2.1 Soils and Soil Physical Properties

Introduction: Soils and Soil Physical Properties

UNIT OVERVIEW

This unit introduces students to the components of soil and soil physical properties, and how each affect soil use and management. The lecture introduces the components of soil and different concepts of soil and soil physical properties, 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

> LECTURE (1 LECTURE, 3.0 HOURS)

The lecture outline introduces students to the components of soil, and different concepts of soil and soil physical properties, with special attention to those properties that affect farming and gardening.

> DEMONSTRATION 1: SOIL TEXTURE DETERMINATION (1.0 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 (1.0 HOUR)

In Demonstration 2, students examine soil horizons, texture, structure, color, depth, pH, etc. in a large soil pit. Students and the instructor should 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 (1.0 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- Components of soil
- Soil physical properties: What are they?
- How soil physical properties affect use

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 R. R. Weil. 1999. *The Nature and Properties of Soils.* Chapter 1, 1.1–1.14 (pp. 1–22)

RECOMMENDED READINGS

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

Lecture Outline: Soils and Soil Physical Properties

for the instructor

A. Introduction

1. What is soil?
   a) Definitions
      i. Different concepts = Different definitions
         - Edaphological (in relation to plant growth)
         - Engineering
         - Pedological (sees soil as a distinct entity)
   b) Functions of soil
      i. Support growth of higher plants
      ii. Primary factor controlling fate of water in hydrologic system
      iii. Nature's recycling system
      iv. Habitat for organisms
      v. Engineering medium

B. How Soil Is Made

1. Soil-forming factors
   a) Time: How long the soil has been forming
   b) Parent material: E.g., rock, alluvium
   c) Biotic factors: Plants, animals, microorganisms
   d) Topography: Slope position, aspect, shape, and amount
   e) Climate: Temperature, moisture, seasonal distribution
2. Soil profiles and soil development
   a) Soil horizons
   b) Soil horizonation
3. What is in soil?
   a) 40–50% mineral
      i. Gravel, cobbles, stones, boulders
      ii. Sand (0.05–2.00 mm)
      iii. Silt (0.002–0.05 mm)
      iv. Clay (< 0.002 mm)
   b) 0–10% biological (see tables 1 and 2 in Detailed Lecture Outline)
      i. Flora and fauna
      ii. Live and dead (organic matter)
      iii. Macroscopic and microscopic
   c) ~50% pore space
      i. Air
      ii. Water
4. Soil classification: 12 Orders

C. Soil Properties

1. Texture
   a) Soil separates (mineral part of soil)
      i. Sand: Gritty
      ii. Silt: Floury when dry, greasy when wet
      iii. Clay (see Baklava demonstration in Supplemental Demonstrations)
   b) Texture triangle
      i. 12 soil textures
2. Structure
   a) What is it?
      i. Arrangement of soil particles into aggregates
      ii. Natural vs. man-made (peds vs. clods)
      iii. Types (shape) (see figure 3, Soil Texture Triangle, in Detailed Lecture Outline)
      iv. Size: very fine, fine, medium, coarse, very coarse, thick, thin
      v. Grade
      vi. Compound structure
         - One structure beside another
         - One structure within another ("parts to…")
      vii. Persistence upon wetting and drying—"Aggregate stability"
   b) What causes structure?
      i. Biological factors/organic matter
      ii. Clay (type and amount)
      iii. Calcium and sodium effects
      iv. Climate (wet/dry, freeze/thaw)
3. Pores
   a) What are they and why are they important?
   b) Types of pores
      i. Interstitial pores: Spaces between mineral grains and peds
      ii. Tubular pores: Pores made by root or animal activity that are or were at one time continuous
      iii. Vesicular pores: Bubble-shaped pores
   c) Sizes of pores
      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
   a) What is it?
   b) Importance
5. Organic matter
   a) Importance of organic matter
      i. Structure
      ii. AWC
      iii. CEC
   b) Relationship to climate

6. Color
   a) How it is measured
   b) Significance of/indicator of:
      i. Drainage and wetness (redoximorphic features) (show samples)
      ii. Organic matter
7. Soil depth
   a) Bedrock
   b) Densely compacted material (tillage pan)
   c) Natural hardpans (soil cemented by iron, lime, gypsum, silica, etc.) (show example)
   d) Strongly contrasting textures (pot effect)
   e) Water tables
8. Soil temperature
   a) Factors influencing soil temperature
      i. Local climate: Soil temperature is highly correlated to air temperature
      ii. Slope steepness and aspect
      iii. Topography: Topography influences microclimates
      iv. Cover: Plants shade the soil, reducing the temperature
      v. Soil color: Darker-colored soils absorb heat more readily than lighter-colored soils
      vi. Horticultural practices: Influence of mulches
   b) Soil temperature influences on soil properties
      i. Biological activity
      ii. Organic matter accumulation: Lower temperature, greater organic matter accumulation
      iii. Weathering of parent materials: Fluctuating temperatures help break down mineral grains; warmer temperatures increase chemical weathering
9. Drainage
   a) Excessively drained
   b) Somewhat excessively drained
   c) Well drained
   d) Moderately well drained
   e) Somewhat poorly drained
   f) Poorly drained
   g) Very poorly drained
10. Odor
   a) Indicator of wetness
11. Permeability
   a) Rate at which water moves through the soil
   b) Measurement (inches/hour)
   c) Properties influencing permeability
      i. Texture (do permeability demonstration in Supplemental Demonstrations)
      ii. Structure
         - Salts
         - Organic matter
         - Compaction and pores
         - Calcium
         - Soil organisms

d) Additional properties influencing infiltration
   i. Dryness
   ii. Surface fragments
   iii. Fire
   iii. Slope