure similar to silicate clays?
   a. Ice cream
   b. Cheese
   c. Cake
   d. Baklava

5. A soil that has a balanced amount of sand, silt and clay has which one of the following for a texture?
   a. Platy
   b. Loam
   c. Silt
   d. Granular

6. Of the following, which is the best to add to a clay soil to help offset the negative effects of the clay?
   a. Sand
   b. Silt
   c. Organic matter
   d. Sodium salts

7. Which one of the following does not contribute to the formation of soil structure?
   a. Biological factors
   b. Amount and type of clay
   c. Iron
   d. Climate

8. Grey or mottled colors in the soil indicate past or present:
   a. Wormholes
   b. Wetness
   c. Drought
   d. Texture

9. The rate at which water moves through the soil is called:
   a. Porosity
   b. Hydraulic speed
   c. Permeability
   d. Saturation potential

10. Which of the following influence the available water-holding capacity of the soil?
    a. *Texture*
    b. *Structure*
    c. *Organic matter*
    d. *Salts*
    e. *a, b and c*
    f. *a, b, c, and d*
    g. a, c, and d

ADDITIONAL QUESTIONS

1. Why are the "empty" places in the soil so important?
    - *Place for air and water to move and be stored*
    - *Place for roots to grow*
    - *Place for organisms to live*
    - *Place for nutrients to be stored*
2. Clay contributes many good characteristics to soil, but if there is too much it can cause problems. What are some of the negative effects of too much clay in the soil and how can these effects be overcome?
    Effects
    - *Hard to work when wet*
    - *Hard to work when dry*
    - *Tendency to seal up when wetted*
    - *Hard for roots to grow*

    How to overcome
    - *Only work soil when the moisture is right*
      Add lots of organic matter, even coarse material
    - *If irrigating, do so gently*
3. What are some of the negative effects of too much sand in the soil and how can these effects be overcome?
    Effects
    - *Droughty*
    - *Low fertility*
    - *Structure collapses easily*

    How to overcome
    - *Add lots of organic matter*
    - *Don't till any more than necessary*
4. Use a soil texture triangle to calculate the soil texture for the following combinations of sand, silt and clay
    a. *25% sand, 30% silt, 45% clay*
    clay
    b. *40% sand, 30% silt, 30% clay*
    clay loam
    c. *60% sand, 10% silt, 30% clay*
    sandy clay loam
    d. *70% sand, 12% silt, 18% clay*
    sandy loam
    e. *90% sand, 5% silt, 5% clay*
    sand
    f. *80% sand, 15% silt, 5% clay*
    loamy sand
    g. *10% sand, 85% silt, 5% clay*
    silt
    h. *5% sand, 75% silt, 20% clay*
    silt loam
    i. *40% sand, 40% silt, 20% clay*
    loam
    j. *55% sand, 5% silt, 40% clay*
    sandy clay
    k. *10% sand, 60% silt, 40% clay*
    silty clay loam
    l. *5% sand, 45% silt, 50% clay*
    silty clay
5. What surface structure is most desirable for gardening? What can you do to help develop this structure and maintain it?
    - *Granular or crumb structure is most desirable*
    - *Add lots of organic materials and encourage biological activity*
    - *Don't till the soil any more than necessary*
    - *Only till under the proper moisture conditions*
    - *Avoid compacting the soil with excessive traffic*
    - *Rotate with a cover crop*
    - *Use proper irrigation techniques*

Resources

PRINT RESOURCES

BOOKS

Brady, Niles, and Ray R. Weil. 2008. *The Nature and Properties of Soil, 14th edition*. Upper Saddle River, NJ: Prentice Hall.

> *Comprehensive (965 pages) textbook on soils—great for those who want to "go deeper" into the origins, classifications, and workings of soil. Used as a college text.*

Buol, S. W., F. D. Hole, R. J. McCracken, and R. J. and Southard. 2011. *Soil Genesis and Classification, 6th Edition*. Ames, IA: Iowa State University Press.

> *College textbook used to teach soil classification.*

Dixon, J. B., and S. B. Weed, eds. 1989. *Minerals in Soil Environments, 2nd Edition*. Madison, WI: Soil Science Society of America.

> *Very technical reference on soil minerals. Only the most hardy go here.*

Dubbin, William. 2001. *Soils*. The Natural History Museum, London. Available from Iowa State University Press, Ames, Iowa.

> *Short overview of soil science. Easy to read and understand, lots of color photos.*

Gershuny, Grace. 1993. *Start with the Soil*. Emmaus, PA: Rodale Press.

> *A general book on soils and soil management geared toward organic gardeners. Easy to read and understand.*

Gershuny, Grace. 2000. *The Soul of Soil: A Soil-Building Guide for Master Gardeners and Farmers, Fourth Edition*. White River Junction, VT: Chelsea Green Publishing.

> *Provides essential information on soil ecosystem management for organic growers. Topics include organic matter management, building and maintaining humus, on-site composting, green manures and crop rotations, cultivation and weed control, nutrient balances and soil testing, and using mineral fertilizers.*

Magdoff, Fred and Harold Van Es. 2010. *Building Soils for Better Crops, Third Edition*. Sustainable Agriculture Network, Handbook Series Book 4. Beltsville, MD: National Agricultural Library.

> *An introductory overview of organic management of soil fertility covering the basics of soil organic matter, physical and chemical properties of soil, ecological soil and crop management. Practical and accessible information. Available in print or to download from* www.sare.org.

Schahczenski, Jeff, and Holly Hill. 2009. Agriculture, Climate Change, and Carbon Sequestration. ATTRA–National Sustainable Agriculture Information Service. IP 338. *attra.ncat.org/publication.html*

> *Provides an overview of the relationship between agriculture, climate change and carbon sequestration. Investigates possible options for farmers and ranchers to have a positive impact on the changing climate and presents opportunities for becoming involved in the emerging carbon market.*

Stell, Elizabeth P., 1998. *Secrets to Great Soil*. Pownal, VT: Storey Communications, Inc.

> *An easy-to-read primer on soils, composting and basic gardening techniques. Includes numerous diagrams.*

WEB-BASED RESOURCES

SOIL SURVEYS

Most of the Natural Resource Conservation Services' soil data information is now online. Soil surveys are also available at local NRCS offices and in many libraries.

U.S. Department of Agriculture, Natural Resources Conservation Service. Soil Surveys by State.

> www.nrcs.usda.gov/wps/portal/nrcs/soilsurvey/soils/survey/state/
>
> *Provides links to soil surveys in each state, many of which are available as online PDFs.*

U.S. Department of Agriculture, Natural Resources Conservation Service. *Web Soil Survey.*

websoilsurvey.nrcs.usda.gov/app/

The USDA's Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. You can use the site to create a custom soil resource report for your area of interest, view or print a soil map, and access data to help you determine the suitability of the soils for a particular use.

U.S. Department of Agriculture, Natural Resources Conservation Service. *National Soil Survey Handbook, Title 430-VI.* Available in libraries and online at:

www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054242

Soil Survey Division Staff. 1993. *Soil Survey Manual.* United States Department of Agriculture, Washington DC., U.S. Government Printing Office.

www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054262

This is the manual that soil scientists use to carry out soil survey work. The most definitive guide on how to describe the physical properties of soil. Available online at:

Soil Survey Staff. 1999. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nd edition.* Natural Resources Conservation Service. United States Department of Agriculture Handbook 436. Available online at:

www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/class/taxonomy/

The reference used to classify soils. Highly technical, used mainly by soil scientists. This publication can also be ordered from the NRCS Distribution Center:

nrcspad.sc.egov.usda.gov/DistributionCenter/

Enter the keywords "Soil Taxonomy, 2nd edition."

You can also order by contacting NRCS at their toll free number: 1-888-526-3227 or by email: NRCSDistributionCenter@ia.usda.gov

OTHER WEB-BASED RESOURCES

Australia's Soil Quality Group Fact Sheets

soilquality.org.au/factsheets/category/physical-indicators

Fact sheets provide clear explanations and illustrations of soil physical qualities, including soil texture, bulk density, and available water.

California Natural Resources Conservation Service (NRCS)

www.nrcs.usda.gov/wps/portal/nrcs/site/ca/home

Home page of the California NRCS, with information on drought assistance, conservation planning, technical resources, and much more.

Canadian Soil Information System

sis.agr.gc.ca/cansis/

Includes Canada's National Soils Database, soil survey reports and maps, and reference materials.

National Sustainable Agriculture Information Service: ATTRA

attra.ncat.org/soils.html

Lists sustainable agriculture publications related to soils and compost; many are available as PDFs.

North Carolina State University

courses.soil.ncsu.edu/resources/physics/texture/soilgeo.swf

NCSU offers a short animation on how the surface area of soil affects the size and shape of soil particles

Soil Science Society of America (SSA): Glossary of Soil Science Terms

www.soils.org/publications/soils-glossary

University of Arizona Cooperative Extension

extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1413.pdf

Describes the use of gypsum and other calcium amendments in southwestern soils to stabilize soil aggregates

University of Florida IFAS Extension

edis.ifas.ufl.edu/ae460

Includes a nice graphic of the relationships among plant available water (PAW), soil field capacity, permanent wilting point, soil unavailable water, and soil textural class, as well as information on using soil moisture sensors.

USDA Natural Resources Conservation Service, Soils Website

www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/

Provides a "portal" to USDA NRCS resources, including surveys, publications, and educational opportunities.

USDA Natural Resources Conservation Service, Munsell System of Color Notation

www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054286

Describes the system used to classify soil color and the significance of soil color in understanding soil composition.

EDUCATION LINKS

soilsassociation.org/Links.htm

Educational links assembled by the United States Consortium of Soil Science Associations

VIDEOS & FILMS

How Water Moves through Soil. USDA Soil Conservation Service, Arizona Department of Agriculture. Irrigation Toolbox (34 minutes)

www.youtube.com/watch?v=Ph-7tQuIbz4

Shows the movement of water through different soil types—great visuals

Symphony of the Soil, 2012. Directed by Deborah Koons Garcia (103 minutes)

www.symphonyofthesoil.com

An artistic and scientific exploration of soil, examining its complex dynamics as well as the human relationship with soil, the use and misuse of soil in agriculture, deforestation and development, and the latest scientific research on soil's key role in ameliorating the most challenging environmental issues of our time. Filmed on four continents, featuring esteemed scientists and working farmers and ranchers.

INSTITUTIONS

Cooperative Extension Service or Farm Advisors office

Staff from these offices will be aware of crop nutrient needs and problems in your area. They can assist you with nutrient deficiency symptoms and known plant nutrition problems in your area.

US Department of Agriculture–Natural Resources Conservation Service (USDA–NRCS) field offices

Information about soils in your area can be obtained from NRCS field offices. They are usually listed in the U.S. Government pages of the phone book under US Department of Agriculture. They may also be listed as USDA Service Center. Some areas do not have NRCS offices but do have Resource Conservation District offices that can provide the same information.

Glossary

REFERENCES USED FOR TERMS

1 From the standard glossary used in soil survey reports

2 National Soil Survey Handbook. 1998. Available online at: *www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054242*

3 Glossary of Soil Science Terms.Soil Science Society of America. Available online at *www.soils.org/publications/soils-glossary*

4 Merriam-Webster Online. *www.m-w.com/*

Absorption
: *Uptake of matter or energy by a substance* [3]

Adsorption
: *The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surfaces of solids by chemical or physical binding* [3]

Acidity
: *Refers to the condition of the soil when the exchange complex is dominated by hydrogen and aluminum ions*

Acidity, salt-replaceable
: *The aluminum and hydrogen that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl* [3]

Acidity, total
: *The total acidity including residual and exchangeable acidity. Often it is calculated by subtraction of exchangeable bases from the cation exchange capacity determined by ammonium exchange at pH 7.0. It can be determined directly using pH buffer-salt mixtures (e.g., $BaCl_2$ plus triethanolamine, pH 8.0 or 8.2) and titrating the basicity neutralized after reaction with a soil.*[3]

Aeration, soil
: *The exchange of air in soil with air from the atmosphere. The air in a well-aerated soil is similar to that in the atmosphere; the air in a poorly aerated soil is considerably higher in carbon dioxide and lower in oxygen.*[1]

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.*[1]

Alkali soil
: *(i) A soil with a pH of 8.5 or higher or with a exchangeable sodium ratio greater than 0.15. (ii) A soil that contains sufficient sodium to interfere with the growth of most crop plants.*[3]

Anion
: *A negatively charged ion (has surplus electrons)* [3]

Anion exchange capacity
: *The sum of exchangeable anions that a soil can adsorb. Usually expressed as centimoles, or millimoles, of charge per kilogram of soil (or of other adsorbing material such as clay).*[3]

Aspect
: *The direction in which a slope faces* [1]

Atom
: *The smallest particle of an element that can exist either alone or in combination* [4]

Base saturation
: *The degree to which material having cation-exchange properties is saturated with exchangeable bases (sum of Ca, Mg, Na, and K), expressed as a percentage of the total cation-exchange capacity* [1]

Boulders
: *Rock fragments larger than 2 feet (60 centimeters) in diameter* [1]

Bulk density
: *A measurement of the oven-dried weight of the less than 2 mm soil material per unit volume of soil. Common measurements are taken at a water tension of 1/10 bar; 1/3 bar; or 15 bar. Bulk density influences plant growth and engineering applications. It is used to convert measurements from a weight basis to a volume basis. Within a family particle size class, bulk density is an indicator of how well plant roots are able to extend into the soil. Bulk density is used to calculate porosity.*[2]

Calcareous soil

A soil containing enough calcium carbonate (commonly combined with magnesium carbonate) to effervesce visibly when treated with cold, dilute hydrochloric acid [1]

Calcium carbonate equivalent

The quantity of carbonate (CO_3) in the soil expressed as $CaCO_3$ and as a weight percentage of the less than 2 mm size fraction [2]

Capillary water

Water held as a film around soil particles and in tiny spaces between particles. Surface tension is the adhesive force that holds capillary water in the soil.[1]

Cation

An ion carries a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.[1]

Cation-exchange capacity (CEC)

The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. The term, as applied to soils, is synonymous with base-exchange capacity but is more precise in meaning.[1]

CEC

See cation exchange capacity

Clay

As a soil separate, the minerals soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.[1]

Claypan

A dense, compact, slowly permeable layer in the subsoil, with a much higher clay content than overlying materials from which is separated by a sharply defined boundary. A claypan is usually hard when dry, and plastic or sticky when wet.[2]

Coarse fragments

See Rock fragments

Coarse textured soil

Sand or loamy sand[1]

Cobble (or cobblestone)

A rounded or partly rounded fragment of rock 3 to 10 inches (7.6 to 25 centimeters) in diameter [1]

Colloid

A particle, which may be a molecular aggregate, with a diameter of 0.1 to 0.001 µm. Soil clays and soil organic matter are often called soil colloids because they have particle sizes that are within, or approach colloidal dimensions.[3]

Compaction

The process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density [3]

Compound

Something formed by a union of elements or parts; especially: a distinct substance formed by chemical union of two or more ingredients in definite proportion by weight [4]

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. Terms describing consistence are defined in the Soil Survey Manual.[1]

Deep soil

See Depth

Depth, soil

Generally, the thickness of the soil over bedrock. Very deep soils are more than 60 inches deep over bedrock; deep soils, 40 to 60 inches; moderately deep, 20 to 40 inches; shallow, 10 to 20 inches; and very shallow, less than 10 inches.[1]

Drainage class (natural)

Refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized: excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained. These classes are defined in the Soil Survey Manual.[1]

Duripan

A subsurface soil horizon that is cemented by illuvial silica, usually opal or microcrystalline forms of silica, to the degree that less than 50 percent of the volume of air-dry fragments will slake in water or HCl [3]

EC

See electrical conductivity

Edaphology

The science that deals with the influence of soils on living things; particularly plants, including human uses of land for plant growth [3]

Electrical conductivity (EC)

The electrolytic conductivity of an extract from saturated soil paste [2]

Element

Basic unit of matter that can't be broken down by chemical means. They are the building blocks of nature. Any of more than 100 fundamental substances that consist of atoms of only one kind and that singly or in combination constitute all matter.[4]

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.[1]

Exchangeable anion

A negatively charged ion held on or near the surface of a solid particle by a positive surface charge and which may be easily replaced by other negatively charged ions (e.g., with a Cl- salt) [3]

Fertility, soil

The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable [1]

Field moisture capacity

The moisture content of a soil, expressed as a percentage of the oven dry weight, after the gravitational, or free, water has drained away; the field moisture content 2 or 3 days after a soaking rain; also called normal field capacity, normal moisture capacity, or capillary capacity [1]

Fine textured soil

Sandy clay, silty clay, or clay [1]

Fragments

Unattached cemented pieces of bedrock, bedrock-like material, durinodes, concretions, and nodules 2 mm or larger in diameter; and woody material 20 mm or larger in organic soils [2]

Genesis, soil

The mode of origin of the soil. Refers especially to the processes or soil-forming factors responsible for the formation of the solum, or true soil, from the unconsolidated parent material.[1]

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.[1]

Gravelly soil material

Material that is 15 to 35 percent, by volume, rounded or angular rock fragments, not prominently flattened, as much as 3 inches (7.6 centimeters) in diameter [1]

Great group

A group of soils that is characterized by common characteristics usually developed under the influence of environmental factors (as vegetation and climate) active over a considerable geographic range and that comprises one or more families of soil—called also great soil group.[4] *See Soil Classification.*

Gypsum

The percent, by weight, of hydrated calcium sulfates in the <20 mm fraction of soil [2]

Hardpan

A hardened or cemented soil horizon, or layer. The soil material is sandy, loamy, or clayey and is cemented by iron oxide, silica, calcium carbonate, or other substance.[1]

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. An explanation of the subdivisions is given in the Soil Survey Manual.

The major horizons of mineral soil are as follows: [1]

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

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

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

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

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

Cr horizon = Soft, consolidated bedrock beneath the soil.

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

Humus

The well decomposed, more or less stable part of the organic matter in mineral soils [1]

Impervious soil

A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.[1]

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 [1]

Infiltration capacity

The maximum rate at which water can infiltrate into a soil under a given set of conditions

Infiltration rate

The rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. The rate can be limited by the infiltration capacity of the soil or the rate at which water is applied at the surface.[1]

Iron depletions

Low-chroma zones having a low content of iron and manganese oxide because of chemical reduction and removal, but having a clay content similar to that of the adjacent matrix. A type of redoximorphic depletion.[1]

Leaching

The removal of soluble material from soil or other material by percolating water [1]

Loam

Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles [1]

Loamy

Texture group consisting of coarse sandy loam, sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam, silt, clay loam, sandy clay loam, and silty clay loam soil textures [3]

Medium textured soil

Very fine sandy loam, loam, silt loam, or silt [1]

Microrelief

(i) Generically refers to local, slight irregularities in form and height of a land surface that are superimposed upon a larger landform, including such features as low mounds, swales, and shallow pits. See also gilgai, shrub-coppice dune, tree-tip mound, tree-tip pit.

(ii) Slight variations in the height of a land surface that are too small to delineate on a topographic or soils map at commonly used map scales (e.g., 1:24 000 and 1:15 840) [3]

Mineral soil
: *Soil that is mainly mineral material and low in organic material. Its bulk density is more than that of organic soil.*[1]

Moderately coarse textured soil
: *Coarse sandy loam, sandy loam, or fine sandy loam* [1]

Moderately deep soil
: *See Depth*

Moderately fine textured soil
: *Clay loam, sandy clay loam, or silty clay loam* [1]

Molecule
: *The smallest particle of a substance that retains all the properties of the substance and is composed of one or more atoms* [4]

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* [1]

Mottling, soil
: *Irregular spots of different colors that vary in number and size. Descriptive terms are as follows: abundance: few, common, and many; size: fine, medium, and coarse; and contrast: faint, distinct, and prominent. The size measurements are of the diameter along the greatest dimension. Fine indicates less than 5 millimeters (about 0.2 inch); medium, from 5 to 15 millimeters (about 0.2 to 0.6 inch); and coarse, more than 15 millimeters (about 0.6 inch).*[1]

Muck
: *Unconsolidated soil material consisting primarily of highly decomposed organic material in which the original plant parts are not recognizable (i.e., "sapric" in Soil Taxonomy). It generally contains more mineral matter and is usually darker in color, than peat.*[2]

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.*

Neutral soil
: *A soil having a pH value of 6.6 to 7.3 (see Reaction, soil)* [1]

Nutrient, plant
: *Any element taken in by a plant that is 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.*[1]

OM
: *See Organic matter*

Order
: *The highest level (most general) of soil classification according to Soil Taxonomy. There are twelve orders: andisols, alfisols, aridisols, entisols, gelisols, histosols, inceptisols, mollisols, oxisols, spodosols, ultisols and vertisols.*

Organic matter (OM)
: *Plant and animal residue in the soil in various stages of decomposition* [1]

Oxidation
: *The loss of one or more electrons by an ion or molecule* [3]

Pan
: *A compact, dense layer in a soil that impedes the movement of water and the growth of roots. For example, hardpan, fragipan, claypan, plowpan, and traffic pan.*[1]

Parent material
: *The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum is developed by pedogenic processes* [2]

Peat
: *Unconsolidated soil material consisting largely of undecomposed, or slightly decomposed, organic matter (i.e., "fibric" in Soil Taxonomy) accumulated under conditions of excessive moisture* [2]

Ped
: *An individual natural soil aggregate, such as a granule, a prism, or a block*

Pedogenesis
: *See Genesis, soil*

Pedology

Soil science, especially the study of soils as a natural body

Pedon

The smallest volume that can be called "a soil." A pedon is three dimensional and large enough to permit study of all horizons. Its area ranges from about 10 to 100 square feet (1 square meter to 10 square meters), depending on the variability of the soil.[1]

Percolation

The downward movement of water through the soil [1]

Permeability

The quality of the soil that enables water or air to move downward through the profile. The rate at which a saturated soil transmits water is accepted as a measure of this quality. In soil physics, the rate is referred to as "saturated hydraulic conductivity," which is defined in the NRCS Soil Survey Manual. 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: [1]

Permeability class	rate per hour
Extremely slow	*0.0 to 0.01 inch*
Very slow	*0.01 to 0.06 inch*
Slow	*0.06 to 0.2 inch*
Moderately slow	*0.2 to 0.6 inch*
Moderate	*0.6 inch to 2.0 inches*
Moderately rapid	*2.0 to 6.0 inches*
Rapid	*6.0 to 20 inches*
Very rapid	*more than 20 inches*

pH value

A numerical designation of acidity and alkalinity in soil. (See Reaction, soil.) [1]

Plowpan

A compacted layer formed in the soil directly below the plowed layer [1]

Ponding

Standing water on soils in closed depressions. Unless the soils are artificially drained, the water can be removed only by percolation or evapotranspiration.[1]

Potential rooting depth (effective rooting depth)

Depth to which roots could penetrate if the content of moisture in the soil were adequate. The soil has no properties restricting the penetration of roots to this depth.[1]

Profile, soil

A vertical section of the soil extending through all its horizons and into the parent material [1]

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: [1]

Reaction class	pH
Ultra acid	*less than 3.5*
Extremely acid	*3.5 to 4.4*
Very strongly acid	*4.5 to 5.0*
Strongly acid	*5.1 to 5.5*
Moderately acid	*5.6 to 6.0*
Slightly acid	*6.1 to 6.5*
Neutral	*6.6 to 7.3*
Slightly alkaline	*7.4 to 7.8*
Moderately alkaline	*7.9 to 8.4*
Strongly alkaline	*8.5 to 9.0*
Very strongly alkaline	*9.1 and higher*

Redoximorphic concentrations

Nodules, concretions, soft masses, pore linings, and other features resulting from the accumulation of iron or manganese oxide. An indication of chemical reduction and oxidation resulting from saturation.[1]

Redoximorphic depletions

Low-chroma zones from which iron and manganese oxide or a combination of iron and manganese oxide and clay has been removed. These zones are indications of the chemical reduction of iron resulting from saturation.[1]

Redoximorphic features

Redoximorphic concentrations, redoximorphic depletions, reduced matrices, a positive reaction to alpha, alpha-dipyridyl, and other features indicating the chemical reduction and oxidation of iron and manganese compounds resulting from saturation.

Reduction

The gain of one or more electrons by an ion or molecule [3]

Relief

The relative difference in elevation between the upland summits and the lowlands or valleys of a given region [3]

Rock fragments

Rock or mineral fragments having a diameter of 2 millimeters or more; for example, gravel, cobbles, stones, and boulders [1]

Root zone

The part of the soil that can be penetrated by plant roots [1]

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.[1]

Saline soil

A nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS/m (mmhos/cm) at 25˚C. Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.[3]

Saline-sodic soil

A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium ratio is greater than 0.15, the conductivity of the soil solution, at saturated water content, of greater than 4 dS m (at 25ºC), and the pH is usually 8.5 or less in the saturated soil.[3]

Salinity

A measure of the "saltiness" of the soil expressed as the electrical conductivity of a saturation extract in decisiemens per meter (dS/m=mmhos/cm) at 25ºC.

The following salinity classes are recognized:[2]

Salinity class	mhos/cm
Non-saline	*0 - 2*
Very slightly saline	*2 - 4*
Slightly saline	*4 - 8*
Moderately saline	*8 - 16*
Strongly saline	*> 16*

Sand

As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.[1]

Sandy

Texture group consisting of sand and loamy sand textures.[3]

SAR

See sodium adsorption ratio

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.[1]

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 (see soil classification).[1]

Shallow soil

See Depth

Silica

A combination of silicon and oxygen. The mineral form is called quartz.[1]

Silt

As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.[1]

Slick spot

A small area of soil having a puddled, crusted, or smooth surface and an excess of exchangeable sodium. The soil generally is silty or clayey, is slippery when wet, and is low in productivity.[1]

Slope

The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.[2]

Slope aspect

The direction toward which the surface of the soil (or slope) faces [2]

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 percent or more of the total exchangeable bases), or both, that plant growth is restricted [1]

Sodicity

The degree to which a soil is affected by exchangeable sodium.1 See sodium adsorption ratio. The following categories are commonly used in California:

Sodicity	*SAR*
Slight	*less than 13:1*
Moderate	*13-30:1*
Strong	*more than 30:1*

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water extract from saturated soil paste. It is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration.2 SAR is calculated from the equation:

SAR = Na / [(Ca + Mg)/2]0.5

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.[1]

Soil classification

The systematic grouping of soils based on their characteristics. The system used in the United States is called Soil Taxonomy. Soil Taxonomy uses the following levels grouping (from most general to most specific): order, suborder, great group, subgroup, family and series.

Soil depth

See Depth, Soil

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: [1]

Name	Size in mm
Very coarse sand	*2.0 to 1.0*
Coarse sand	*1.0 to 0.5*
Medium sand	*0.5 to 0.25*
Fine sand	*0.25 to 0.10*
Very fine sand	*0.10 to 0.05*
Silt	*0.05 to 0.002*
Clay	*less than 0.002*

Stones

Rock fragments 10 to 24 inches (25 to 60 centimeters) in diameter if rounded or 15 to 24 inches (38 to 60 centimeters) in length if flat [1]

Stony

Refers to a soil containing stones in numbers that interfere with or prevent tillage [1]

Structure, soil

The arrangement of primary soil particles into compound particles or aggregates. The principal forms of soil structure are: platy (laminated), prismatic (vertical axis of aggregates longer than horizontal), columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are either single grained (each grain by itself, as in dune sand) or massive (the particles adhering without any regular cleavage, as in many hardpans).[1]

Subgroup

See Soil Classification

Suborder

See Soil Classification

Subsoil

Technically, the B horizon; roughly, the part of the solum below plow depth [1]

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." [1]

Surface soil

The A, E, AB, and EB horizons, considered collectively. It includes all subdivisions of these horizons.[1]

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." [1]

Tilth, soil

The physical condition of the soil as related to tillage, seedbed preparation, seedling emergence, and root penetration [1]

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.

Very deep soil

See Depth

Very shallow soil

See Depth

Water holding capacity (or available water capacity or plant available water)

The volume of water that should be available to plants if the soil were at field capacity. It is commonly estimated as the amount of water held between field capacity and permanent wilting point, with corrections for salinity, fragments, and rooting depth. It is commonly expressed as inches of water per inch of soil.2 The following classes are used in California, based on the water holding capacity of 60-inch depth (or depth to a limiting layer):

Water holding capacity class	Water holding capacity/ 60 inches or limiting layer
Very low	*0 to 2.5*
Low	*2.5 to 5*
Moderate	*5 to 7.5*
High	*7.5 to 10*
Very high	*more than 10*

See available water capacity

Water table

The upper surface of ground water or that level below which the soil is saturated by water. Also the top of an aquifer.[1]

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.[1]

2.2

Soil Chemistry and Fertility

Introduction: Soil Chemistry & Fertility

UNIT OVERVIEW

This unit introduces students to basic concepts in soil chemistry, with an emphasis on how soil chemistry relates to the development and maintenance of soil fertility.

The unit begins with a review of basic chemistry concepts and terminology, including atoms, compounds, ions, and chemical reactions. Soil nutrients essential to plant growth and the processes involved in nutrient uptake are introduced, with particular attention paid to cation exchange capacity (CEC) and base saturation as they relate to soil fertility. Soil pH and its effects on nutrient availability are also covered.

Lecture 2 provides an overview of the biogeochemical cycles involved in making essential nutrients available to plants; the physiological role of essential plant nutrients; the characteristic symptoms of plant nutrient deficiencies; and the soil amendments used to supply limiting nutrients for organic farming systems.

MODES OF INSTRUCTION

> LECTURE (2 LECTURES, 1.5–2.0 HOURS EACH)

Lecture 1 covers basic chemistry concepts and definitions relating to soil chemistry, in particular, nutrient uptake processes and plant nutrients.

In Lecture 2, the role of individual plant nutrients and nutrient cycling are discussed.

> DEMONSTRATIONS

Five suggested demonstrations are designed to be integrated into the lecture. They provide visual representations and analogies for the concepts presented in the outline.

> ASSESSMENT QUESTIONS (1.0 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- Basic chemistry concepts (atomic structure and atomic bonding) and terminology
- Principles and processes involved in cation exchange
- pH and its effects on nutrient availability
- Soil acidity
- Soil alkalinity
- Plant nutrients: What they are, their cycles and how they move through the soil, their use by plants, and the problems plants exhibit when deficient in nutrients

SKILLS

This material is primarily conceptual, providing background for the skill-based sessions in Part 1, Organic Farming and Gardening Skills

REQUIRED READINGS (SEE RESOURCES SECTION)

Gershuny, Grace. 1996. *Start With the Soil,* Chapter 5; Chapter 7, pages 163-173; Chapter 8, pages 187-195; Chapter 9, pages 200-205

Brady, Nyle C., and Ray R. Weil. 2008. *The Nature and Properties of Soils,* Chapter 1, 1.15-1.16; Chapter 16: 16.1-16.4; 16.12

RECOMMENDED READINGS

Stell, Elizabeth P. 1998. *Secrets to Great Soil,* Chapter 2; Chapter 6; Chapter 7, pp. 150-157

Parnes, Robert. 1990. *Fertile Soil: A Grower's Guide to Organic and Inorganic Fertilizers,* Chapter 2, pp. 9-19; Chapter 16 (micronutrients)

Lecture 1: Basic Soil Chemistry Concepts & Nutrient Uptake

Pre-Assessment Questions

1. What are the three most important plant nutrients? What are three other essential plant nutrients?
2. How do plants obtain nutrients from the soil?
3. What might happen if levels of one essential plant nutrient are very low or very high?
4. What is soil pH and why is it important to know the pH of your soil?
5. How does the organic matter content of the soil influence soil fertility?

A. Introduction to Basic Chemistry Concepts

1. Atoms and elements

   Element: a basic unit of matter that can't be further simplified, such as oxygen or iron. Elements are the building blocks of nature. Each element is assigned a symbol of one or more letters, such as O for oxygen and Fe for iron.

   Atom: the smallest part of an element that cannot be broken down by chemical means. Each atom is in turn made up of protons, neutrons, and electrons. Protons have positive electrical charges, electrons have negative charges, and neutrons have no charge. Protons and neutrons are in the center of the atom, comprising the nucleus, while electrons orbit the nucleus. Atoms have no net charge, so there are an equal number of protons and electrons, which is the atomic number. The number of neutrons varies, and is determined by subtracting the atomic number from the mass number (the atomic weight rounded up to the nearest whole number). The atomic weight for each element is given on the periodic table.

2. Compounds, molecules, and atomic bonds

   Atoms combine to form molecules. A collection of like molecules that consist of two or more different kinds of elements is called a compound. Molecules are represented by using the symbols of the elements with subscripts to tell how many there are of each. For example, water is represented as H_2O, which means it has two hydrogen atoms and one oxygen atom.

   One way that different atoms can join together is by sharing electrons. This is a type of chemical bond or atomic bond.

3. Ions

   When there is an imbalance in the number of protons and electrons of an atom, the resulting atom or molecule is called an ion. Ions are commonly formed, for example, when a compound dissolves in water. A cation is a positively charged ion (missing electrons) and an anion is a negatively charged ion (has surplus electrons). The example below shows calcium carbonate (on the left) when it dissolves in water (on the right). The superscript numbers indicate the number of missing (+) or surplus (-) ions. If no number is given and there is just a + or - then there is an imbalance of only one (1) electron.

   $CaCO_3 \rightleftarrows Ca^2 + CO_3^{2-}$

   Where:

   $CaCO_3$ = Calcium Carbonate
   Ca^{2+} = Calcium (cation)
   CO_3^{2-} = Carbonate (anion)

A molecule in solution is usually in equilibrium with its constituent ions. In other words, some molecules are breaking into ions while other ions are recombining to form molecules.

4. Elements needed by plants
   a) From water and air
      Carbon (C), Hydrogen (H), Oxygen (O)
   b) From soil
      Nitrogen (N), Phosphorus (P), Sulfur (S), Potassium (K), Calcium (Ca), Magnesium (Mg), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), Boron (B), Molybdenum (Mo), Cobalt (Co), Chlorine (Cl)
5. Chemical reactions

   Chemical reactions occur when atoms are rearranged to form new molecules or compounds. For example, carbon dioxide and water can combine to form a sugar (as in photosynthesis). This reaction is written out like this:

   $$6CO_2 + 6H_2O + \text{Energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

   (Note that since energy is required to make the reaction happen, this energy is released when the sugars are broken down. This energy-releasing equation is called respiration and is what happens in our bodies—and in some form in all organisms—all the time.)

   Redox reactions are paired oxidation and reduction reactions that are very common and important in nature. Oxidation occurs when an element or molecule loses an electron, and reduction occurs when another element or molecule gains the electron. The electron donor is said to be oxidized and the electron acceptor is reduced. The "ox" in redox is used because it was first studied in aerobic environments, with oxygen as the element that accepts the electrons (and thus increases in quantity in the new molecule).

   A common redox reaction occurs in the soil when ammonia is added: In the presence of oxygen, ammonia (NH_3) is oxidized to form nitric acid (HNO_3, which now contains oxygen) and water

   $$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$$

   (ammonia + oxygen → nitric acid + water)
6. Adsorption vs. absorption

   Adsorption and absorption are two similar soil science terms with almost opposite meanings

   Adsorption means to be held onto the outside of something. In soils this refers to how ions are held to the outer surfaces of mineral and organic particles.

   Absorption means to be taken up into something, such as water being taken up by a sponge or nutrients being taken into plant roots

   Picture a life raft at sea: Absorbed would be the people in the life raft, adsorbed would be the people hanging to the outside of the life raft
7. Organic vs. organic

   Organic is another term with multiple meanings. To the chemist, organic refers to many kinds of compounds containing carbon, which may be natural or synthetic (human-made). Many of the synthetic pesticides used are "organic" by this definition.

   Organic also refers to agricultural practices based on maintaining soil fertility through organic matter. Such systems do not use synthetic organic chemicals. When growers or food processors abide by a particular set of U.S. Department of Agriculture regulations and their practices are confirmed for that site by a certifying agency, they legally may market their food as "organic."

B. Soil Colloids

1. Definition

   Colloid: A particle, either mineral or organic, with a diameter of 0.1 to 0.001 µm. Because of their small size, colloids go into suspension in a solution—they float around for great lengths of time without settling out. Clay particles and soil organic matter are common examples of soil colloids.

2. Importance

   Colloids have properties that are important in soil chemistry. For example, because of their small size they have a high relative surface area that has a charge, so they can adsorb cations. This is key for Cation Exchange Capacity (see CEC, below), but also for maintaining the structure of the soil (binding particles together) and for its water-holding capacity (higher concentration of colloids means greater ability to hold water).

C. Soil Solution

1. Definition

   Water in the soil is referred to as the soil solution because it contains dissolved materials (cations and ions) as well as suspended colloids of clay and organic matter

   While plants tend to get their nutrients from the soil solution, the solution does not contain sufficient nutrients at any one time to last the life of the plant. Usually these nutrients are replenished from the pool of exchangeable nutrients (those that are adsorbed onto colloids; see CEC, below). Still more nutrients are held in what is called the stable pool (bound up in solid form as minerals or organic matter).

D. Cation Exchange Capacity (CEC) and Base Saturation

1. CEC

   a) Definition

      CEC is a measure of the ability of the soil to adsorb cations. Plants are primarily able to take up the ionic form of nutrients via their roots. Many of these nutrients are taken up as cations (remember, these are positive ions). Most soils have at least some ability to hold onto cations at negatively charged sites, called exchange sites, on soil particles. **(Demonstration: Use magnets to demonstrate attraction of positive to negative.)** The cations are held loosely to the edges (adsorbed) such that they can be easily replaced with similarly charged cations. The total amount of the cations that the soil can hold adsorb is the cation exchange capacity (CEC).

   b) Measurement: CEC is measured as milliequivalents (meq) per 100g of soil or centimoles (cmol) per kg. These are actually two ways of expressing the same numbers.

   c) Factors influencing CEC

      i. Amount and type of clay

         Higher amounts of clay in the soil (relative to sand and silt; see more at Unit 2.1, Soil Physical Properties) mean higher CEC. Certain kinds of clay (smectites, montmorillonite) have higher CEC than others (such as kaolinite).

      ii. Amount of organic matter

         Higher amounts of organic matter in the soil mean higher CEC

      iii. pH-dependent CEC

         Clay minerals and organic matter have a CEC that varies with pH. As pH increases, so do the number of negative charges on the clay or organic matter particles, and thus so does the CEC.

2. Base saturation

a) Definitions

Base saturation refers to the percentage of CEC sites that are occupied with bases (usually Ca^{2+}, Mg^{2+}, K^+ and Na^+) instead of ions that make the soil acidic (H+ or Al3+). Base saturation is often expressed as a percent.

The term *exchangeable bases* usually refers to the Ca^{2+}, Mg^{2+}, K^+ and Na^+ adsorbed to CEC sites.

b) Significance

Soils with high base saturations are considered more fertile because many of the "bases" that contribute to it are plant nutrients. Usually the base saturation is 100 percent when the pH is above about 6.5. Since rainfall tends to leach bases out of the soil, areas with higher rainfall tend to have lower base saturations than areas with lower rainfall, unless the parent material is high in bases (such as limestone).

E. Anion Exchange Capacity (AEC)

1. Definition

While positively-charged cations adsorb to negatively-charged sites, the opposite is true for negatively-charged anions: They adsorb to sites with a positive charge. This is anion exchange capacity, AEC. Nutrients that are usually supplied by anions are nitrogen (as NO_3), phosphorus (as HPO_4^{2-}), sulfur (as SO_4^-), chlorine (as Cl^-), boron (as $B_4O_7^{2-}$) and molybdenum (MoO_4-).

2. Measurement: Just like CEC (above), AEC is measured as milliequivalents (meq) per 100g of soil or centimoles (cmol) per kg.

3. pH-dependent AEC: Most clay particles only have negative exchange sites, so they have CEC in neutral and high pH conditions and sometimes AEC at low pH. Soil organic matter has both negative and positive exchange sites; it usually has CEC and may have AEC in very low pH (2 or lower) conditions. Most productive soils in the U.S. have pH well above the pH necessary for AEC, so this process plays a minor role in nutrient provision here. Highly weathered soils of the tropics are more likely to have AEC.

4. Nutrient leaching: Because there is generally little adsorption of anions, many (particularly nitrates) are easily leached down through the soil with rain or excess irrigation. This can lead to groundwater contamination, which can even happen in organic farming if the N is not well managed.

F. pH

1. What is pH?

pH stands for "potential of hydrogen" and it is expressed as the negative of the log of the concentration of hydrogen (H^+) ions. It is given as a number between 0 and 14. (Pure water is neutral with a pH of around 7.) In acidic soils (pH < 7), H^+ ions predominate. In alkaline soils (pH > 7), OH^- ions predominate. Soils with pH of 7 are neutral. **(Demonstrate different methods of measuring pH; see pH demonstration in Demonstrations.)**

▶ **TABLE 2.11** | SOIL REACTION AND pH

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

2. Effect of pH on nutrient availability and uptake (see ◀ Figure 2.8, Nutrient Availability at Different pH Values)

   Although pH does not directly affect plants, it does affect the availability of different nutrients to plants. As we've seen in the CEC and AEC sections above, nutrients need to be dissolved in the soil solution before they can be accessed by plants. The soil pH changes whether a nutrient is dissolved in the soil solution or forms other less-soluble compounds (e.g., calcium compounds in high pH soils with high calcium carbonate concentrations), or if dissolved is then susceptible to leaching (e.g., nitrate).

3. pH and soil microbes

   Soil microbes have reduced activity in low pH soils. This can cause them to take much longer to release necessary nutrients, such as N, P, and S, from organic matter.

G. Acidity

1. Definitions

   Acidity refers to the condition of the soil when the exchange sites on soil colloids (collectively called the *exchange complex*) are dominated by hydrogen (H^+) and aluminum (Al^+) ions. As described above, these soils have pH <7.

2. Distribution of acid soils

   Acidic soils usually occur where rainfall leaches the cations out of the soil over time. In the U.S. there is a fairly strong correlation between precipitation and pH, with soils receiving more than about 30 inches of annual precipitation having a pH < 6. (See map on page 163 of *Start with the Soil*.)

3. Problems associated with acidity

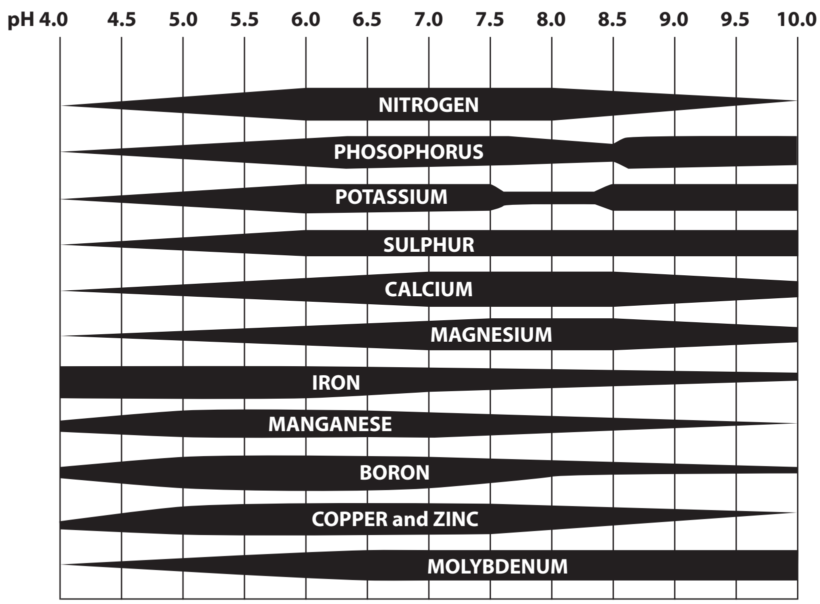
   Aluminum toxicity: Aluminum becomes more available when pH is pH <6 and especially <4.75, and can be toxic to plants.

   Manganese toxicity: This may occur in soil that are high in Mn and that have a pH < 5.

4. Acid soils and liming

   Lime (calcium carbonate) is added to acid soils to raise the pH (see Unit 1.11, Reading and Interpreting Soil Test Reports). Calcium (Ca^{2+}) replaces hydrogen and aluminum on the exchange sites. For a good reference on liming, see the Soil Quality – Agronomy Technical Note Number 8 (listed in Resources). **(See Acid Demonstration in Demonstrations.)**

◀ **FIGURE 2.8** | NUTRIENT AVAILABILITY AT DIFFERENT pH VALUES. MAXIMUM AVAILABILITY IS INDICATED BY WIDEST PART OF BAR.



H. Alkaline, Saline, and Sodic Soils

1. Overview

   Alkalinity and acidity: Soils that vary from a neutral pH have varying degrees of alkalinity (pH > 7) or acidity (pH < 7). The mean soil pH in the U.S. is around 6.4.

   Salinity: Soils that have excess soluble salts in the soil solution have varying degrees of salinity

   Sodicity: Soils that specifically have excess sodium in the soil solution are called sodic

2. Alkalinity

   Soils in arid and semi-arid areas can lack enough rainfall to leach cations, especially calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+), from the soil. These cations bind many of the CEC sites, blocking hydrogen (H^+) ions from binding and making the soil alkaline. This can also happen if irrigating with water high in calcium bicarbonate or magnesium bicarbonate.

3. Salinity

   A soil containing sufficient soluble salts (these salts include Mg^{2+}, Na^+, Ca^{2+}, chloride (Cl^-), sulfate
   (SO_4^{2-}), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}). Saline soils mainly occur in dry areas, again, where there is not enough precipitation to leach the salts from the soil, so the salts build up over time. In order for there to be salts in the soil, there must be a source for them. Some come from former ocean floors that were under ancient seas but are now exposed. Some parent material (rocks from which the soil was formed) also may release salts, such as carbonate from limestone or sodium from feldspar. **(See Salt Crust Example and Conductivity Demonstration in Demonstrations.)**

   Some salts are toxic to plants and others bind so tightly to water that the plants cannot access it. In addition, it can be difficult for non-saline water to infiltrate saline soils, so it may be necessary to add gypsum to the water to aid infiltration.

4. Sodicity

   A soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant types. Many saline soils are also sodic, although not necessarily. Sodium is toxic to plants. It also causes soil particles to disperse (separate), which causes cracking and sealing of the soil surface, leading to poor soil structure and decreased water intake.

   Sodic soils can be reclaimed with a two-step process. First the sodium is flushed from CEC sites by adding amendments high in calcium (such as lime, gypsum, or dolomite) or by adding sulfur followed by lime. (The sulfur is converted to sulfuric acid by microbial activity. The sulfuric acid then reacts with lime to free calcium.) In either case, the Ca^{2+} ions replace the Na^{+} cations, freeing the Na^{+} in the soil solution. The second step is to leach out the sodium ions by irrigating in excess of what the plant needs.

5. Quantitative definitions

   Specifically, alkaline, saline, and sodic soils are defined as such:

   a) Alkaline soil: Has a pH of > 8.5 or with an exchangeable sodium percentage (ESP, that is, the percent of the CEC occupied just by sodium) greater than 15%. Soils at this ESP contain sufficient sodium to interfere with the growth of most crop plants.
   b) Saline soil: Soil salinity is determined by measuring the electrical conductivity (EC) of a saturated paste of soil: if the EC is greater than 4 dS/m (decisiemens per meter), the soil is classified as saline. However this is a rough range: salt-sensitive plants can be affected at half this EC and highly tolerant plants can handle up to about twice this EC.
   c) Sodic soil: A soil in which the ESP is at least 15%.The amount of sodium in the soil may also be expressed by the Sodium Adsorption Ratio (SAR), which reflects the degree to which the CEC sites in the soil are occupied by sodium instead of other cations. A soil with a SAR greater than 13 is considered sodic. An ESP of 15% is roughly equivalent to a SAR of 13.
   d) Saline-sodic soil: A soil containing both high soluble salts in general and high sufficient exchangeable sodium in particular. The ESP is at least 15%, the EC of the soil solution is >4 dS/m , and the pH is usually < 8.5.

I. Soil as a Medium for Plant Growth

1. Nutrient uptake processes

   (This section is adapted from material produced by the University of Saskatchewan)

   Imagine you are a tiny creature trying to move around in the soil. You are surrounded by millions of pores of all sizes and shapes, shaped and blocked by particles of organic matter and minerals. The surfaces of these particles are chemically active, adsorbing ions and organic molecules all around you. You start to learn your way around, but your microenvironment changes with each wet-and-dry cycle and freeze-and-thaw cycle. Sometimes it's not a physical process but a biological one that rearranges the structure of your little world, like a burrowing animal that tunnels through. In short, you live in a constantly changing soil ecosystem that has numerous barriers to the movement of organisms and chemicals.

   In terms of soil fertility we are particularly interested in the physical component of the soil ecosystem. For a nutrient to be available for the plant to take up it must meet two criteria: 1) it must be in the proper chemical form to pass the root membrane; and 2) it must be available at the root surface.

   Nutrients move through the soil to plant roots in three ways:

   - root interception
   - mass flow
   - diffusion

Each nutrient will have one or more of these methods of movement depending on its chemical form (including how strongly they are adsorbed by mineral and organic matter particles) and soil physical and chemical conditions (including the concentration of the nutrient in the soil)

a) **Root interception**

Plant roots are constantly expanding (opening up blocked pores as they do so), growing from areas of depleted nutrients (e.g., because of prior plant uptake) to regions where nutrients are more concentrated

Although many plants, such as cereals and other grasses, have a very extensive root system, they contact less than 5% of the soil volume. The root interception mechanism is very valuable, however, because root growth can extend the root into areas where mass flow and diffusion then take over. For example, a root could grow within a few millimeters of some soil phosphorus hot spot. Although the root does not technically bump into the nutrient and intercept it, the root is close enough for diffusion to occur and the phosphorus to move into it (see below). In some cases, the presence of mychorrhizal fungi increases the nutrient-absorption capacity of root systems (see Unit 2.3, Soil Biology and Ecology). Root interception allows for uptake of some calcium, magnesium, zinc, and manganese.

b) **Mass Flow**

Growing plants are continually taking up water from the soil profile, a process driven by transpiration (loss of water from the plant via stomata on the leaves). Dissolved in the soil water are soluble nutrients. These nutrients are transported along with the water to the root surface. Nutrients, such as nitrogen as nitrate and sulfur as sulfate, that are held very weakly by soil particles readily move along with the water. But nutrients, such as phosphorus as orthophosphate, that are strongly adsorbed to the soil particles are not able to reach roots by mass flow. Mass flow allows for the uptake of most of a plant's nitrogen, calcium, magnesium, sulfur, copper, boron, manganese and molybdenum.

c) **Diffusion**

Diffusion is the movement of ions along a gradient from a high concentration to a lower concentration, until the ions are evenly distributed. For example, imagine you have a tank of water with a removable barrier in the middle. On one side of the barrier you pour ink, while the other side stays pure water. If you remove the barrier very slowly you will see the ink and water mix as the molecules move from an area of high concentration (the inky side) to an area of low concentration (the pure water side). Similarly, nutrients move from areas of high concentration in the soil solution to areas of lower concentration. This is a very slow process, but it is the dominant mechanism of movement for phosphorus and potassium, which are strongly adsorbed on the soils and present in low concentrations in the soil solution.

Lecture 2: Plant Nutrient Requirements & Nutrient Cycles

A. Plant Nutrient Requirements

1. Introduction

   a) Nutrient balance

      Although it is easier to consider one nutrient at a time, it is important to think of plant needs holistically. Supplying one nutrient while ignoring other plant needs, including other nutrients and environmental factors such as temperature, water, and light, may have little benefit or even be detrimental to the crop.

      Justus von Liebig (1803–1873) analyzed plant samples and proposed a law of the minimum. This law states that plant growth is proportional to the amount available of the most limiting plant nutrient. For example, if I supply nitrogen sufficient to produce 70 bushels of wheat per acre but only supply enough phosphorus for 50 bushels per acre, then I will get only 50 bushels per acre (providing everything else is sufficient). This concept has since been expanded to include not only nutrients but also environmental factors.

      As important as Liebig's contributions are, they do not address the situation holistically. In the above example, for instance, nitrogen that is applied in excess of what the crop will consume is in danger of being leached into the groundwater, where it will become a pollutant (see Unit 1.6, Irrigation–Principles and Practices). Also, applying too much of any one nutrient can be injurious. For example, if too much nitrogen is supplied to tomatoes relative to the amount of phosphorus supplied, you may end up with vigorous plants that don't produce any fruit.

      One advantage of organic farming and gardening is that natural and organic soil amendments, unlike many synthetic ones, frequently supply many nutrients at once, including micronutrients

   b) Feed the plant or feed the soil

      One of the main distinctions of organic farming and gardening is its emphasis on feeding the soil rather than on feeding the plant (which most contemporary agricultural practices do). The crux of this idea is that healthy soil produces healthy, productive plants. However, we still need to keep in mind the nutrient needs of the plant, because the plant may need some nutrient that the soil is perfectly content to do without.

      The reason for this is that most soils are well suited to supply the needs of the native vegetation. While a soil may have no problem supporting coastal chaparral or a deciduous forest, it may be ill suited for growing a healthy field of lettuce or a corn crop.

   c) Macronutrients and micronutrients

      Plant nutrients are divided into two categories. Macronutrients are those that make up the greatest proportion of the plant and so are needed in large quantities. These are nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. Micronutrients are needed in small quantities, but are no less important; however, deficiencies of these are less likely to occur. Micronutrients include boron, copper, iron, manganese, molybdenum, zinc, chlorine, and cobolt.

   d) Nutrient cycling

      The amount of each chemical element in the world (with some exceptions) is fixed. Consequently, if we remove all of one element from a location, it's not going to be available there anymore unless it is replaced. This is a very important consideration in soil chemistry and plant nutrition. While some nutrients cycle within the farm, returning to the soil via manure or compost, other nutrients leave the farm, e.g., when crops are taken to market. The nutrients in these crops need to be replaced in the soil. In this sense, farming and gardening are little more than moving nutrients around.

Some details of different nutrient cycles will be discussed further below (see the sections on the individual nutrients)

e) Mobility of nutrients within the plant

Some nutrients are mobile within plants; others remain where they are. This affects how nutrient-deficiency symptoms appear. Nutrients that are mobile can move from older leaves to the sites of new growth, especially if those nutrients are in short supply. Consequently, when these nutrients are lacking, symptoms first appear in the older (lower and inner) leaves. Mobile nutrients include nitrogen, potassium, phosphorus, magnesium, molybdenum, and zinc.

Nutrients that are immobile cannot be translocated to young, new growth. As a result, deficiency symptoms first appear in younger (upper and outer) tissues. Nutrients that are immobile include sulfur, calcium, iron, manganese, boron, and copper.

2. Carbon, hydrogen, and oxygen

a) Plants and animals are primarily made up of carbon, hydrogen, and oxygen. Plants obtain carbon and oxygen from the air (as CO_2 and O_2) and hydrogen and oxygen from water (H_2O). With the help of light energy, they recombine these three elements into carbohydrates. This happens in the leaves of plants during photosynthesis:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

b) Carbon, hydrogen, and oxygen also combine to form hydrocarbons, the long molecular chains that make up fats, and the same three elements combine with nitrogen to form the main structure of proteins. Overall, these three elements are key components of the large organic molecules that comprise all living beings. The carbon cycle, as depicted in ◀ Figure 2.9, the Carbon Cycle, describes the movement of carbon as it is recycled and reused by animals, plants, and microbes.

c) Carbon also plays a key role in global climate change, as increased levels of CO_2 and CH_4 (methane) in the atmosphere (along with water vapor and a few other gases) reflect infrared radiation to the earth, overall increasing the average surface temperature. Ecologists and soil scientists have been examining the potential for building up soil organic matter as a way to sequester C, removing it from the atmosphere and maintaining it in the soil. How large a role this could play in mitigating C emissions from human activity is being debated.

3. Nitrogen (N)

a) Physiological role in plant development

Plants take up nitrogen either as the ammonium ion (NH_4^+) or nitrate (NO_3^-). Most organic compounds in plants contain nitrogen, including amino acids, nucleic acids, many enzymes and energy transfer materials such as chlorophyll, ADP, and ATP. N is necessary for the production of sugars such as is found in sweet ripe fruit. Growing plants must have N to form new cells, so it is essential for plants.

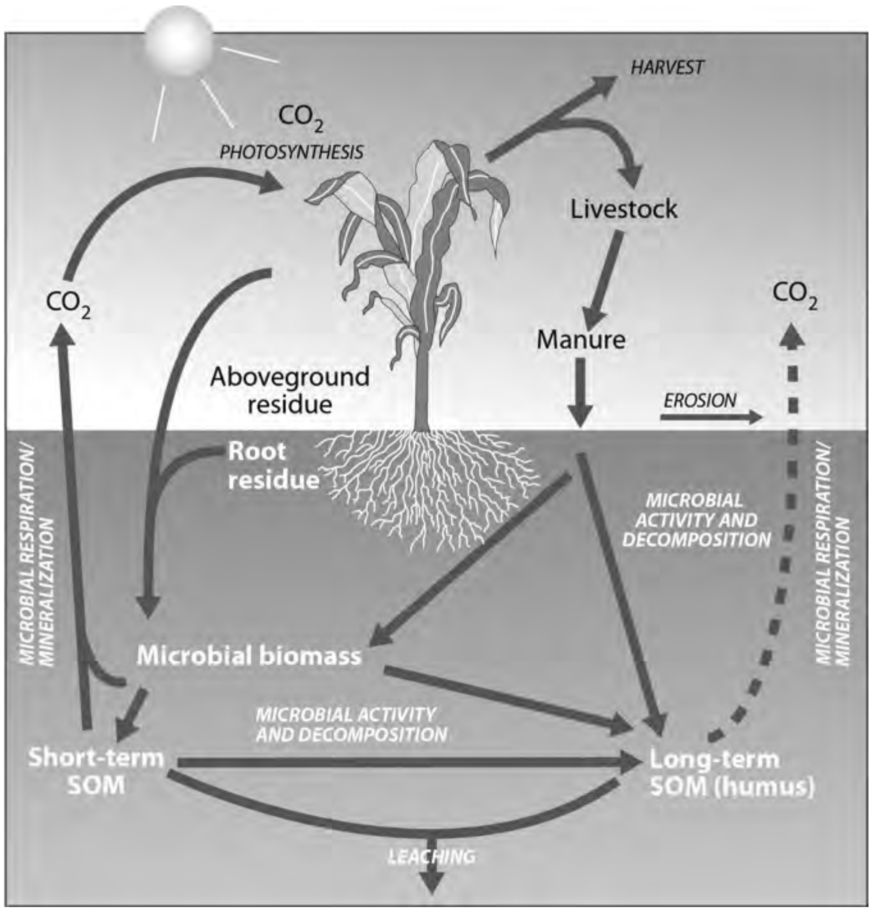
b) Soil nutrient imbalances

Nitrogen deficiency symptoms in plants include:

i. Slow growth, stunted plants

ii. Yellow-green color (chlorosis)

FIGURE 2.9 | THE CARBON CYCLE (ADAPTED FROM MICHIGAN STATE UNIVERSITY EXTENSION BULLETIN E-2646)



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   iii. Firing (burnt look) of tips and margins of leaves beginning with more mature leaves
   iv. Low protein content of crops

c) Symptoms of nitrogen excess include:
   i. Dark green, succulent, vegetative growth at the expense of seed production in grain crops, the expense of fruit production in tomatoes and some tree crops, and the expense of sugar content in beets
   ii. Watery potatoes
   iii. Frost damage if there is too much succulent growth when frost hits
   iv. Weakened stems (lodging)
   v. Delayed flowering or fruiting
   vi. Boron or copper deficiency due to inhibited uptake of these nutrients

d) Forms of nitrogen in the soil

   Nitrogen occurs in the soil in various forms:
   i. Nitrogen gas in the soil air (N_2)
   ii. Nitrate (NO_3^-)
   iii. Nitrite (NO_2^-)
   iv. Ammonium (NH_4^+)
   v. Ammonia (NH_3)—a gaseous, transitory form
   vi. In various other forms as part of complex organic molecules

These forms are the main components of the nitrogen cycle (see ◀ Figure 2.10, the Nitrogen Cycle, page 2-66)

e) Nitrogen fixation

  i. Nitrogen gas makes up about 78% of the atmosphere. It is a very stable form of nitrogen, but it is unavailable to plants. However, certain bacteria are able to transform N_2 gas into nitrate. This is called biological nitrogen fixation (as opposed to industrial nitrogen fixation carried out by chemical factories, which use large amounts of energy to "fix" the N_2 gas into ammonium). During biological N fixation, microbes form symbiotic relationships with plants: the microbes provide N to the plants and the plants provide sugars from photosynthesis to the microbes.

  ii. The main N-fixing bacteria in agricultural systems are from the genus *Rhizobium*, and are associated with plants of the bean family (Leguminosae). Bacteria in the genus *Frankia* and some species of free-living or lichen-forming cyanobacteria also are able to fix N, but are generally less important in agroecosystems.

  iii. In some cases, there may not be sufficient natural populations of *Rhizobia* to form symbioses in a high proportion of the crop, or the *Rhizobia* species present in the soil may not be the right species for the crop you are planting. In these cases it may be necessary to inoculate the seed with a commercial inoculant when the crop is planted. Some seeds come pre-inoculated, while others need to be mixed with an inoculant prior to planting.

  iv. Inoculating legume seed does not mean that it will not be necessary to supply additional N to the crop. The crop and the *Rhizobia* themselves need N to get started. Also, *Rhizobia* need sufficient phosphorus, iron, molybdenum, and cobalt.

▶ **TABLE 2.12** | COMPARISON OF NITROGEN FIXATION SOURCES.
VALUES ARE IN MILLIONS OF METRIC TONS PER YEAR ON A GLOBAL BASIS (APPROXIMATE VALUES)

NON BIOLOGICAL		**BIOLOGICAL**	
Industrial	~50	Agricultural land	~90
Combustion	~20	Forest and other land	~50
Lightning	~10	Seas	~35
TOTAL	~80		~175

f) Ammonification and nitrification

Ammonification is the release of ammonium ions from decomposing organic matter. This process is also called N mineralization, as it changes the unavailable organic forms of N into plant-usable forms. Many microbes are capable of doing this, so an environment that is favorable to microbial growth makes for fairly rapid ammonification. The ammonium that is produced is held in the soil solution, adsorbed onto CEC sites, or taken up by plants.

Nitrification is a two-stage process in which ammonium is transformed into nitrate. This, too, depends on microbial activity: *Nitrosomas* spp. oxidize ammonium to nitrite and *Nitrobacter* spp. oxidize nitrite to nitrate.

g) Denitrification

N can be lost from wet soils where anaerobic conditions occur. Under these conditions some bacteria get their oxygen from nitrate rather than oxygen gas, releasing N_2 gas back into the atmosphere. This process is called denitrification. Though N can be lost from the soil ecosystem this way, denitrification can be a very useful function where excess concentrations of nitrate occur in the soil.

To minimize denitrification, soil should have good structure and thus good aeration and drainage, a pH near neutral, and residues incorporated in the upper few inches of the soil where there is more oxygen. Note that due to microhabitats and conditions in the soil, even well- drained soils may have areas that become anaerobic at some times.

h) Immobilization

N is unavailable to plants (immobilized) when it is in the organic form. Usually, rates of mineralization in the soil are higher than rates of immobilization. However, if organic matter added to the soil has less than 1.5% N, soil microbes will rapidly take up the available N, so that the rate of immobilization will temporarily exceed the rate of mineralization. This temporarily decreases the amount of N available to plants.

i) Losses of N through leaching and volatilization

N is one of the nutrients most easily lost from the soil. Ammonia is easily volatilized, so organic matter left on the soil surface will rapidly lose total N. Volatilization increases with warmer temperatures.

N as nitrate is easily leached, moving down through the soil profile with precipitation or high levels of irrigation. This is a loss to the crop because of a decrease in the pool of plant-available N, as well as a problem for ground and surface water, where excess N generally has negative ecosystem effects. Leaching occurs most in sandier soils, exposed soils (i.e., without crops to take up the N), and in soils low in organic matter.

j) Supplying nitrogen to the soil

There are many ways that N can be supplied to the soil. These include green manures (N-fixing cover crops), crop rotation with leguminous crops, and amendments. Amendments that supply high quantities of N include animal manures, guano, cottonseed meal, bone meal, hoof and horn meal, bloodmeal, and fish emulsion.

Care must be taken when using amendments high in ammonia, such as fresh poultry manure. Ammonia is a strong base that can "burn" plants. However, its use over an extended period of time will acidify the soil as bacteria oxidize the ammonia to form nitric acid.

CARBON-NITROGEN RATIOS

Microbial action can either mineralize or immobilize nitrogen. The main factor in determining which will happen is the carbon to nitrogen (C:N) ratio. Microbes use carbon (from organic matter) for growth as well as for energy. The nitrogen entering their bodies needs to be in a fixed ratio to the amount of carbon. The critical range of the C:N ratio is ~22:1 to 25:1. Ratios higher than this (i.e., more than 25:1) will cause N to be immobilized. Lower ratios will lead to available NH4+ or NO3- as organic matter decomposes. Most plant residues have C:N rations of 20:1-100:1; the bodies of microorganisms have a C:N ratio of 4:1 to 9:1. Usually soil OM stabilizes with a C:N ratio somewhere between 8:1 to 15:1.

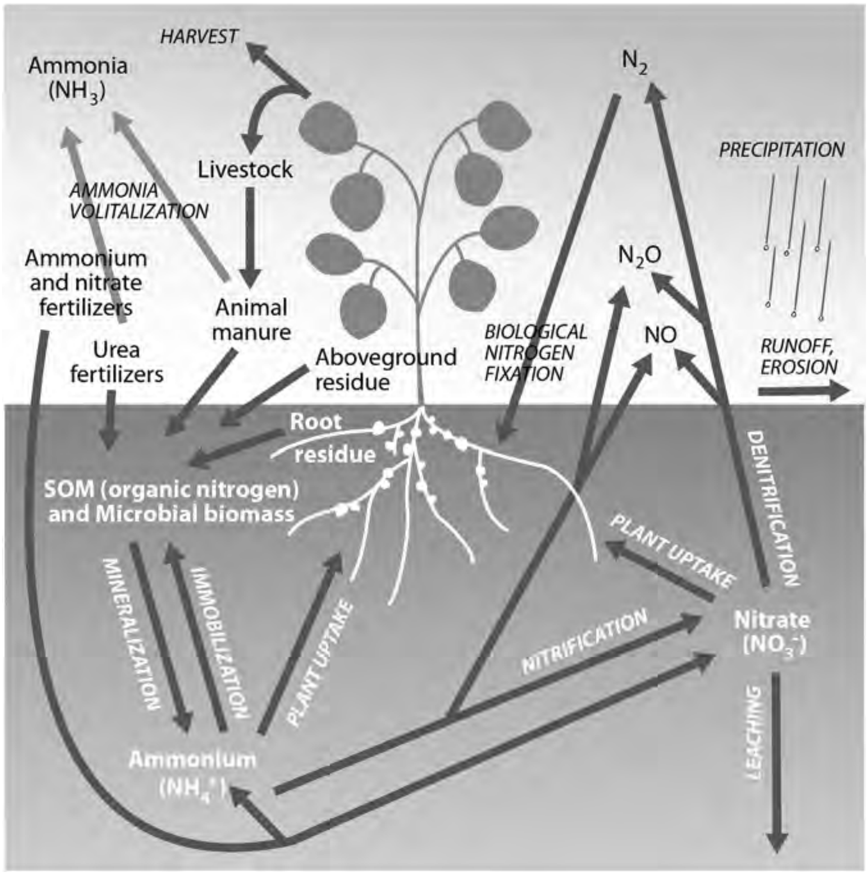
NITRATE TOXICITY

When infants consume nitrate, it is converted to nitrite in the anaerobic conditions in the gut. This nitrite gets absorbed into hemoglobin molecules, which reduces their oxygen-carrying capacity, and can cause "blue-baby syndrome" (see Supplement 4, Nitrate Contamination of Groundwater, in Unit 1.5, Irrigation—Principles and Practices). In humans, nitrate can also react with amino acids to form nitrosamines, which are carcinogenic.

PHOSPHORUS AND WATER QUALITY

When soil is lost through erosion, it carries any P that is adsorbed to it. When the P enters freshwater lakes and streams it acts as a fertilizer, causing an excess growth of plants and algae. When the plants and algae die, they are consumed by microbial decomposers, which respire as their populations grow, and use up dissolved O_2 in the water. This decreases the amount of O_2 available for fish, invertebrates, and plants, in some cases creating "dead zones."

◀ **FIGURE 2.10** | THE NITROGEN CYCLE (ADAPTED FROM MICHIGAN STATE UNIVERSITY EXTENSION BULLETIN E-2646)



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4. Phosphorus (P)
   a) Physiological role in plant development

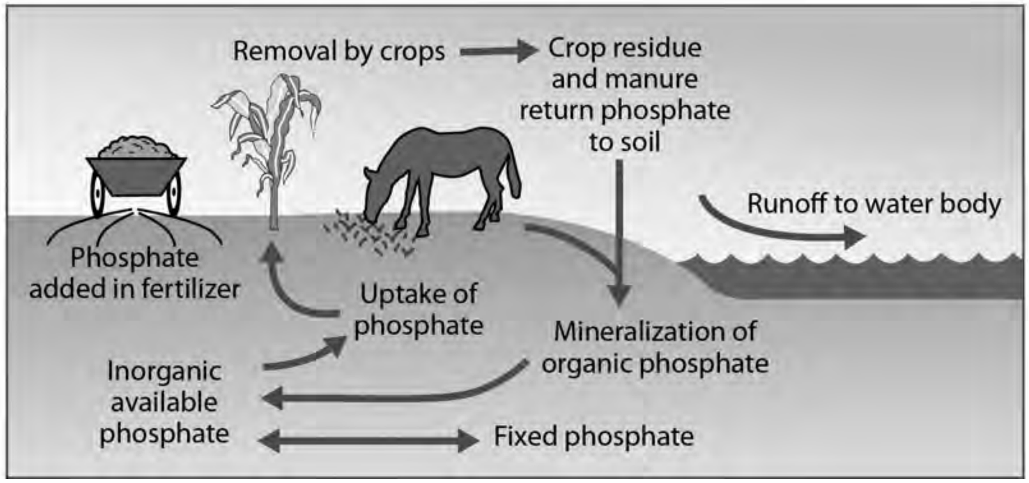
      P is present in all living cells, including as nucleic acids (DNA and RNA), as part of phospholipid cell membranes, and as molecules for energy storage and transfer (ATP). P also stimulates early growth and root formation, hastens bloom time, and promotes seed production and size. It is used in protein synthesis and is found in legume nodules.
   b) Soil nutrient imbalances

      P must be balanced with N both in the plant and in the soil. In the soil, P and N compete to be taken up. Because N is highly mobile and P is one of the least mobile nutrients, excessive N availability can cause a P deficiency, even if there is enough P in the soil for the crop.

      Phosphorus deficiency symptoms in plants include:

      i. Slow growth, stunting
      ii. Purplish coloration on foliage of some plants
      iii. Dark green coloration with tips of leaves dying
      iv. Delayed maturity
      v. Poor grain, fruit, or seed development

◀ **FIGURE 2.11** | THE PHOSPHORUS CYCLE (ADAPTED FROM WWW.EXTENSION.UMN.EDU/DISTRIBUTION/CROPSYSTEMS/)



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c) The phosphorus cycle (see ◀ Figure 2.11, the Phosphorus Cycle)

Phosphorus is not easily leached from the soil because it is adsorbed tightly to soil particles. Consequently, the main losses of P from agroecosystems are either by removal of crops (e.g., for sale and use off-farm) or by soil erosion. Most phosphate pollution of lakes and streams is from sediment that is high in P.

d) Phosphorus in soils and factors affecting its availability

i . Plants take up phosphorus as $H_2PO_4^-$, HPO_4^{2-}, or PO_4^{3-} depending on soil pH. $H_2PO_4^-$ is more available in very acid conditions while PO_4^{3-} is more available in very alkaline conditions. Maximum availability occurs between pH 6.5 and 7.2.

ii. Some soils will bind P in nearly irreversible forms. This "fixing" capacity of a soil is largely dependent on the amount and types of clay present in the soil. For example, clays made up of iron, aluminum, and manganese oxides have high P-fixing ability. These clays are commonly found in weathered soils (Oxisols and Ultisols) in warm humid climates and in soils affected by volcanic ash (Andisols). Usually these conditions are dealt with by adding enough P to the soil to satisfy its P-fixing ability.

iii. Phosphorus is highly immobile. Because roots only take up what is only a fraction of an inch away, if the P is not close to the root, it will not be available. Maintaining adequate moisture throughout the growing season facilitates P movement.

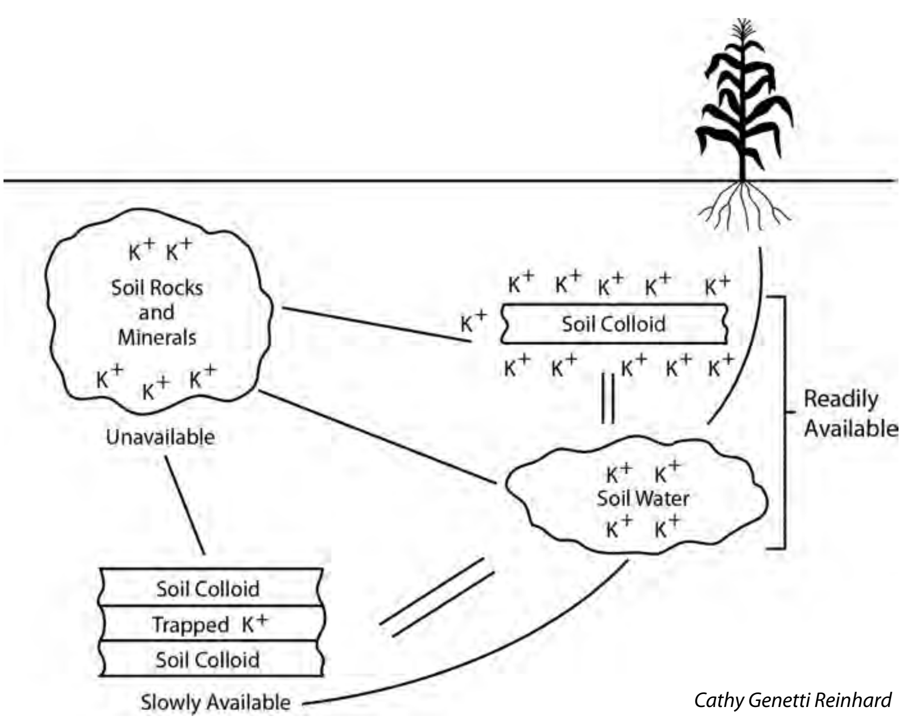
iv. P availability is also affected by temperature. In cool temperatures, plants may show P deficiencies even though there is enough present in the soil for the plant needs. As temperatures warm, deficiency symptoms may go away. Organic P tends to be more available than inorganic, so use of organic amendments, along with promoting biological activity, will make P more available.

e) Phosphorus in amendments

The best source of P to use in the garden is "recycled," from compost and manures. Compost and manures are fairly low in P content but their organic form of P may be more available than from some other sources. Organic amendments should have a pH between 6.5 and 6.8 to maximize availability. Another option is bone meal (finely ground bones from slaughterhouses), which is high in P but requires a soil pH of less than 7 for it to slowly be converted in the soil solution into a plant-available form. Rock phosphate (sold in hard and soft, or "colloidal," forms) is another option for providing P. However, the product is mined and also needs a soil pH less than 7 for it to become plant-available.

5. Potassium (K)
   a) Physiological role in plant development
      Potassium plays a role in several key processes in plants:
      i. Regulating the rate of photosynthesis (by activating enzymes used in photosynthesis and by helping in the production of the energy storage molecule ATP)
      ii. Opening and closing stomata (openings on leaves) to allow CO_2 in and O_2 out and to regulate water loss
      iii. Transporting sugars within plants, again by its role in ATP production
      iv. Starch formation, by activating the enzyme responsible for this process
      v. Plant growth, by helping to produce proteins (the building blocks) and enzymes that regulate growth
   b) Soil nutrient imbalances
      i. Potassium deficiency symptoms in plants include:
         - Slow growth
         - Tip and marginal "burn" starting on more mature leaves and progressing toward the top of the plant
         - Weak stalks, plants lodge (fall over) easily
         - Small fruit or shriveled fruit and seeds
         - Reduced disease and pest resistance
         - Increased sensitivity to drought, frost, and salts
         - White or yellow spots develop along the edges of clover leaves; in severe cases these join to give a scorched appearance
      ii. Excess potassium can cause:
         - Magnesium deficiency
         - Calcium deficiency in acid soils
   c) The potassium cycle (see ◀ Figure 2.12, the Potassium Cycle)

◀ **FIGURE 2.12** | THE POTASSIUM CYCLE



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   d) Potassium in soils: Factors affecting its availability
      Plants take up potassium in the form of potassium ions (K^+) from CEC sites or the soil solution. Because K dissolves readily, it is highly mobile in the soil; however, it can get trapped on CEC sites in between the layers inside clay particles.
      Potassium is present in some rocks, such as granite, so soils formed from these rocks have a large supply of K. Even though a soil test may not show much K at one point in time, it is usually released in sufficient quantities for plant growth. This is the case for many soils in the Sierra Nevada and southern California.

e) Potassium in amendments

Sources of K include wood ashes, granite dust, seaweed, greensand, and langbeinite (also called sulfate of potash-magnesia or Sul-Po-Mag). Greensand and langbeinite are mined, non-renewable resources. Granite dust is also non-renewable, but granite occurs in such huge quantities over extensive areas that it will be available for a long time. In neutral or alkaline soils, wood ashes may increase the soil pH to undesirable levels.

Potassium in organic residues tends to be more highly available than that supplied by inorganic sources. So even though the total quantity of potassium supplied by these residues may be less, it may be more effective. If organic residues are regularly returned to the soil, K is not likely to be deficient.

6. Other macronutrients: Calcium, magnesium, sulfur

a) Calcium (Ca)

Calcium is an essential part of cell wall structure and must be present for the formation of new cells throughout the plant. Calcium also helps control movement into and out of cells, including by reacting with waste products to precipitate them or to render them harmless to the plant.

Calcium is not mobile in plants. Young tissue is affected first when there is a deficiency. Deficiency symptoms in plants include:

i. Death of growing points, including on the root tips and shoot or leaf tips

ii. Abnormal dark green appearance of foliage

iii. Premature shedding of blossoms and buds

iv. Weakened stems because cell membranes lose permeability and disintegrate

v. Blossom-end rot of tomatoes

vi. Short, thick, bulbous roots

Plants take up Ca as an ion (Ca^{2+}). Calcium is normally so abundant that it usually only needs to be added to very acidic soils where lime is required. However, excessive irrigation can leach Ca from the soil enough to cause deficiency symptoms in plants. Excess Ca can lead to a deficiency of Mg or K.

Sources of Ca include plant residues, poultry manure, wood ashes, seashells, lobster shells, legume hay, limestone, and gypsum.

b) Magnesium (Mg)

Magnesium is the central atom of chlorophyll molecules, so it is required for photosynthesis. It also helps activate key enzymes for converting CO_2 gas into carbohydrates, as well as many plant enzymes required in growth processes. Magnesium also activates enzymes necessary for P transfer within plants.

Magnesium is mobile within plants and can be translocated from older tissue to younger tissue during conditions of deficiency. Symptoms of Mg deficiency include:

i. Chlorosis (yellowing) between the veins in older leaves; marginal yellowing with a green fir-tree shape along the big midrib of the leaf

ii. Upward curling of leaves along their margins

iii. Stunted growth

iv. Ripe fruit is not sweet

Plants take up Mg in its ionic form (Mg^{2+}). Magnesium is generally available throughout the dry-climate Western states but it is often more deficient than Ca. Like Ca, Mg is easily leached, and soils with low CEC have low Mg content. It is important to have a balance of Mg, K, and Ca ions so that no one of these elements dominates the CEC sites.

Sources of Mg include plant residues, fresh poultry manure, dolomitic limestone, and langbeinite (Sul-Po-Mag—see Section on K, above)

c) Sulfur (S) (see ◀ Figure 2.13, the Sulphur Cycle)

Sulfur is part of two amino acids (cysteine and methionine) that are incorporated into proteins. Sulfur is also essential for nodule formation by N-fixing bacteria on the roots of legumes. It is present in oil compounds that give plants such as garlic and onions their characteristic odor. (Vidalia onions, known for their sweetness, come from an area that has low S soils.)

Sulfur deficiency problems can occur if growers rely on fertilizers that are concentrated with other nutrients (e.g., N, P, and K) but are free of S. Symptoms of S deficiency in plants include:

i. Pale young leaves, light green to yellowish in color, sometimes with veins lighter than surrounding tissue. In some plants older tissue may be affected also.

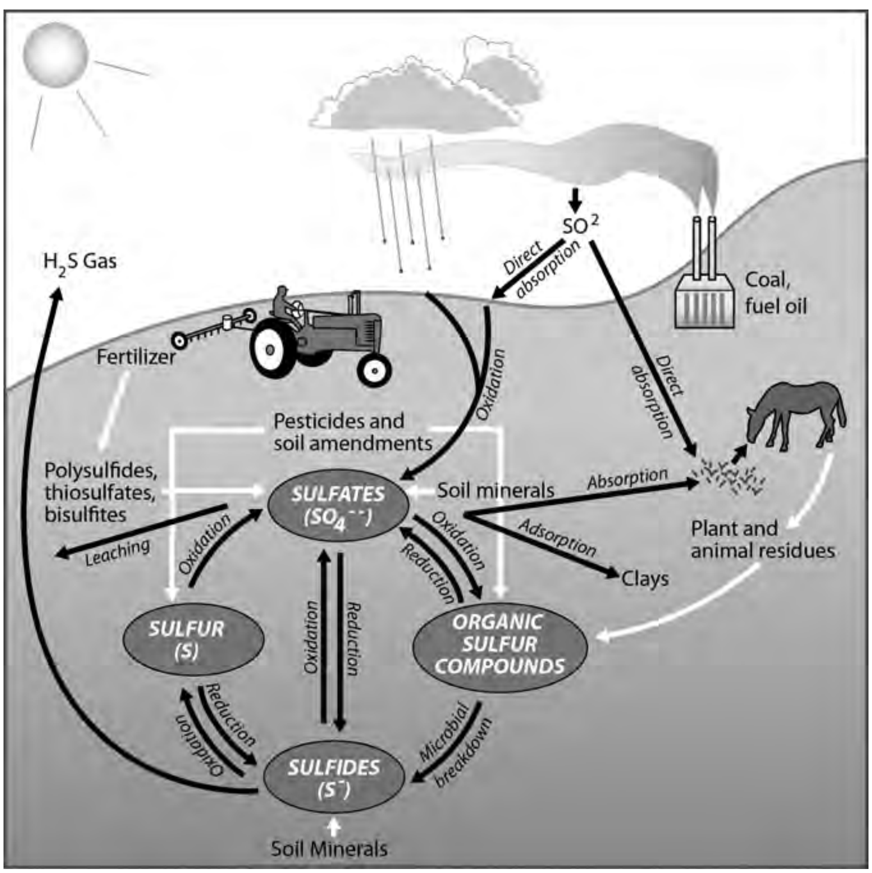
ii. Small and spindly plants

iii. Slow growth rate and delayed maturity

Plants take up S as the sulfate ion SO_4^{2-}. Sulfur is also sometimes absorbed from the air through leaves in industrial areas where S is in high concentration.

The use of organic residues in amounts to satisfy other nutrient requirements will usually provide sufficient sulfur. Other sources of sulfur include animal manures (S is usually well balanced with N), langbeinite (Sul-Po-Mag—see section above on P), gypsum, and pure S from natural sources (granular sulfur is preferred since sulfur dust is an explosion hazard).

◀ **FIGURE 2.13** | THE SULFUR CYCLE



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7. Micronutrients
   a) Introduction

      Micronutrients are those plant nutrients that are needed only in small quantities compared to other (macro-) nutrients. This, however, does not diminish their importance. The effects of micronutrients on plants are difficult to understand, partly because of their interrelationships with each other and with macronutrients and partly due to how the plants respond to micronutrients individually.

      The response of many plants to micronutrients is nearly an all or nothing affair. As long as the concentration of the micronutrients falls within a certain range, the response of the plant is the same, regardless of the exact concentration of the nutrient. If the concentration of the nutrient falls above this range, toxicity problems occur and if the concentration is below the range, the plants become deficient in the nutrient.

      Interrelationships of micronutrients and with macronutrients are many. For example, excess nitrate-N can lower pH and reduce Fe uptake. Phosphorous can form a precipitate with Fe, making the Fe unavailable for plant uptake. Iron, copper, manganese, and zinc cations can interfere with each other for plant uptake.

      Availability of micronutrients is highly dependent on soil pH and organic matter. At certain pH levels, micronutrients can bind to inorganic compounds and become unavailable. Organic matter can diminish the effect of pH, supplying micronutrients if their concentrations in the soil are low and binding them up if their concentrations are too high, reducing their toxicity.

   b) Boron ($B_4O_7^{2-}$)
      i. Boron is needed in plants for:
         - Synthesizing protein
         - Transporting starches and sugars
         - Regulating N and carbohydrate metabolism
         - Root growth
         - Fruit and seed formation
         - Water uptake and transport
         - Boron contributes more than any other micronutrient to the quality of produce.

      ii. Boron is non-mobile in plants and so a continuous supply is necessary at all growing points. Symptoms of boron deficiency include:
         - Death of terminal growth, causing lateral buds to develop and producing a "witches'-broom" effect
         - Thickened, curled, wilted, and chlorotic leaves
         - Soft or necrotic spots in fruit or tubers
         - Reduced flowering or improper pollination

      Boron is required in minute quantities by plants, but may be insufficient in some soils. Boron can also become toxic in amounts not much higher than that needed by plants. Boron toxicity is most frequently a problem in soils formed at the bottoms of enclosed basins in arid areas where groundwater evaporates upward through the soil, leaving salt concentrations near the surface (playas).

   c) Copper (Cu^{2+})

      Copper is a catalyst for respiration (combusting sugars for energy in plants) and an activator of several enzymes. It is important for carbohydrate and protein synthesis.

      Symptoms of copper deficiency include:
      i. Stunted growth
      ii. Dieback of terminal shoots in trees
      iii. Poor pigmentation

iv. Wilting and eventual death of leaf tips

v. Formation of gum pockets around central pith in oranges

Copper is fairly abundant and deficiencies rarely occur. It is found as impurities in the structures of clay particles and other soil compounds. As these materials weather the copper is released, and then adsorbed onto CEC sites, from where it may be taken up by plants or leached from the soil. Consequently, soils formed from highly weathered materials may be deficient in copper. However, since copper can be highly toxic at low levels, amendments should not be used except where the need for it has been established.

d) Iron (Fe^{2+}, Fe^{3+})

Iron plays several critical roles in plants. It is used in chlorophyll synthesis, during respiration, and as a constituent of some enzymes and proteins. It also activates nitrogen fixation.

Symptoms of Fe deficiency include:

i. Interveinal chlorosis—a yellowing of the leaves between the veins

ii. Twig dieback

iii. Death of entire limbs or plants

Plants require Fe in larger amounts than any other micronutrient. Iron is very abundant in the soil, but some of its forms are so insoluble that plants may suffer a deficiency in spite of its abundance (this would be like being stranded in the ocean yet being thirsty for want of fresh water). This is particularly true at pH levels above 7; where there is a high content of lime or manganese; or where there is poor aeration. Treatment may consist of adding iron in a form that won't be bound up in the soil or by lowering the soil pH.

e) Manganese (Mn^{2+})

Manganese is part of multiple enzymes and is a catalyst of other enzymes, and so is used in the metabolism of N and inorganic acids; for the formation of vitamins (carotene, riboflavin, and ascorbic acid); for the assimilation of CO_2 during photosynthesis; and in the breakdown of carbohydrates.

Symptoms of manganese deficiency include:

i. Interveinal chlorosis of young leaves, with a gradation of pale green coloration with darker color next to the veins. There is no sharp distinction between veins and interveinal areas as with iron deficiency.

ii. Development of gray specks, interveinal white or brown streaks, or interveinal brown spots

Similar to Fe, high pH (over 6.5) may make Mn unavailable, as can soils very high in organic matter (muck soils). High Mn levels may induce iron deficiency. Improving soil structure can improve Mn availability.

f) Molybdenum (MoO_4^{2-})

Molybdenum is necessary for nitrogen fixation and for converting nitrate-N taken up by plants into a form the plant can use to build amino acids and thus proteins. Because of this a Mo deficiency can cause an N deficiency in plants.

Symptoms of molybdenum deficiency include:

i. Stunting and lack of vigor (induced nitrogen deficiency)

ii. Marginal scorching and cupping or rolling of leaves

iii. "Whiptail" of cauliflower

iv. Yellow spotting of citrus

As with boron, molybdenum is needed only in minute quantities and is toxic at levels above what plants require. Molybdenum has been found in quantities sufficient to be toxic to livestock in forage grown in inland desert areas such as the San Joaquin Valley and Nevada. Molybdenum levels tend to be low in highly leached soils.

g) Zinc (Zn^{2+})

Zinc activates enzymes that run photosynthesis, helps regulate and combust carbohydrates, and is part of the synthesis of the plant hormone auxin. It is also key for seed and grain maturation and production.

Symptoms of zinc deficiency include:

i. Decrease in stem length and a rosetting of terminal leaves
ii. Reduced fruit bud formation
iii. Mottled leaves (interveinal chlorosis)
iv. Dieback of twigs after first year
v. Striping or banding on corn leaves

Soils formed from highly weathered materials may be deficient in Zn, while soils formed from igneous rocks tend to have higher levels of Zn. Warm soil temperatures improve Zn availability, as does a well-aerated soil. High levels of available P can cause Zn deficiency in plants.

h) Others

Other micronutrients that may be of importance are:

i. Cobalt (Co^{2+})

Cobalt has not yet been shown to be essential for plants, but is generally beneficial. However, it is essential in the symbiotic relationship between legumes and their associated Rhizobia bacteria.

ii. Chlorine (Cl^{-})

Chlorine is required for photosynthetic reactions in plants. However, the quantities needed are so small that deficiencies are rare and usually in places with high rainfall and sandy soils, where Cl anions would leach out.

iii. Silicon (Si)

While not an essential plant nutrient, Si gives plants mechanical strength and may help minimize water loss and increase disease resistance. Plant pathologists are especially interested in the potential for improving disease resistance.

Demonstrations: Soil Chemistry

DEMONSTRATION OVERVIEW

The following demonstrations provide visual representations and visual analogies for the concepts presented in Lecture 1. When possible, they should be integrated into the lectures.

MAGNET DEMONSTRATION

Lecture 1, D. 1

PURPOSE

To show how unlike charges attract and like charges repel

MATERIALS

- 2 bar magnets, preferably labeled

METHODS

Hold the negative ends of the magnets together, show how they repel, then hold the negative to the positive and show how they attract.

pH DEMONSTRATION

Lecture 1, F. 1

PURPOSE

To demonstrate different methods of measuring pH

MATERIALS

- pH meter
- Colorimetric pH test kit (I use the Hellige-Truog)

METHODS

Measure the pH of the soil sample using the different techniques. Compare the results. Explain why differences may occur.

ACID DEMONSTRATION

Lecture 1, G. 4

PURPOSE

To show how to test for the presence of carbonates in the soil

MATERIALS

- Soil sample with free carbonates, e.g., $CaCO^3$
- Dilute hydrochloric acid or vinegar

METHODS

Drop acid onto the soil to show how it effervesces. The effervescence is the release of CO_2 bubbles from the carbonates.

SALT CRUST EXAMPLE

Lecture 1, H. 3

PURPOSE

To show how high salt concentrations might look in the soil

MATERIALS

- Salt crust

METHODS

Pass around samples of salt-encrusted soil

CONDUCTIVITY DEMONSTRATION

Lecture 1, H. 3

PURPOSE

To demonstrate that saline soils conduct electricity

MATERIALS

- Saline soil sample
- Nonsaline soil sample
- Distilled water
- 2 beakers or jars
- Table salt
- Conductivity tester: Any kind of device that shows that electricity will pass through a saline soil but not a nonsaline soil will do. A device that combines a light bulb and a voltmeter is a good choice.

METHODS

1. Prepare the two samples (saline and nonsaline) by placing them into separate jars and mixing distilled water into each until a smooth paste is created.
2. Place the electrodes of the tester into the nonsaline sample. Notice that the light bulb does not light.
3. Remove the electrodes and rinse them with distilled water. Then place them into the saline soil. Notice that the light bulb lights.
4. Remove electrodes from samples and rinse them with distilled water. Place them back into the nonsaline sample. Stir in table salt until enough has been added to make the light bulb light up.

Note: The operation can be simplified by having four electrodes. Use alligator clips on the tester wires to connect them to the electrodes.

Assessment Questions

TRUE OR FALSE

1) The bulk of a plant is made up of minerals extracted from the soil.

   True False

2) Clay soils can hold more nutrients than sandy soils.

   True False

3) The main source of nitrogen in the soil is rocks.

   True False

4) Phosphorus becomes a pollutant when it is leached into the groundwater.

   True False

5) Alkaline soils are predominant in the arid western states.

   True False

MULTIPLE CHOICE

1) Which one of the following refers to the nutrient-holding ability of the soil?
   a. Alkalinity
   b. Cation Exchange Capacity
   c. Available Water Capacity
   d. Nutrient Loading
2) Leaching of bases out of a soil causes the soil to become
   a. Alkaline
   b. Acid
3) Salinity problems are most likely to occur in
   a. Dry environments
   b. Upper New York state
   c. Tropical rainforests
   d. Humid areas
4) Which of the following is NOT a plant nutrient?
   a. Nitrogen
   b. Copper
   c. Aluminum
   d. Potassium
5) Nutrients needed in large quantities by plants are called
   a. Meganutrients
   b. Micronutrients
   c. Macronutrients
   d. High end nutrients
6) Certain plant nutrients are called micronutrients because
   a. They are too small to see with the naked eye
   b. They are not all that important to the plant
   c. They are only needed in small quantities

7) Which one of the following plant nutrients comes from the air?
   a. Carbon
   b. Potassium
   c. Hydrogen
   d. Copper

8) Which of the following affects nutrient availability? (circle all correct responses)
   a. pH
   b. Soil organic matter content
   c. Texture
   d. Soil moisture

9) An ion with a positive charge is called a(n)
   a. Cation
   b. Anion
   c. Onion
   d. Positron

10) Clay particles tend to have a
   a. Positive charge
   b. No charge
   c. Negative charge

ASSESSMENT

1) How can knowledge of the climate of an area help you make an initial assessment of soil fertility?

2) Your plants are showing signs of iron deficiency. You check the soil pH and it is 8.0. What would most likely be the best way to eliminate the iron deficiency and why?

3) You know that the air around you is full of nitrogen, yet your garden regularly shows signs that it could use a little of it. How can you harness some of the nitrogen for your garden?

4) Is adding a large quantity of nitrogen-rich amendments to your garden before you plant necessarily a good thing to do? Why or why not?

5) What is the most important thing you can do to a mineral soil in order to ensure an adequate supply of and maximum availability of plant nutrients?

Assessment Questions Key

TRUE OR FALSE

1) The bulk of a plant is made up of minerals extracted from the soil.

   True **False**

2) Clay soils can hold more nutrients than sandy soils.

   True *False*

3) The main source of nitrogen in the soil is rocks.

   True **False**

4) Phosphorus becomes a pollutant when it is leached into the groundwater.

   True **False**

5) Alkaline soils are predominant in the arid western states.

   True *False*

MULTIPLE CHOICE

1) Which one of the following refers to the nutrient-holding ability of the soil?
   - *a. Alkalinity*
   - **b. Cation Exchange Capacity**
   - *c. Available Water Capacity*
   - *d. Nutrient Loading*

2) Leaching of bases out of a soil causes the soil to become
   - *a. Alkaline*
   - **b. Acid**

3) Salinity problems are most likely to occur in
   - **a. Dry environments**
   - *b. Upper New York state*
   - *c. Tropical rainforests*
   - *d. Humid areas*

4) Which of the following is NOT a plant nutrient?
   - *a. Nitrogen*
   - *b. Copper*
   - **c. Aluminum**
   - *d. Potassium*

5) Nutrients needed in large quantities by plants are called
   - *a. Meganutrients*
   - *b. Micronutrients*
   - **c. Macronutrients**
   - *d. High end nutrients*

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   - *a. They are too small to see with the naked eye*
   - *b. They are not all that important to the plant*
   - **c. They are only needed in small quantities**

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8) Which of the following affects nutrient availability? (circle all correct responses)
   - **a. pH**
   - **b. Soil organic matter content**
   - **c. Texture**
   - **d. Soil moisture**

9) An ion with a positive charge is called a(n)
   - **a. Cation**
   - *b. Anion*
   - *c. Onion*
   - *d. Positron*

10) Clay particles tend to have a

   a. *Positive charge*

   b. *No charge*

   c. <u>Negative charge</u>

ASSESSMENT

1) How can knowledge of the climate of an area help you make an initial assessment of soil fertility?
   - *Humid areas tend be more heavily leached, have lower pH and lower fertility*
   - *Dry areas tend to have higher base saturation, higher pH, more fertile*
   - *Warm areas tend to have more highly weathered soils as compared to cooler ones, lower relative fertility*

2) Your plants are showing signs of iron deficiency. You check the soil pH and it is 8.0. What would most likely be the best way to eliminate the iron deficiency and why?
   - *Lower the pH so that the iron in the soil can become more available (usually done by adding sulfur or acid organic materials). If iron supplements are used they, too, will be unavailable due to the high pH unless chelated forms of iron are used.*

3) You know that the air around you is full of nitrogen, yet your garden regularly shows signs that it could use a little of it. How can you harness some of the nitrogen for your garden?
   - *Nitrogen-fixing green manures*
   - *Intercrop with nitrogen-fixing plants*

4) Is adding a large quantity of nitrogen-rich amendments to your garden before you plant necessarily a good thing to do? Why or why not?

   No.
   - *Large amounts of nitrogen without plants to take it up can lead to losses by leaching (polluting groundwater) or volatilization (polluting air)*
   - *Too much nitrogen can burn seedlings*
   - *An imbalance of nitrogen with respect to other nutrients is unhealthy for the plants*

5) What is the most important thing you can do to a mineral soil in order to ensure an adequate supply of and maximum availability of plant nutrients?

   Maintain high levels of organic matter and foster biological activity

Organic matter helps by
   - *Buffers micronutrients, keeping them from becoming toxic or imbalanced*
   - *Chelates certain micronutrients to keep them available to plants*
   - *Increases cation exchange capacity*
   - *Supplies certain nutrients such as nitrogen, phosphorus, and sulfur*
   - *Improves physical condition of soil (air and water relationships enhanced), which helps to ensure maximum availability of nutrients*
   - *Buffers the effect of high or low pH*

Biological activity helps by
   - *Breaking down certain compounds to release nutrients*
   - *Breaking down organic matter*
   - *Some micro-organisms are involved with nitrogen fixation*
   - *Organisms can help move otherwise immobile nutrients through the soil*

Resources

PRINT RESOURCES

Brady, Nyle C., and Ray R. Weil. 2008. *The Nature and Property of Soils, 14th Edition*. Upper Saddle River, New Jersey: Prentice-Hall, Inc.

A good general soils text, used for introductory soils classes at universities. great for those who want to "go deeper" into the origins, classifications, and workings of soil.

California Fertilizer Association. 1997. *Western Fertilizer Handbook, 2nd Edition*. Danville, IL: The Interstate Printers & Publishers, Inc.

This book contains general information about soils and more detailed information about plant nutrients and fertilizers. Some parts may be difficult to understand. Emphasis is on inorganic fertilizers.

Foth, Henry D. 1990. *Fundamentals of Soil Science, 8th Edition*. New York: John Wiley & Sons.

Gershuny, Grace. 1993. *Start with the Soil*. Emmaus, PA: Rodale Press.

A general book on soils and soil management geared toward organic gardeners. Easy to read and understand.

Hanson, Blaire, Stephen R. Grattan, and Alan Fulton. 1999. *Agricultural Salinity and Drainage*. Publication 3375. UC Irrigation Program. Oakland, CA: University of California Division of Agriculture and Natural Resources.

An indispensable reference for anyone farming in an area where salinity might be a problem.

Parnes, Robert. 1990. *Fertile Soil: A Grower's Guide to Organic and Inorganic Fertilizers*. Davis, CA: agAccess.

Probably the best reference here on plant nutrients, with good coverage of organic amendments. Some useful reference charts in the appendices.

Stell, Elizabeth P. 1998. *Secrets to Great Soil*. Pownal, VT: Storey Communications, Inc.

An easy to read primer on soils, composting, and basic gardening techniques. Lots of diagrams.

Troeh, F. R., and L. M. Thomposon. 2005. *Soils and Soil Fertility, 6th Edition*. Ames, IA: Wiley-Blackwell.

A general soils text used in introductory soils classes.

WEB-BASED RESOURCES

LIMING (PH)

Liming to Improve Soil Quality in Acid Soils – Agronomy Technical Note No. 8. USDA.

www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_019229.pdf

SALINITY

Saline and Sodic Soils

www.ag.ndsu.edu/langdonrec/soil-health/saline-sodic-soils/view

CARBON

C sequestration potential

www.strauscom.com/rodale-whitepaper/

NITROGEN

www.extension.umn.edu/agriculure/nutrient-management/nitrogen/understanding-nitrogen-in-soils

PHOSPHORUS

www.extension.umn.edu/agriculture/nutrient-management/phosphorus/the-nature-of-phosphorus/

www.extension.umn.edu/agriculture/nutrient-management/phosphorus/understanding-phosphorus-fertilizers/

www.ess.uci.edu/~reeburgh/fig4.html

www.sera17.ext.vt.edu/SERA_17_Publications.htm

POTASSIUM

www.ipipotash.org

www.extension.umn.edu/agriculture/nutrient-management/potassium/

SULFUR

www.extension.umn.edu/agriculture/nutrient-management/secondary-macronutrients/

www.soils.wisc.edu/extension/pubs/A2525.pdf

CALCIUM

soils.usda.gov/sqi/files/08d3.pdf

www.soils.wisc.edu/extension/pubs/A2523.pdf

www.psu.edu/ur/NEWS/news/liming.html

BASE CATION SATURATION RATIO

www.extension.umn.edu/agriculture/nutrient-management/soil-and-plant-sampling/soil-cation-ratios/

NUTRIENT CYCLING & SOIL FERTILITY

www.extension.umn.edu/distribution/horticulture/m1193.html#nutp

MISCELLANEOUS NUTRIENTS

eap.mcgill.ca/MagRack/COG/COGHandbook/COGHandbook_1_3.htm

www2.hawaii.edu/~nvhue/sustain_ag/sustag895.html

DEFICIENCY SYMPTOMS

extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1106.pdf

INSTITUTIONS

Cooperative Extension Service or Farm Advisors Office

Staff from these agencies will be aware of crop nutrient needs and problems in your area. They can assist you with nutrient deficiency symptoms and known plant nutrition problems in your area.

Soil and Plant Tissue Labs

These labs can test your soil or crop for deficiencies. Some websites containing listings of laboratories:

attra.ncat.org/attra-pub/soil_testing/

gardeningproductsreview.com/resources/soil-testing-for-the-home-gardener/state-state-list-soil-testing-labs-cooperative-extension-offices/

www.al-labs-west.com/

www.clemson.edu/agsrvlb/sera6/changes/accompli.htm

2.3

Soil Biology and Ecology

Introduction: Soil Biology & Ecology

UNIT OVERVIEW

This unit introduces students to the biological properties and ecosystem processes of agricultural soils.

The lecture reviews the constituents of soils and the physical characteristics and soil ecosystem processes that can be managed to improve soil quality. Demonstrations and exercises introduce students to techniques used to assess the biological properties of soils. Such assessments help inform decisions about soil management with the goal of maintaining crop productivity and soil health in organic farming and gardening systems.

MODES OF INSTRUCTION

> LECTURE (1 LECTURE, 1.5 HOURS)

The lecture covers the basic biology and ecosystem processes of soils, focusing on ways to improve soil quality for organic farming and gardening systems.

> DEMONSTRATION 1: ORGANIC MATTER DECOMPOSITION (1.5 HOURS)

In Demonstration 1, students will learn how to assess the capacity of different soils to decompose organic matter. Discussion questions ask students to reflect on what environmental and management factors might have influenced the test results and what the results suggest about nutrient cycling rates and the quality/health of the soils tested.

> DEMONSTRATION 2: SOIL RESPIRATION (1 HOUR)

Demonstration 2 covers the use of Draeger gas detection tubes for measuring carbon dioxide levels liberated from soils as an indicator of soil biological activity and soil quality/health.

> DEMONSTRATION 3: EARTHWORM POPULATION (1 HOUR)

Demonstration 3 takes students through the process of sampling soil for earthworm types. Discussion questions ask students to consider the presence and abundance of certain earthworm types as indicators of soil quality/health.

> DEMONSTRATION 4: SOIL ARTHROPODS (1 HOUR)

Demonstration 4 covers the preparation and materials used to collect and identify soil arthropods. Discussion questions ask students to consider the presence and diversity of soil arthropods as indicators of soil quality/health.

> ASSESSMENT QUESTIONS (1 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- Soil quality/soil health
- Mineralization/immobilization
- Autotrophic/heterotrophic food webs
- Functional groups of soil biota
- Rhizosphere ecology
- Management effects on soil ecosystems

SKILLS

- How to assess soils for biological activity through measuring the rate of decomposition of cellulose
- How to assess soil biological activity through measuring soil respiration
- How to assess soil biological activity through earthworm census
- How to assess the soil ecosystem structure through a soil arthropod census

Lecture 1: Soil Biology & Ecology

Pre-Assessment Questions

1. What is soil?
2. What forms of life exist in soil ecosystems?
3. How would you define a "healthy" agricultural soil?
4. What is a food web?
5. Can you describe a decomposer food web that may exist in the soil?
6. What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizers and pest control agents on the soil ecosystem?

A. What Is Soil? (should be a review in part; see also Unit 2.1, Soils and Soil Physical Properties)

1. Soil components
   a) Mineral
      i. Derived from parent material
   b) Soil organic matter
   c) Water and air
      i. 1/2 soil volume = pore space
      ii. Importance of gas diffusion: When diffusion is slow, as with water-saturated soil, respiration byproducts (such as CO_2) accumulate and inhibit aerobic processes (such as respiration itself)
      iii. CO_2 is about 1% in dry soil, up to 10% in saturated soil
   d) Biota: The smallest life forms are inseparable from soil organic matter
2. Soil structure vs. soil texture
   a) Soil texture, a native characteristic
      i. Soil texture: The relative percentage of sand, silt, and clay particles
      ii. The bricks, boards, and mortar (the physical materials) that make up soil
      iii. The particle sizes have surface area:volume effects. This influences properties such as cation exchange capacity (CEC), pore space, water holding capacity, and aggregate formation.
   b) Soil structure, a manageable characteristic
      i. Soil structure: The arrangement of soil particles. The "architecture" of soil—what shapes you build with the "bricks, boards and mortar."
      ii. Determines movement of gases and water in soil
      iii. Creates small habitat spaces
      iv. Water stability: Aggregates that retain shape when wetted maintain a more stable soil structure
      v. Influences soil tilth/soil health

B. What Is a Healthy Soil? (see also Unit 1.1, Managing Soil Health)

1. Question: Is soil merely a solid medium that holds nutrients for plant growth or does soil serve other functions?
2. Soil health and soil quality are generally synonymous
3. Definition of soil health: "Capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health."

a) Soil is recognized as an essential component of the biosphere
b) Soil is required for significant production of food and fiber
c) Soil contributes to maintaining and enhancing air and water quality
d) Soil filters and chemically alters water
e) The definition of soil health must be broad enough to encompass the many functions of soil

4. Assessment of soil health
   a) Analogous to monitoring human health
   b) Indicators needed to identify problems and to monitor the effects of management
   c) Requires a holistic approach
   d) Should include physical, chemical, and biological attributes of soil
   e) Indicators must be measurable by as many people as possible, at many different skill levels
   f) Definition and assessment of soil quality is complicated by the fact that soil is not (typically) directly consumed by animals and humans, unlike air and water
   g) Basic data set of soil health indicators
      i. Soil texture
      ii. Rooting depth
      iii. Water infiltration
      iv. Bulk density
      v. Water holding capacity
      vi. Soil organic matter
      vii. pH
      viii. Cation exchange capacity (CEC)
      ix. Extractable N, P, and K
      x. Microbial biomass C and N
      xi. Potentially mineralizable N
      xii. Soil respiration
      xiii. Soil temperature
5. Protection of soil health as a national priority
   a) National Research Council recommendation (1993): "Protecting soil quality, like protecting air and water quality, should be a fundamental goal of national environmental policy"
   b) National Resource Conservation Service (2012): Healthy soils initiative called "Unlock the Secrets of the Soil" (*www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/*)
   c) USDA Sustainable Agriculture Research and Education program (2014): Organized National Conference on Soil Health and Cover Crops (*www.sare.org/Events/National-Conference-on-Cover-Crops-and-Soil-Health*)

C. Nutrient Cycling and Decomposition

1. Mineralization/immobilization
   a) Soil nutrients occur as parts of:
      i. Inorganic compounds: Some of these are available to plants
      ii. Organic compounds: Are part of living organisms and decaying organic matter. These nutrients are stored ("immobilized") in the biomass of the organisms and are unavailable until released during decay or consumption.
   b) Soil organisms are constantly transforming nutrients between these 2 forms

c) Mineralization: Soil organisms excrete inorganic waste compounds that may adhere to CEC sites and/or dissolve in soil water (soil solution) for possible uptake by crop plants. Net mineralization must be greater than net immobilization for nutrients to be available to crop plants.

d) Immobilization: Soil organisms consume inorganic compounds to construct living tissues. These nutrients are temporarily stored and unavailable for plant uptake.

2. Soil organic matter (SOM): Includes all organic substances in or on the soil
   a) Living organisms—include plant roots and all soil biota (< 5% of SOM)
      i. Cellulose, the major carbohydrate structural building block for plants, is the most abundant compound on earth and the major component of soil organic matter
      ii. Lignin is the second largest input into SOM
   b) Fresh and decomposing organic residues (40–60% of SOM)
      i. Easily decomposable (active, labile) fraction: The quantity of this fraction of SOM changes quickly in response to management practices and is the organic matter fraction from which the majority of plant nutrients are liberated into the soil solution for uptake by plants
      ii. Moderately decomposable fraction: This fraction is physically and/or chemically more complex than labile OM. Its decomposition is slower and therefore fewer nutrients are mineralized from it in a given season.
   c) Resistant (recalcitrant) fraction: Also called humus, and is resistant to further decomposition (33–50% of SOM). Has greater influence on the structure/physical properties of soils than on nutrient availability.
   d) See Appendix 1, Major Organic Components of Typical Decomposer Food Sources
   e) Physical factors influencing decomposition
      i. Particle size: High surface area:volume = more rapid decomposition. For example, flail mowing breaks cover crops into smaller pieces for more rapid decomposition prior to planting a subsequent crop.
      ii. Some surface properties of plants (e.g., waxes, pubescence) decrease the rate of decomposition
      iii. High content of structural compounds, e.g., lignin that supports woody plant stems, decreases the rate of decomposition
   f) Limiting factors in decomposition of SOM
      i. Nutrient availability: Decomposers tend to concentrate the nutrients that are in short supply, e.g., N, P, and K. Micronutrients are not usually a limiting factor.
      ii. C:N ratio of organic matter: High abundance of C compared to N slows the decomposition process. If C:N < 20–30:1 = net mineralization. If C:N > 20–30:1 = net immobilization
      iii. Soil moisture: Necessary for respiration by organisms doing the decomposition
      iv. Oxygen levels: Also necessary for respiration by decomposers
   g) Plant secondary compounds may inhibit decomposition (such as polyphenols, tannins found in many woody perennials)

3. Nitrogen cycle (see ◀ Figure 2.10 in Unit 2.2, Soil Chemistry and Fertility)
   a) Proteins break down —> amino acids —> ammonium (form of N usable by some plants) —> nitrate (form of N usable by most plants)
   b) Ammonification (aerobic or anaerobic): The biochemical process in the N cycle above whereby ammonium is released from nitrogen-containing organic compounds (amino acids)

c) Nitrification (aerobic): The biochemical process in the N cycle above whereby bacteria convert ammonium to nitrate

   i. Inhibited by low oxygen or low temperatures

   ii. This leads to ammonium build-up in cold, wet soils

D. Soil Food Webs

1. Soil food web ecology

   a) Food webs trace the path of energy or nutrients passing from one organism to the next

2. Heterotrophs vs. autotrophs in food webs

   a) Autotrophs form the base of food webs, and acquire their own C from the atmosphere. In the soil food web, this begins with C fixation by plants, which is photosynthesis. Energy for most life is derived from sunlight that has been transformed by photosynthetic plants into organic compounds.

   b) Heterotrophs in food webs consume organic matter to acquire carbohydrates for respiration. By consuming organic matter, they release nutrients, making them available to other plants and animals, or become food themselves for other organisms.

   c) Energy loss = 80–90% at each step in the food chain

   d) Food web structure and properties

      i. Resilience = speed of recovery after disturbance. Resilience decreases with increasing number of trophic levels due to increasing complexity—it takes longer to reestablish complex food web relationships

      ii. Disturbance selects for shorter food chains: In farmed soils, disturbance can be chemical (pesticides, fertilizers) or physical (cultivation, organic matter incorporation, removal of surface organic layer)

      *The frequency of soil disturbance by physical or chemical agricultural inputs and other disturbances is important to the overall assemblage of soil biota and food chain length

      iii. Fungi:bacteria biomass ratio characteristics of soil ecosystems

         - Productive agricultural soils have a ratio of 1:1 or less (higher in no-till). These are bacterial-dominated food webs with rapid cycling of nutrients.
         - Deciduous forest soils, 5:1 to 10:1 (fungal dominated)
         - Coniferous forest soils, 100:1 to 1000:1 (fungal dominated)

   e) Some heterotrophic roles in soil food webs

      i. Shredders: Shred organic matter, increasing the surface area and making the food available to more microorganisms. These include earthworms and arthropods.

      ii. Grazers: Feed on bacteria and fungi, stimulating and controlling the growth of those populations. Grazers include protozoa, nematodes, and microarthropods.

      iii. Higher-level predators: Consume other heterotrophs, like grazers and shredders, helping control the lower trophic-level predator populations

   f) Unique food web for each ecosystem, determined by:

      i. Climate

      ii. Soil/parent material

      iii. Vegetation

      iv. Land management practices

E. Soil Biota

1. Community characteristics
   a) High diversity of organisms in soil can rival that of coral reef ecosystems
   b) High abundance of organisms, on the order of hundreds of millions to billions of microbes in 1 g of soil
   c) High biomass of organisms, e.g., from hundreds to thousands of pounds of microbes per acre of soil
2. Habitats
   a) Habitats within soil ecosystems are unevenly distributed
   b) Habitats are concentrated at organic matter sites
      i. Root zone (rhizosphere)
         - Succession of organisms as root grows
         - Some root exudates (molecules released into the soil by the roots, including sugars and amino acids) may stimulate microorganisms and thus increase labile SOM
      ii. Litter (dead organic matter on the soil surface)
      iii. Surfaces of soil aggregates
      iv. Incorporated organic matter
3. Functional classification
   a) Microorganisms
      i. Colonial growth forms (cells about 1/25,000 inch wide)
         - Bacteria, archaea, and yeast
         - Adapted to high surface area:volume environments
         - Colonize surfaces, crevices, pores
         - Teaspoon of soil contains 100 million to 1 billion bacteria
         - Biomass equivalent to 2 cows per acre
         - Functional roles include: N fixers, nitrifiers, denitrifiers, decomposers (the byproducts of which help in the formation of soil aggregates), pathogens
      ii. Mycelial growth forms (hyphae length ranges from a few cells to many yards)
         - Fungi actinomycetes, and oomycetes
         - Penetrate organic matter
         - Translocate nutrients
         - Functionsal roles include: Decomposers, mutualists, pathogens, predators (e.g., nematode-trapping fungi)
      iii. Algae
         - Dominated by "blue-green" algae (Cyanophyta) and eukaryotic algae
         - Present where sunlight is available near soil surface, active when there is moisture available, too
         - Help bind soil particles together, reducing erosion potential (biological soil crusts)
         - Increase water retention capacity of soil through exudates
         - Often 1000 to 10,000 per g of soil
         - Functional roles: Primary producers (photosynthesizers), N fixers
   b) Microfauna

      Note: This section and the macrofauna section below are based on information from the European Atlas of Soil Biodiversity; see Resources for details
      i. Protozoans (1/5000 inch to 1/50 inch wide)

- Small animals (acellular) living in water films
- Encystment (hibernating in a cyst): Distinctive response to drying out
- Inhabit transitory environments, so reproduce rapidly
  – Colpoda divide once or twice per day at 12oC
- Several distinct types
  – Ciliates have fringe of small hairs used for locomotion
  – Amoebae have an amorphous body shape
  – Flagellates have a whip-like tail for locomotion
- Functional roles: Predators (e.g., of bacteria, other microorganisms), decomposers (feed on detritus)

ii. Nematodes (1/500 inch in diameter, 1/20 inch in length)
- Global distribution
- Soil abundance = million/m^2
- Outer cuticle protects; resistant to toxins
- Functional roles include: Microbivores, omnivores, predators, some parasites (10%)
- Abundant at sites with high OM concentration

iii. Rotifers (1/50 to 1/120 inch long)
- Multicellular, though still microscopic
- Live in water films on moist soils; one of most abundant taxa in the top layer of soil or litter (32,000 to 2 million per m^2)
- Can undergo anhydrobiosis (survive drying down by forming a cyst)
- Primary feeding strategies: Grazing the bacterial film on SOM or other particles or filter feeding on bacteria, yeast, and algae in the soil water
- Functional roles: Herbivores (e.g., on algae), decomposers (feed on detritus)

iv. Tardigrades (1/25 inch)
- Multicellular, though still microscopic
- Terrestrial tardigrades live on moss or lichen
- Can undergo anyhydrobiosis (survive drying down by forming a tun)
- Primary feeding strategies: Some use stylets to pierce moss, algae, protozoans, rotifers or nematodes and suck out fluids; others consume whole microfauna
- Functional roles: Herbivores, predators

v. Functional roles of microfauna do not include shredding of organic matter into smaller pieces

c) Mesofauna

i. Potworms (Enchytraeida, 1/50 to 2 inches long)
- Small annelids (related to earthworms
- Tolerate pH < 4
- Thousands/m^2 in high organic matter soil
- No burrows
- Feed on fungal hyphae, microorganisms, feces

ii. Collembolans (springtails, 1/100 to 4 inches long)
- Small arthropods (related to insects); with mites, the most numerous soil arthropods
- Live in soil and leaf litter
- Hundreds to thousands per handful of soil high in SOM
- Feed on fungal hyphae, bacteria, detritus

iii. Mites (acari, 1/125 to 1/30 inches long)
    - Small arachnids (related to spiders); with collembolans, the most numerous soil arthropods (1000 to 10,000 per m2)
    - Global distribution
    - Live in soil and in habitats with high quantities of OM
    - Primarily predators, feeding on collembola, nematodes, insect larvae

iv. Insect larvae
    - Fly (Diptera) larvae are probably the most important
    - In home compost systems, black soldier fly larvae (in the family Stratiomyidae, order Diptera) can play a key role in consuming organic matter, on par with earthworms
    - Diverse functional roles include: Predators, parasites, herbivores, decomposers (feeding on detritus)

v. Symphyla (1/125 to 1/30 inches)
    - Small soil-dwelling myriapods, related to millipedes and centipedes
    - Primarily eat decaying vegetation and microorganisms, but also seeds, roots, and root hairs in agroecosystems, thus damaging crops when they do
    - Up to 20,000 per m2

vi. Overall, mesofauna regulate microfauna (and other mesofauna!) by grazing

vii. Minor shredding of organic matter

viii. Total of 500 to 200,000 per square meter, far less abundant and with lower biomass than microfauna

d) Macrofauna

i. Earthworms (1/3 to 45 inches long)
    - 3 ecological types: Anecic—large, live in permanent burrows in the soil, feed on litter from the surface mixed with ingested soil; endogeic—small, live in temporary burrows in the soil, feed on rich soils to obtain nutrients from organic matter; epigeic—small, live at the soil surface in litter, feed on litter there
    - Obtain nutrition from partially decomposed organic matter and part from microbes living on the organic residues they ingest
    - Stimulate microbial activity through effects on SOM, microbial inoculation onto substrates, soil structure, etc.
    - Mix and aggregate soil
    - Increase water infiltration
    - Provide channels for root penetration deep into soil
    - Bury and shred organic matter
    - Abundance decreases after disturbance (tillage, chemicals)

ii. Myriapods
    - Millipedes (Diplopoda, 1/12 to 11 inches long) and centipedes (Chilopoda, 1/8 to 11 inches long)
    - Millipedes live in litter and upper layers of soil; some are shredders that feed on organic matter, others are predators on arthropods or earthworms, others pierce and suck plant cells. More common in soils high in calcium carbonate (e.g., from limestone); 15 to 800 per m^2.
    - Large species of centipedes live in litter or close to the soil surface, while small and narrow species of centipedes live in deeper soil layers. They are primarily generalist predators consuming insect adults and larvae, collembolans, mites, nematodes, potworms and earthworms, and occasionally leaf litter; 20-300 per m^2.

iii. Isopods (woodlice, 1/15 to 2 inches long)
- Crustaceans, related to lobsters and crabs
- Live in leaf litter, in vegetation, under stones
- Generally are decomposers, feeding on dead organic material, but sometimes are predators of bacteria, fungivores, or herbivores

iv. Mollusks (snails and slugs, ¼ inch to 10 inches)
- Live in damp soil conditions (although snails can hibernate for up to 4 years in dry conditions)
- Most active at night or on cloudy, foggy days
- Small component of soil fauna biomass but can be of high agronomic and ecological significance (especially when populations near ½ million per acre)
- Primarily herbivores, especially of succulent foliage such as seedlings and fruit near the ground, but also detritivores

v. Insects
- Many insects live in or on the soil as larvae or adults, and thus fill many functional roles in the soil food web. Two examples include:
  - Ants: Ant diversity can be very high, with tens to hundreds of species in a few acres. Ants fulfill multiple trophic roles, e.g., herbivores, predators, scavengers, parasites.
  - Carabid beetles: Both larvae and adults may live in the soil. May be predators, e.g., feeding on snails or collembola, fungivores, frugivores (eating seeds), or herbivores.

vi. Macrofauna shred and incorporate plant remains (may become pests by feeding on living plants if insufficient organic residues present)

vii. Also alter the soil structure, e.g., by burrowing, mixing, defecating, and helping form soil aggregates

e) Megafauna

i. Large invertebrates, vertebrates, including moles, mice, rabbits, gophers, snakes, and lizards

ii. Primary ecosystem engineers of the soil: Important for moving and turning soil, contributing to nutrient cycling, aeration, and drainage

iii. Fill a range of functional roles: Herbivores and predators of invertebrates and small vertebrates

F. Rhizosphere Ecology

1. Definitions

a) Rhizosphere (**R**): The narrow zone of soil subject to the influence of living roots, as manifested by the leakage or exudation of substances that promote or inhibit microbial activity

b) Rhizoplane (**r**): The actual root surface, which provides a highly favorable nutrient base for many species of bacteria, archaea and fungi

c) Edaphosphere (**S**): Soil beyond root influence

d) Rhizosphere Effect: Soil microorganisms are stimulated by the roots

i. **R:S** ratio generally greater than 1 (i.e., more biota in **R** than in **S**)

e) Rhizosphere succession: The sequence of changes in the composition and densities of soil microbes and fauna in the area surrounding a growing root (see below)

2. Roots
   a) Root environment
      i. Determined by above-ground processes (products of photosynthesis are translocated to roots)
      ii. Exudates (see below), sloughed hairs, and epidermal (root's surface) cells feed soil organisms in **R** and **r**
      iii. Plant roots also can release bicarbonate (HCO_3-), which raises the soil pH. This can make some cations (e.g., Fe^{+3}, Ca^{+2}, Mg^{+2}, and K^{+1}) unavailable to plants. Irrigation water may also contain bicarbonate and affect soil pH and availability of some nutrients.
      iv. Oxygen decreases, CO_2 increases in root zone over time due to plant and **R** organism respiration
   b) Root form
      i. Fibrous roots
         - Most monocots (e.g., grasses, corn)
         - Primary root replaced by series of adventitious roots
      ii. Tap roots
         - Most monocots and gymnosperms
         - Tap root persists and forms many lateral branches
      iii. Root depth
         - Species specific, influenced by environmental conditions
   c) Root structure
      i. Root cap
         - Live cells produced by meristem
         - Protects root, like a bud scale
         - Constantly replaced (5–6 day turn over)
         - Responds to gravity
      ii. Meristematic zone: 2 mm (.08 inch) zone where most cell division happens
      iii. Zone of elongation: Rapid growth, cells from meristem
      iv. Mucilage
         - Covers root from tip to beginning of root hair zone
         - Secreted by root cap and epidermal cells
         - Possible functions: Lubricates and protects root as it grows through the soil, helps with nutrient uptake, prevents drying, fills spaces between root and soil and helps bind soil aggregates, food for microbes, including beneficial microbes
      v. Root hair (differentiation) zone
         - Are lateral outgrowths of single epidermal cells; microscopic
         - Root hairs have life span of days to weeks; rye plants can produce over 100 million per day
         - Do not become large structural roots, though help anchor the plant in the soil
         - Key role is improving nutrient absorption by increasing surface area for nutrient and water uptake. Root hairs make up the majority of root surface area.
         - Food sources that support rhizosphere microbes, contribute significant amounts of soil organic matter
      vi. Lateral roots
         - Originate from the vascular bundle inside the root cortex
         - Cortex and epidermis are ruptured by new lateral root
         - Bacteria colonize these emergence sites

vii. Vascular bundle
    - Xylem and phloem in the root cortex
    - Connects roots to the rest of the plant, including for transport of photosynthetic products (sugars) to the roots and of water and nutrients from the soil up to the aboveground portion of the plant
    - Foliar sprays may move into roots (depends on molecular weight)
    - Herbicides, antibiotics may also move into roots
    - Streptomycin moved from Coleus leaves to roots in 24 hrs; bacteria in the rhizosphere were suppressed by the streptomycin

d) Root nutrition
  i. Maximum nutrient uptake occurs behind meristem (in the elongation and root hair zones)
  ii. Water and nutrients are withdrawn from narrow band around roots
  iii. Replenished from surrounding soil by mass flow (the movement of nutrients with the overall flow of water to plant roots); all ions in solution move towards root during mass flow
  iv. If mass flow is slower than uptake, a depletion zone is created around the root, resulting in lack of some nutrients
  v. If uptake is slower than mass flow for a particular ion (or even nonexistent if the ion is not used by the plant) certain ions may accumulate around the root

e) Root exudates
  i. Amounts
    - 20–50% more C enters the soil from exudates, sloughed cells, and root hairs than is present as fibrous roots at end of growing season = substantial contribution to SOM
    - Amount of exudates increased by:
      – Wetting, after a drying spell
      – Physical or chemical injury (e.g., mowing, grazing of perennial grass cover crop)
      – Abrasion, phytotoxic residues, osmotic stress
  - Amount of exudate varies with plant species and age, as well as the soil environment
  ii. Types
    - Carbohydrates and amino acids: Most-researched components of exudates
      – 10 sugars, glucose and fructose most common
      – 25 amino acids
    - Also organic acids, fatty acids, sterols, enzymes, volatile compounds, and growth factors
    - Type of exudate varies with plant species, age, soil environment
    - Difficult to separate plant and microbe sources
  iii. Exudates released from meristem zone
    - Nematodes and zoospores congregate there

f) Management effects on rhizosphere
  i. Synthetic fertilizers
    - Sometimes no effect
    - Sometimes increase **R:S** indirectly through stimulation of plant growth
  ii. Organic manures
    - Same indirect positive effect on **R:S**

- Also may decrease **R:S** ratio since edaphic (**S**) microbes are also stimulated by organic matter input
- After 4 weeks of decomposition, **R:S** generally increases

3. Soil organisms
   a) Bacteria and archaea
      i. Most responsive to plant exudates
      ii. 2 to 20 fold increase in bacterial populations in **R** vs. **S**
      iii. Pseudomonas most consistently abundant in rhizosphere
      iv. Also Rhizobium (some are used in DNA transfer as part of genetic engineering) and Achromobacter
      v. Azotobacter, non-symbiotic nitrogen fixer
         - If inoculated on seed can persist in rhizosphere
      vi. Rhizobium, Nitrosomonas, and Nitrobacter, all important to the nitrogen cycle (see ◀ Figure 2.10 in Unit 2.2), common in **R**
   b) Fungi
      i. Average increase of 10 to 20 fold in **R** of crop plants from **S**
      ii. Fusarium is a dominant genera of **R** fungi
      iii. Mycorrhizae can provide physical and chemical suppression of pathogens
   c) Protozoans
      i. Mainly bacteria grazers, so some increase is expected in **R**
      ii. Example: In a wheat field, bacteria **R:S** was 23:1, protozoan **R:S** was 2:1
      iii. Some large amoebae may provide biocontrol of some fungi
   d) Nematodes
      i. Root substances stimulate egg hatching of some parasitic nematodes
      ii. Host and non-host plants may stimulate hatching of nematodes, e.g., some crucifers and chenopods stimulate Heterodera hatching, but don't support root invasion by larvae. Some plants will cause eggs of parasitic nematodes to hatch, but then are not susceptible to attack by the parasite. Therefore the plant stays healthy, and the nematodes fail to thrive.
      iii. Nematodes tend to congregate around elongation zone of roots
      iv. Degree of nematode attraction is proportional to root growth rate
      v. Some root exudates repel nematodes (e.g., isothiocyanates in mustard)
   e) Microarthropods
      i. Some grazers consistently more abundant around roots
   f) Rhizosphere succession
      i. Root tip releases labile carbon
      ii. Labile carbon stimulates rapid increase of microbes and thus nutrient immobilization in **R**
      iii. Grazers increase, tracking the microbe population increases
      iv. Water and carbon in root hair zone decrease
      v. Microbes eventually decrease; grazers cause net mineralization and release of nutrients from SOM
      vi. Later, grazers encyst or migrate

G. Management Effects on Soil Ecosystems

1. No-tillage or reduced-tillage cropping systems
   a) Organic litter is retained on the soil surface
   b) Physical disturbance is minimized
   c) Surface soil stays cooler and moister
   d) More surface organic matter available as food substrate
   e) Ratio of fungi to bacteria increases over time
   f) Earthworms and arthropods become more plentiful
   g) Effects on nutrient cycling: May increase total soil N, improve N use efficiency of plants, but may increase N_2O emissions
   h) Effects on soil physical properties: May increase SOM and aggregation
2. Rotations
   a) Monocultures and clean cultivation
      i. Create little habitat for soil organisms, leading to less abundant and diverse soil ecosystems
      ii. Consistent plant hosts may serve to develop populations of pathogenic organisms, causing pest problems and crop losses that facilitate the need for pesticide use.
   b) Complex rotations
      i. Result in greater variety of microbial food sources (roots, root exudates, and residues)
      ii. Increase diversity of soil organisms, leading to increased competition for resources, as well as predation of pathogens and pests
      iii. Interrupt plant-host pest cycles
   c) Multiculture or polyculture
      i. Growing more than one crop in one field
      ii. More closely mimics natural ecosystem
      iii. Likely to support even greater diversity of soil organisms, especially invertebrates
      iv. Also interrupts plant-host pest cycles
3. Biocides (insecticides, herbicides, fungicides)
   a) Effects vary depending on:
      i. Type of chemical
      ii. Species of soil organism in question
      iii. Concentration and other exposure factors
   b) High levels of pesticide use generally reduce food web complexity
      i. Methyl bromide and other fumigants are extreme examples, resulting in temporary soil sterilization
      ii. Eliminate most organisms
      iii. Some bacteria quickly return
      iv. Other organisms only slowly return
   c) Biocides and predator-release phenomenon
      i. In cases where biocides selectively eliminate predators, lower trophic levels may become more abundant
      ii. Destabilizing effect on food webs
         - Overgrazing on food sources results in depletion of food sources
         - Population explosion, followed by crash

- Immobilization of nutrients, followed by rapid mineralization at a rate that is not necessarily compatible with crop needs. May result in leaching of water-soluble nutrients, especially forms of N.

d) Earthworms

  i. Most strongly affected (negatively) by fungicides and fumigants

  ii. Herbicides

    - Don't seem to be directly toxic to earthworms
    - Indirect negative effect through elimination of vegetation

4. Food web structures

  a) Fungi/bacteria ratio

  b) Dominant microbe influences other trophic levels

5. Interaction with fertility needs (also see Unit 1.1)

  a) Measures of available nitrogen

    i. Conventional cropping systems

      - Most N provided by additions of fertilizer
      - Measurements of nitrate reflect accurately (but highly temporally) what is available to plants
      - Key management decisions are when to apply fertilizer

    ii. Cropping systems based on organic matter management

      - Soil food web becomes primary source of N derived from organic matter inputs
      - Soil analysis in efficiently managed farming systems may indicate "inadequate" levels of N at any given time because much of soil N is immobilized
      - Cumulative release of mineral N over growing season may match amounts seen in conventional system
      - Managing the timing of mineralization (through tillage, OM quality [e.g., C:N ratio], incorporation of high-OM nutrient amendments, irrigation) by soil food web becomes more critical
      - If managed well, less risk of nutrient loss through leaching or volatilization

Demonstration 1: Organic Matter Decomposition in Litter Bags

for the instructor

OVERVIEW

To demonstrate the capacity of different soils to decompose organic matter, this exercise requires you to bury cellulose disks (Whatman filter paper) in a variety of locations. This should be done at least two weeks prior to the class to allow decomposition to proceed before the disks are retrieved on the day of the class. To accelerate decomposition, filter paper disks can be dipped in a bucket of water with some fish emulsion added just before burial.

MATERIALS NEEDED

- Whatman filter paper discs
- Plastic mesh bags†
- Flags to mark burial sites
- Flat shovel
- Litter Bag Data Sheet (see Appendix 2)
- Pencils

† For plastic mesh bags, you may use pond and pool netting obtained from a local feed and seed supply. It is a 3/8-inch polypropylene mesh. Cut the mesh into 6-inch x 12-inch pieces, fold in half, then fold the edges over and staple the edges shut. Other sources are the mesh bags that bulbs are sold in, garlic or onion bags, or the mesh bags that imported rice noodles are packed in. The smaller the mesh size, the smaller the organisms that will be excluded from the bag. This feature can be exploited by comparing decomposition rates of organic matter buried in bags of different mesh sizes. Organic matter in bags with very fine mesh will be decomposed primarily by microflora and microfauna. Organic matter in larger mesh bags will also be decomposed by larger fauna.

PREPARATION

1. Place litter bags in soil at least two weeks prior to class. Place them vertically in soil and all at the same depth. For a 10 cm disc, 0 to 10 cm is a convenient depth.
2. Flag each site, and make a note of the burial locations. A minimum of 3 bags should be placed in each habitat. Possible habitats include raised garden beds, cultivated fields, fallow fields, orchards, compost piles, vermicompost bins, weedy borders, and on the soil surface (not buried).

PROCEDURE

1. After two weeks, bring students out to the sites and ask them to observe the biotic, abiotic, and human management elements of the soil habitat that each bag was in, noting features such as relative soil moisture, presence or evidence (e.g., burrows or tunnels) of any soil organisms, vegetative cover and shading, and prior cultivation.
2. Students or the instructor can unbury the bags. This should be done very gently, as the paper is likely to be very fragile. (If too rapid decomposition makes this demonstration difficult, an alternative material to use is a 50/50 cotton/polyester fabric. Even if the cotton is entirely degraded, the polyester matrix will remain intact. Strips would have to be weighed before and after burial to determine mass loss.)
3. Gently brush soil from discs. Ask students to visually estimate the percentage of the disc remaining. You may wish to provide a sheet showing examples of visual estimates of percentages, e.g., to help standardize results.
4. Record results and calculate the average percentage of the disc remaining for each habitat selected. A sample form is provided (see Appendix 2, Litter Bag Data Sheet) for recording data. Appendix 3 provides an example of a filled-out data sheet.

PREPARATION TIME

1 hour to make 24 bags, 1 hour to bury 24 bags (allow additional time for gathering materials)

DEMONSTRATION TIME

1.5 hours

DISCUSSION QUESTIONS

1. After retrieving the litter bags, ask students to offer hypotheses about why the disks decompose more rapidly in some habitats than others.
2. What environmental factors might have influenced the results?
3. What management factors might have influenced the results?
4. Can you see any signs of biological activity on the disks (e.g., fungal mycelia, soil animals, invertebrate feces, comminution)?
5. What do the results suggest about nutrient cycling rates in the soils tested?
6. Can these observations for cellulose decomposition rates be extrapolated to other types of organic matter?
7. What are the limitations of this method?

VARIATIONS

If possible, pair the litter bag demonstration with other methods of assessing biological activity, such as:

- Carbon dioxide evolution (see Demonstration 2, Soil Respiration)
- Earthworm density (see Demonstration 3, Earthworm Populations)
- Tullgren funnel extractions of microarthropods (see Demonstration 4, Soil Arthropods)
- Microbial biomass measurements (this generally requires more extensive lab work, but you might check with local agricultural or ecological researchers to see if anyone doing similar work could accommodate a few samples and help your students analyze the results)

Demonstration 1: Organic Matter Decomposition in Litter Bags

step-by-step instructions for students

INTRODUCTION

The decomposition of organic matter is an important soil process for organically managed farms and gardens. Organic matter includes a vast array of compounds that are biologically decomposed at various rates, depending on the compounds' physical and chemical complexity. Physical factors such as temperature and moisture as well as biological factors such as activity of soil organisms heavily influence decomposition rates, and are all influenced by management practices.

We can use discs of filter paper to represent uniform pieces of cellulose-rich organic matter. If discs are placed in the soil for a set period and then retrieved, we can begin to understand the capacity of various soils to decompose cellulose. By placing the discs in plastic mesh bags prior to putting them in the soil, we make it easier to retrieve the discs intact. Decomposition can be estimated by a visual estimate of percentage surface area remaining. A more quantitative method is to weigh the discs prior to putting them in the field, then collecting them, rinsing them, drying them (e.g., in a drying oven) and reweighing them to estimate mass loss.

MATERIALS NEEDED

- Whatman filter paper discs
- Plastic mesh bags
- Stake wire marking flags
- Flat shovel
- Litter Bag Data Sheet (see Appendix 2)
- Pencils

PREPARATION

1. Litter bags, each consisting of a filter paper disc placed inside a plastic mesh bag, were placed in soil at least two weeks prior to this class. They were placed vertically in the soil, all at the same depth. For a 10 cm disc, 0 to 10 cm is a convenient depth, but your instructor will tell you the actual depth used.

   Depth of litter bags:______________________.

PROCEDURE

1. With your instructor, visit each site where the litter bags have been buried. At each site, observe the biotic, abiotic, and human management elements of the soil habitat that each bag was in.
   - What is the relative soil moisture at each site? Is it damp, dry, or in between?
   - Do you see any presence or evidence of any soil organisms? Are there burrows or tunnels, and if so, are they large or small? What kind of organisms might be using them?
   - Is there vegetative cover of the soil? If so, what kind (grasses, broad-leaf plants, woody shrubs, weeds, crops) and what size (overhead, several feet, close to the ground)? Do the plants shade the soil?
   - Is there evidence of prior or current cultivation?
2. Unbury the litter bags. This should be done very gently, as the paper is likely to be very fragile.
3. Gently brush soil from discs. Visually estimate the percentage of the disc remaining.

4. Record results and calculate the average percentage of the disc remaining for each habitat, using the data sheet supplied.n.

DISCUSSION QUESTIONS

1. After retrieving the litter bags, ask students to offer hypotheses about why the disks decompose more rapidly in some habitats than others:
   a. What environmental factors might have influenced the results?
   b. What management factors might have influenced the results?
   c. Can you see any signs of biological activity on the disks (e.g., fungal mycelia, soil animals, invertebrate feces)?
2. What do the results suggest about nutrient cycling rates in the soils tested?
3. Can these observations for cellulose decomposition rates be extrapolated to other types of organic matter?
4. What are the limitations of this method?

Demonstration 2: Soil Respiration

for the instructor

OVERVIEW

Soil microbes breathe in oxygen and breathe out carbon dioxide; using Draeger gas detection tubes to measure the carbon dioxide output gives an indication of the relative activity of the microbes. The brief instructions below point the instructor to comprehensive directions in the Soil Quality Test Kit Guide published by the NRCS: www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=nrcs142p2_053873. Follow the link to Soil Respiration Test for directions and photos.

MATERIALS

See Soil Respiration Test in the NRCS Soil Quality Test Kit Guide for the full list. Among more common items such as a soil thermometer and stopwatch, you will also need to construct 6-inch diameter rings with fitted lids that have holes with stoppers, allowing equipment such as soil thermometers and Draeger tubes to be inserted. The Draeger tubes will need to be specially ordered, e.g., from a scientific supply company (see Sources of Supplies at the end of this outline). Students may record measurements in the Soil Respiration Data Sheet in Appendix 4.

PREPARATION

Here, too, see the Soil Respiration Test (see directions in the Soil Quality Test Kit Guide: *www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=nrcs142p2_053873.* Follow the link to *Soil Respiration Test* for directions and photos for the complete preparation needed for the demonstration. In addition to gathering and constructing materials, the site will need to be brought to proper soil moisture. From the test guide: "Microbial activity is greatest when the soil is moist (at or near field capacity). If the soil is dry, a second respiration measurement should be made at a minimum of six hours (preferably 16 to 24 hours later) after the infiltration test or wetting of the soil. If the soil is saturated, soil respiration is inhibited, and this test should not be run."To save time during the demonstration, rings can be placed and soils wetted the previous day. It may be useful to combine the litter bag (demonstration 1) and soil respiration measurements, allowing students to compare results from two different methods of measuring soil biological activity.

Locate best sites to use before the demonstration. As with the litter bag demonstration, select a variety of habitats to test, such as raised garden beds, cultivated fields, fallow fields, orchards, compost piles, vermicompost bins, and weedy borders.

PROCEDURE

Divide class in teams of two or more, and assign each team to one sample site. Demonstrate the technique first using equipment prepared at different stages, à la Julia Child. Use one ring to show how rings should be placed and headspace measurements taken. Have a second ring already placed and capped so you can demonstrate how to collect a CO_2 sample. Then send teams out to do their own sampling, using the Soil Respiration Data Sheet (Appendix 4) to record their measurements.

See the Soil Respiration Test (online) for details on how to perform the tests, including preparing the sample area, inserting the rings in the soil, preparing the rings for measurement, taking the measurements, and using the Draeger tubes.

CALCULATIONS

Soil Respiration (lb CO_2 - C/acre/day) =
PF × TF × (%CO_2 - 0.035) × 22.91 × H

PF = pressure factor = 1

TF = temperature factor = (soil temperature in Celsius + 273) ÷ 273

H = inside height of ring = 5.08 cm (2 inches)

If a laptop is available in the field, students can enter the data into a spreadsheet and do these calculations. Calculators could also be used with printed spreadsheets in the field.

PREPARATION TIME

1–2 hours (varies depending on what materials are available)

DEMONSTRATION TIME

1–1.5 hours

DISCUSSION QUESTIONS

1. Compare soil respiration results for different sites. How may management practices on the different sites have influenced results?
2. If measurements were made before and after wetting soil, compare before and after results. How does soil moisture influence biological activity?
3. Would it be possible to estimate all carbon imports and exports to a soil ecosystem? What information would you need to start to make such an estimate?

SOURCES OF SUPPLIES

Draeger tubes, latex tubing, hypodermic needles:

Fisher Scientific, Pittsburgh, PA
www.fishersci.com

(800) 766-7000

Draeger tubes:

Scientific Industries
2207 Blue Bell Ave. Boulder, CO 80302
(303) 443-7087

Demonstration 2: Soil Respiration

step-by-step instructions for students

INTRODUCTION

Soil is alive, teeming with organisms that are eating, growing, breathing, and reproducing. Many of these organisms, from microorganisms such as bacteria and archaea, to macroorganisms such as earthworms and insects, and even plant roots, take in oxygen (O_2) and release carbon dioxide (CO_2). The release of CO_2 from the soil is called soil respiration and is a key component of healthy agroecosystems.

Soil respiration can be limited by soil moisture, temperature, and oxygen availability Optimal respiration rates usually occur around 60% of water-filled pore space, with lower rates when the soil is either dry or saturated with water. Biological activity doubles for every 18˚F rise in temperature until the optimal temperature is reached, although this optimum level varies for different organisms. Activity then declines as temperature rises above optimum. The most efficient soil organic matter decomposers are aerobic, so soil respiration rates are highest where there is high O_2 availability, such as in well-aggregated soil with many macropores, and decline when O_2 concentrations are low, as in soils that are saturated with water. Note that soil respiration is highly variable both spatially and seasonally, especially as soil moisture, temperature, and oxygen availability change, so it's important to keep these factors in mind when interpreting your results.

Soil respiration also depends on the availability of decomposable organic substrates, that is, all the bits of organic matter of various sizes that are food for micro- and macroorganisms. Additions of organic materials will generally increase soil respiration. Organic materials with low carbon to nitrogen (C:N) ratios (e.g., manure, leguminous cover crops) are easily decomposed, so the addition of these materials to soil will increase soil respiration quickly. Materials with high C:N ratios (e.g., compost, sawdust) decompose more slowly but provide a more stable, long-term supply of organic material than legumes and manure. C:N that is too high has drawbacks: Soil microbes will compete with crop plants for the limited nitrogen supply when soil is amended with products having C:N ratios higher than 25:1.

The history of the sampling site is also important. Tillage or cultivation loosens the soil and creates better O_2 accessibility, increasing decomposition of organic matter and respiration rates. However, high respiration rates without adequate replenishing of organic materials can result in net loss of soil carbon. Use of agricultural chemicals that directly kill or otherwise impair soil microorganisms, such as fungicides and nematocides, on the site is also important to consider. Although these pesticides target pathogenic organisms, they may also impair the beneficial organisms and temporarily decrease soil respiration.

Management factors influencing soil respiration

INCREASES SOIL RESPIRATION

- Adding organic amendments, such as cover crops, composts (including composted manure), and crop residues
- Irrigating to proper moisture content
- Tillage

DECREASES SOIL RESPIRATION

- Removing or burning crop residues
- Continuous tillage without organic matter replacement
- Chemical pesticides (e.g., fungicides and nematocides)

MATERIALS

Soil Respiration Test in the NRCS Soil Quality Test Kit Guide Procedure

Follow the instructions from the Soil Respiration Test, as provided by your instructor.

CALCULATIONS:

Soil Respiration (lb CO_2 -C/acre/day) =
PF X TF X (%CO2 - 0.035) x 22.91 x H

PF = pressure factor = 1

TF = temperature factor = (soil temperature in Celsius + 273) ÷ 273

H = inside height of ring = 5.08 cm (2 inches) if not measured

Interpretation of soil respiration values

In general, a higher respiration rate indicates better soil quality. A high soil respiration rate, indicative of high bio-logical activity, can be a good sign of rapid decomposition of organic residues into nutrients available for plant growth. A low respiration rate, when soil temperature and moisture are favorable for biological activity, would indicate too little organic matter input (i.e., the soil organisms have too little organic matter to consume). Some general guidelines to interpreting respiration values are presented in ▶ Table 2.13. These are only guidelines and should not be applied to every soil type and management situation.

▶ **TABLE 2.13** | GENERAL SOIL RESPIRATION CLASS RATINGS AND SOIL CONDITION AT OPTIMUM SOIL TEMPERATURE AND MOISTURE CONDITIONS, PRIMARILY FOR AGRICULTURAL LAND USES (Woods End Research, 1997)

SOIL RESPIRATION (lbs. CO_2-C/ac/day)	CLASS	SOIL CONDITION
0	No soil activity	Soil has no biological activity and is virtually sterile
< 9.5	Very low soil activity	Soil is very depleted of available organic matter and has little biological activity
9.5 – 16	Moderately low soil activity	Soil is somewhat depleted of available organic matter, and biological activity is low
16 – 32	Medium soil activity	Soil is approaching or declining from an ideal state of biological activity
32 – 64	Ideal soil activity	Soil is in an ideal state of biological activity and has adequate organic matter and active populations of microorganisms
> 64	Unusually high soil activity	Soil has a very high level of microbial activity and has high levels of available organic matter, possibly from the addition of large quantities of fresh organic matter or manure

These guidelines are rules of thumb, but the soil respiration rate must be interpreted within the context of other indicators. For example, if the soil has very low nitrate concentrations and high respiration rates, there may be high nitrogen immobilization (when microbes bind up nitrogen in organic forms, so it's not available to other organisms, such as plants); this can result from adding soil amendments that have high C:N ratios.

Similarly, as mentioned in the introduction, high respiration rates without adequate input of organic matter can indicate too much decomposition, leading to a decrease in the stable component of soil organic matter. This then decreases the key properties of soil organic matter, such as aggregation, cation exchange, and water holding capacity, that make it such an important part of soil health. High respiration rates can happen immediately following a tillage operation, due to exposure of organic matter to organisms and oxygen, as well as after rainfall. The increase in soil respiration is affected by the length of time the soil is dry before the rainfall event.

Spatial differences, even on a small scale, are helpful to consider in interpreting soil respiration rates. Under dry conditions, soil respiration tends to be higher in the crop row than between the rows, due to respiration from the crop roots. This difference disappears during wet conditions, when pore space is filled and oxygen availability drops in both microhabitats. However, when the soil between rows has been compacted (e.g., by wheels) and the soil is wet, soil respiration tends to be lower than in the row, because of lower soil porosity under compaction.

DISCUSSION QUESTIONS

1. Compare soil respiration results for different sites. How may management practices on the different sites influence results?
2. If measurements were made before and after wetting soil, compare the before and after results. How does soil moisture influence biological activity?
3. Would it be possible to estimate all carbon imports and exports to a soil ecosystem? What information would you need to start to make such an estimate?

Demonstration 3: Assessing Earthworm Populations as Indicators of Soil Quality

for the instructor

OVERVIEW

This demonstration introduces students to techniques for assessing earthworm populations as indicators of soil quality.

You have a choice of two methods for this demonstration. The shovel-count method will be more tedious for the students because they will have to sort through the soil and remove all earthworms. The vermifuge method may take a little more effort at first to gather the materials needed, but it will make the students' work easier.

MATERIALS

SHOVEL-COUNT METHOD

- Shovels
- Earthworm Data Sheet (Appendix 5)
- Pencils

VERMIFUGE METHOD

- Sample rings†
- Clippers
- Watering can
- Scoop
- Stirring rod
- Fresh water
- Jars
- Earthworm Data Sheet (Appendix 5)
- Pencils
- Ground yellow mustard seed (available in bulk from health food stores or from herb companies)‡

†Sample rings define the sample area and prevent vermifuge from escaping sample area. A simple design is to cut the top 8–12 inches from a 5-gallon drum and weld on a piece of metal pipe that overhangs each side by 6 inches to use as a handle. The ring is pressed into the soil to 2–3 inches depth, and vermifuge is added within the sample ring. Sample rings can also be fashioned from sheet metal, housing duct pipes, or large clean paint cans with the bottom cut off.

‡60 ml (volume) or 32 grams of yellow mustard powder to 4.5 liters of tap water = 13 ml/1 liter or 7g/liter.
4.5 liters of vermifuge is the amount required per sample area in this demonstration.

PREPARATION

SHOVEL-COUNT METHOD

For the shovel-count method, very little preparation is required. Identify sample areas, try to collect a similar soil volume at each location, and record results.

VERMIFUGE METHOD

The vermifuge method requires more preparation. Sample rings must be obtained or made. Other materials must be gathered. To minimize the amount of time needed for the demonstration, sample rings can be set out the day before. Ideally a minimum of 4 can be set out per habitat. Select areas with contrasting management regimes. Possible habitats include orchard, row crop, fallow, and uncultivated field soils.

To begin the demonstration, gather group at one sample ring to explain technique. Divide class evenly among the number of sample rings and have each "ring-team" collect their sample. Have one person in each team do a shovel-count at each site for comparison. Collect results and derive an average abundance per habitat. Observe species differences and discuss results.

PROCEDURE

1. Select sample area.
2. Place sample rings on the surface of the site and push them several inches into the soil.
3. Carefully clip vegetation and removed all litter from inside sample area.
4. Slowly sprinkle 4.5 liters of vermifuge into each sample area, distributing it evenly over the entire surface.
5. After all of the vermifuge solution infiltrates the soil, wait 10 minutes, and make a second vermifuge application (4.5 liters).
6. Collect all earthworms that surface inside the sample area.
7. After 10 minutes elapse since infiltration of the second vermifuge application, use a hand spade to dig through the surface layer of soil (~5 cm deep) and collected any more earthworms found there.
8. Rinse earthworms in water, drain, and store in containers inside an insulated cooler with ice packs (unless samples are to be counted in the field and returned to the sample area).
9. An alternate method that does not require a sample ring can be found in the USDA Soil Quality Test Kit Guide, which is available on the internet (see Resources section).

PREPARATION TIME

For the shovel-count method, 0.5 hour is all that is needed. For the vermifuge method, several hours or more may needed to gather materials.

DEMONSTRATION TIME

1.5–2 hours

DISCUSSION QUESTIONS

1. Most earthworm species found in farmed soils in the U.S. were not present in those soils 400 years ago. Where do you think they came from?
2. Compare your findings from different habitats. Which habitats had the most earthworms per sample area? Which had the highest diversity (greatest number of species)? Why?
3. Determine what ecological types of earthworm were present in each sample area (see ▶ Table 2.13, page 2-114). How do you think these results were influenced by soil management practices in those areas. Consider factors such as amount and type of soil disturbance, organic matter inputs, presence of surface organic layer, etc.
4. How do these findings relate to agricultural productivity and sustainability?
5. If you were in charge of management decisions for the farm soils that were sampled, would you alter any practices based on this information? Why?

Demonstration 3: Assessing Earthworm Populations as Indicators of Soil Quality

step-by-step instructions for students

INTRODUCTION

Earthworms are representative of the many organisms that make up soil food webs, and their abundance can be an indicator of soil biological activity.

There are a number of ways to estimate how many earthworms are living in a particular field. Perhaps the simplest is the shovel-count: turn over a shovel-full of soil and count the worms present. Dig down 8 inches to a foot, and count every earthworm you can find in the shovel-full. Do this in half-a-dozen or more spots in each soil type on your land and come up with an average for each. If you find 5 to 10 worms per shovel-full, that represents a fairly healthy earthworm community. If this is done at about the same time each year the results will give some indication of how management practices are affecting earthworm populations.

Keep in mind that earthworm populations are very patchily distributed, and their location and abundance are heavily influenced by soil moisture, temperature, organic matter, time of year, and probably several other variables such as barometric pressure. For these reasons, a sufficient number of samples must be collected in order to accurately characterize earthworm populations in a particular field. Using more standardized sampling methods may also help.

Another method for sampling earthworms uses a vermifuge, or chemical irritant, which causes the earthworms to burrow to the soil surface, where they can be collected by hand. For many years the standard vermifuge has been a very dilute solution of formalin (about 8 ml formalin in 4.5 liters of water). However, recent studies have shown that mustard powder in water can be equally as effective.

Those interested in developing an even greater depth of understanding about earthworm ecology and how it interacts with farming may want to do more than just count numbers of earthworms present. Earthworms can be classified according to some simple physical characteristics that are directly related to their ecological roles in soil. ▶ Table 2.14 (next page) highlights the three types of earthworms.

Try using ▶ Table 2.14 to determine if you have more than one type of earthworm in your samples. Most California farm soils have endogeic earthworms, but epigeic and anecic species are rare. Epigeic species are more likely to be found in fields that have a permanent organic mulch on the surface. They may be added along with composts, but are not likely to thrive in the absence of an organic cover. Anecic species are desirable because of the work they do incorporating organic matter into the soil, mixing surface and deeper soil horizons, and creating deep channels for aeration, infiltration, and easy root penetration. Anecic earthworms could be introduced by direct inoculation, but transferring blocks of soil (one cubic foot each) from an area with a large earthworm population into a farm soil might work better.

Another idea is to set aside a small portion of a farm to be managed as an earthworm reservoir. If needed, the soil could be limed to bring it near pH 7, fertilized, irrigated regularly, and a cover crop established and cut periodically to provide an organic mulch as food and cover. A population of an anecic species could be introduced into this area and built up. Nightcrawlers can be purchased from bait dealers, who generally get them from nightcrawler harvesters in the Pacific Northwest.

From this reservoir, blocks could periodically be taken and introduced into the field. This might be done each year in the fall when earthworm activity is increasing. Remember to provide an organic mulch. The rate of spread would vary with species and conditions in the field. *Lumbricus terrestris,* the nightcrawler, is capable of traveling at least 19 meters (62 feet) on the soil surface in the course of one evening foray.

MATERIALS NEEDED

Assemble materials as per instructor's outline

SHOVEL-COUNT METHOD

1. For the shovel-count method, very little preparation is required. Identify sample areas, try to collect a similar soil volume at each location, and record results.

VERMIFUGE METHOD

1. Select sample area
2. Place sample rings on the surface of the site and push them several inches into the soil.
3. Carefully clip vegetation and removed all litter from inside sample area.
4. Slowly sprinkle 4.5 liters of vermifuge into each sample area, distributing it evenly over the entire surface.
5. After all of the vermifuge solution infiltrates the soil, wait 10 minutes, and make a second vermifuge application (4.5 liters).
6. Collect all earthworms that surface inside the sample area.
7. After 10 minutes elapse since infiltration of the second vermifuge application, use a hand spade to dig through the surface layer of soil (~5 cm deep) and collected any more earthworms found there.
8. Rinse earthworms in water, drain, and store in containers inside an insulated cooler with ice packs (unless samples are to be counted in the field and returned to the sample area).
9. An alternate method that does not require a sample ring can be found in the USDA Soil Quality Test Kit Guide, which is available in the internet (see Resources section).

TABLE 2.14 | THREE DIFFERENT TYPES OF EARTHWORMS

GROUP	WHAT THEY LOOK LIKE	WHERE THEY LIVE	WHAT THEY EAT	MEANING OF NAME	EXAMPLE
Epigeic	small; dark red or brown; fast growing move quickly	areas with a lot of organic matter: forest litter layer; manure piles; cool compost piles	large proportion of diet is organic matter	epi = on Gaia = earth	*Lumbricus rubella*, *Eisenia fetid*a (red worm, manure worm)
Endogeic	small to medium; light or no pigmentation; slower moving	continous burrows in soil; often found in root ball; generally feed and defecate below ground	mixture of buried organic matter and mineral soil, decaying roots	endo = within Gaia = earth	*Allolobophora chlorotica*, *Aporrectodea caliginosa*
Anecic	large and very muscular; wedge-shaped tail; color on front end, less on tail end; slow growing	build permanent, vertical burrows that are very deep; raised midden of castings and residue marks burrow entrance	feed by pulling organic matter from surface down into burrow before ingesting	unknown	*Aporrectodea longa* *Lumbricus terrestris* (night-crawler)

A visual guide to these three types of earthworms can be found here:
www.nrri.umn.edu/worms/identification/ecology_groups.html

Demonstration 4: Soil Arthropods

for the instructor

OVERVIEW

This demonstration introduces students to techniques for sampling soil arthropods and familiarizes them with their functional roles.

For this short demonstration, both of these exercises provide a hands-on, show-and-tell of soil arthropods. You should have identification keys available, and some familiarity with what kinds of animals students are likely to find.

A pitfall trap is buried so the top sits flush with the soil surface, allowing surface-dwelling arthropods to fall in. Preserving liquid can be used in the bottom of the trap to keep the arthropods there for easy removal and identification. A Tullgren funnel uses light to dry out a soil or compost sample, driving out organisms so they can be collected and identified.

MATERIALS

PITFALL TRAPPING

- Cups (e.g., 500 or 1000 ml plastic drink cups; 1 per trap if one-time installation, or 2 per trap if you wish to repeat the trapping)
- Trowel
- (Optional) Preserving agent, e.g., ethanol or propylene glycol, especially for demonstrations that will run several days or more from start to finish. You need enough for 5-10 cm in the bottom of each trap.

TULLGREN FUNNELS

- Funnels (1 for each Tullgren funnel set-up)†
- Light source (4 to 40 watt —7 watt "Christmas" style lights work well; each funnel needs its own light source)
- Aluminum foil (if light source does not have a shade for focusing the heat on the sample)
- Screen (1 piece per funnel)‡
- Jars (1 per funnel)
- Ethanol or propylene glycol. You need enough for 10–20 cm in the jar below the funnel.

† Steep-sided funnels with no seams work well; inverted soda bottles work, and inverted polypropylene Erlenmeyer flasks with bottoms removed are excellent. Use 500 ml flasks for 5 x 5 cm soil cores, and 2000 ml flasks for compost or litter samples.

‡ Examples for screen material are fine hardware cloth or plastic needlework backing—it should be fine enough to allow small organisms to pass through (e.g., less than 1-cm openings). The screen should be trimmed to fit across the mouth of or in the middle the funnel, as its role is to hold the sample in place in the funnel while it dries out.

FOR BOTH METHODS

- Dissection microscopes or hand lenses
- Identification guide, e.g., *www.cals.ncsu.edu/course/ent525/soil/soilpix/index.html*
- Soil Arthropod Data Sheet (Appendix 6)

PREPARATION

PITFALL TRAPPING

Select sampling areas in different habitats. Try for a minimum of 3 or 4 samples per habitat. Traps can be set 24 to 48 hours in advance of the demonstration. Traps can also be collected before the demonstration if time is at a minimum, although it will help students contextualize their results if they can see where and how the traps were set.

At each sampling site, bury a cup so that the top edge is flush with the soil surface; to help prevent the cup from filling with soil, you can bury two cups together, one inside the other, and then remove the top cup to have a clear working cup below. If you are using two cups for your trap, set the lower one down enough so the top cup is flush with the soil surface. The top of the cup may be left open, covered with hardware cloth, or covered with a board, leaving enough room between the board and pitfall trap for free access by surface roaming creatures (e.g., by propping the board up with a stone under each side).

If collected frequently, pitfalls may be left empty so that live specimens are obtained. You may also obtain specimens by adding 5–10 cm of soapy water in the bottom of the trap, or by using a preservative such as 70% ethanol (rubbing alcohol mixed 7:3 with water) or propylene glycol ("non-toxic" antifreeze). Preservatives help ensure the organisms do not eat one another; propylene glycol has the added benefit of not evaporating.

TULLGREN FUNNELS

Collect samples from various habitats. You can use soil cores (approx. 5 x 5 cm^2), decomposing leaf litter, or compost.

Set up one Tullgren funnel for each sample. Place a piece of screen across the mouth of or part-way down a funnel. Carefully place the sample on the screen . If too much sample material falls through the funnel, add more screens, or a piece of coarse cheesecloth below the funnel. Place a wide-mouth jar with 10–20 cm of 70% ethanol or of propylene glycol under the funnel—this is where the organisms will be collected. Place the light source above the funnel, with the light above, but not touching, the sample. Do not shake or disturb funnels, keeping the sample jars as free of soil as possible. Let samples stand in funnels with the lights on for 5–7 days.

Samples can be collected and extracted in advance of the demonstration, although as with pitfall traps, it will help students contextualize their results if they can see how the samples were collected and how the Tullgren funnels work.

PROCEDURE

Observe the collected arthropods under magnification, either with dissecting scopes or hand lenses. If live collections are made from the pitfall traps, students can observe behavioral adaptations of the animals (e.g., springing springtails, fast-moving predators like centipedes and mesostigmatid mites, and slower-moving fungal grazers like oribatid mites and millipedes). Have simple keys available for help with identification. For a quantification exercise, have students count species or functional groups and calculate a diversity index, e.g., the Shannon index (see here: *www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html*) or Simpson's index, to compare habitats.

PREPARATION TIME

2 hours to 7 days, depending on which exercises are followed (less time generally for the pitfall trap, more for the Tullgren funnel) and what materials are available or need to be obtained.

DEMONSTRATION TIME

From 0.5 hour for a brief show-and-tell, where students observe samples previously collected, to 1 to 2 hours if students are involved in collecting samples, observing, and quantifying.

DISCUSSION QUESTIONS

1. Can you guess which animals might be predators? Which ones might be grazers? What about their shape indicates their functional group, that is, how they feed?
2. What effects do each habitat have on the soil organisms found there? Think about the sizes of creatures, diversity, food-web interactions, and pigmentation.
3. Which habitats had the greatest abundance? Which had the greatest diversity? Why?
4. What effects do you think different soil management practices have on soil arthropods? Besides the various effects of organic matter inputs, think about the influence of physical disturbance.

Assessment Questions

1) What is soil?

2) What forms of life exist in soil ecosystems?

3) How would you define a "healthy" agricultural soil?

4) What is a soil food web?

5) What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizer and pest control agents on the soil ecosystem?

Assessment Questions Key

1) What is soil?
   - *An ecological system consisting of inorganic minerals (sand, silt, clay, and nutrients), pore spaces, water, gases, organic matter, living organisms, and plants*
2) What forms of life exist in soil ecosystems?
   - *Bacteria, fungi, actinomycetes, millipedes, isopods, mollusks, insects, insect larvae, worms and many small vertebrate animals such as gophers, ground squirrels, moles, etc.*
3) How would you define a "healthy" agricultural soil?
   - *A soil with a set of desirable physical and chemical properties which has the capacity to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health. This would include many of the following general characteristics:*

   a) adequate rooting depth for the crop(s) to be grown

   b) a 3–5% organic matter content

   c) maintains stable soil aggregates

   d) allows for rapid water infiltration without soil erosion

   e) a low bulk density (good structure with minimal compaction)

   f) pH between 6 and 7

   g) an extractable nutrient profile within the optimal range of physiological tolerance for the crops to be grown

   h) good water holing capacity and well-drained

   i) high soil biological diversity and activity (soil respiration)

   j) adequate supplies of labile organic matter with potentially mineralizable nitrogen

   k) seasonal soil temperatures from 60–85ºF
4) What is a soil food web?
   - *The entire assemblage of soil organisms (producers, consumers and decomposers) in a soil ecosystem interacting among and between trophic levels*
5) What might be some negative effects of the long-term practice of monoculture cropping and the use of synthetic chemical fertilizer and pest control agents on the soil ecosystem?
   - *Loss of SOM, reduction in soil aggregation, reduction in nutrient- and water-holding capacity, reduction in soil biological diversity and activity, increased pest and disease incidence*

Resources

PRINT RESOURCES

Coleman, David, and Dak Crossley. 1996. *Fundamentals of Soil Ecology.* San Diego, CA: Academic Press.

The best textbook introduction to the subject that I know of. Gives an overview of the basics, and attempts to consider the applications.

Dindal, Daniel, ed. 1990. *Soil Biology Guide.* NY: Wiley.

A weighty tome, with chapters including taxonomic keys and basic biology/ecology on virtually all organisms found in soils.

Doran, John, and Alice Jones (eds.). 1996. *Methods for Assessing Soil Quality.* Special Publication # 49. Madison, WI: Soil Sci. Soc. America.

Soil quality is the current buzzword in soil science circles. This volume explores the application of the idea to sustainable environmental management.

*Gershuny, Grace, and Joseph Smillie. 1999. *The Soul of Soil: A Soil-Building Guide for Ecological Farmers and Gardeners, 4th Edition.* White River Junction, VT: Chelsea Green Publishing.

More hands-on and less academic than the above works, this book is aimed at plant growers and has lots of practical information.

Gibbons, Boyd. 1984 (September). Do we treat our soil like dirt? *National Geographic,* pp 351-388.

An overview of US soils, from soil biota to bankrupt farmers, done in classic NG style, with lots of great photos and drawings.

Gliessman, Stephen R. 1998. *Agroecology: Ecological Processes in Sustainable Agriculture.* Chelsea, MI: Ann Arbor Press.

Provides a brief overview of the most commonly used conventional agricultural practices and the environmental and agroecological consequences of their use.

Tugel, Arlene, Ann Lewandowski, and Deb Happe-vonArb, eds. 2000. *Soil Biology Primer, Revised Edition.* Ankeny, Iowa: Soil and Water Conservation Society.

An excellent overview of soil biology, loaded with glossy photos and colorful chart. Available from www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/.

WEB-BASED RESOURCES

Appropriate Technology Transfer for Rural Areas (ATTRA)

attra.ncat.org/publication.html#soils

Colorado State University Extension, Garden Notes: The Living Soil

www.ext.colostate.edu/mg/gardennotes/212.html

Introduces various types of beneficial soil organisms and their roles, as well as how to encourage beneficial organisms by creating a favorable soil environment.

European Atlas of Soil Biodiversity

eusoils.jrc.ec.europa.eu/library/maps/Biodiversity_Atlas/

Information-rich resource on soil organisms offers a comprehensive guide to soil biology, soil ecosystem functions, and the ecosystem services that soil organisms provide (e.g., nutrient cycling).

Food and Agriculture Organization (FAO) of the United Nations

www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/soil-biodiversity/agriculture-and-soil-biodiversity/en/

Discusses the effect of different agricultural practices on soil organisms. Includes information on how to improve soil biodiversity through soil management, sustainable agriculture, and agroecological farming options.

www.fao.org/docrep/009/a0100e/a0100e0d.htm

Describes the categories and characteristics of soil organisms, including beneficial and harmful organisms in agricultural soils. Includes a

discussion of the effects of organic matter on soil properties.

Great Lakes Worm Watch!

www.nrri.umn.edu/worms/identification/ecology_groups.html

Excellent description of earthworm ecological groups

Nature Education, The Rhizosphere – Roots, Soil and Everything in Between

www.nature.com/scitable/knowledge/library/the-rhizosphere-roots-soil-and-67500617

Comprehensive description of the rhizosphere, including an excellent description and graphics of legume-rhizobia symbiosis, mycorrhizal fungi and nutrient acquisition, and root system architecture. Includes a useful glossary

USDA, Natural Resources Conservation Service

www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/

www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource/

Resources and publications on soil health, including information sheets and technical notes on soil organic matter, soil erosion, soil biodiversity, and soil quality evaluation

http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053868

Thorough discussion of the soil food web, written by Elaine Ingham.

SOIL QUALITY

Appropriate Technology Transfer for Rural Areas (ATTRA)

www.attra.org/attra-pub/soil-lab.html#Soil%20Health°

Illinois Soil Quality Initiative (ISQI)

www.aces.uiuc.edu/~asap/resources/isqi/soilhealth.html

Life in the Soil

www.crcslm.waite.adelaide.edu.au

Soil and Health Library

www.soilandhealth.org/index.html

Soil Biological Communities

www.blm.gov/nstc/soil/index.html

Soil Ecology Society

vax.wcsu.edu/ses/ses.html

Soil Quality Institute—NRCS

www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

The Soil Foodweb: Its Importance in Ecosystem Health, Elaine Ingham

www.rain.org/~sals/ingham.html

University of California Sustainable Agriculture Research and Education Program (UC SAREP)

www.sarep.ucdavis.edu/soil/websites.htm

SOURCES OF SUPPLIES

Fisher Scientific, Pittsburgh, PA
www.fishersci.com
(800) 766-7000

Scientific Industries
2207 Blue Bell Ave. Boulder, CO 80302
(303) 443-7087

Appendix 1: Major Organic Components of Typical Decomposer Food Sources

	PROTEINS	FATS	CARBOS	SIMPLE CELLULOSE	HEMI-CELLULOSE	LIGNIN	ASH
Oak leaf (young)	9	8	22	13	16	21	6
Oak leaf (old)	3	4	15	16	18	30	5
Pine needle	2	24	7	19	16	23	2
Grass leaf	2	2	13	24	33	14	0
Corn stem	1	2	15	18	30	11	8
Wood	0	4	2	22	47	22	1
Horse manure	7	2	5	24	28	14	9
Bacteria	50–60	10–35	5–30	4–32	0	0	5–15
Fungi	14–52	1–42	8–60	2–15	0	0	5–12
Earthworm	54–72	2–17	11–17	0	0	0	9–23
Arthropods	38–50	13–26	14–31	5–9	0	0	0

Appendix 2: Litter Bag Data Sheet

burial date: location:

retrieval date: details:

LITTER BAG #	HABITAT	% REMAINING (VISUAL ASSESSMENT)	AVERAGE PER HABITAT	OTHER OBSERVATIONS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				

Appendix 3: Litter Bag Data Sheet Example

burial date: location:

retrieval date: details:

LITTER BAG #	HABITAT	% REMAINING (VISUAL ASSESSMENT)	AVERAGE PER HABITAT	OTHER OBSERVATIONS
1	compost	5		
2	compost	25		
3	compost	80		
4	compost	90	50.0	
5	orchard soil	100		
6	orchard soil	100		
7	orchard soil	70		
8	orchard soil	90	90.0	
9	raised garden bed	97		
10	raised garden bed	99		
11	raised garden bed	72		
12	raised garden bed	95	90.8	
13	row crop	97		
14	row crop	95		
15	row crop	94		
16	row crop	96	95.5	
17	soil surface	100		
18	soil surface	100		
19	soil surface	100		
20	soil surface	99	99.8	

Appendix 4: Soil Respiration Data Sheet

Soil Respiration (at Initial Field Water Content) | **Date:**

Sample site	Ring height	Start time	End time	Soil temp °C	Draeger tube %CO_2 (n=1)	Soil respiriration lbs C/A/ day*	Draeger tube %CO_2(n=5)	Soil respiration lbs C/A/day*
1						0.0		0.0
2						0.0		0.0
3						0.0		0.0
4						0.0		0.0
5						0.0		0.0
6						0.0		0.0
7						0.0		0.0
8						0.0		0.0

Soil Respiration (at least 6 hours after irrigation or soil wetting) | **Date:**

Sample site	Ring height	Start time	End time	Soil temp °C	Draeger tube %CO_2 (n=1)	Soil respiriration lbs C/A/ day*	Draeger tube %CO_2(n=5)	Soil respiration lbs C/A/day*
1						0.0		0.0
2						0.0		0.0
3						0.0		0.0
4						0.0		0.0
5						0.0		0.0
6						0.0		0.0
7						0.0		0.0
8						0.0		0.0

* Soil respiration = PF x ((Soil Temp C + 273)/273) x (CO_2% - 0.035) x 22.91 x Ring Ht = lbs CO_2 -C/acre/day

PF = Pressure Factor = 'raw' barometric pressure in inches Hg/29.9 inches.

Note: This adjustment is necessary at elevations > 3,000 ft.; otherwise PF = 1

H = 5.08 cm (if not measured)

Conversion: Degrees Celsius = 5/9 x (Degrees Fahrenheit - 32)

Notes:

Appendix 5: Earthworm Data Sheet

DATE:

SAMPLE SITE	EPIGEIC EARTHWORMS	ENDOGEIC EARTHWORMS	ANECIC EARTHWORMS	TOTAL EARTHWORMS	EARTHWORMS PER SQ METER
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

NOTES:

Epigeic:	Small; dark red or brown color; fast growing; move quickly
Endogeic:	Small to medium; light or no pigmentation; slower moving
Anecic:	Large and very muscular; wedge-shaped tail; color on front end, less on tail end; slow growing

Appendix 6: Arthropod Data Sheet

	1	2	3	4	5	6	7	8	9	10	11
sample site:											
isopods											
springtails											
spiders											
mites											
earwigs											
aphids											
beetles											
fly larvae											
fly adults											
ants											
wasps											
crickets											
millipedes											
centipedes											
slugs & snails											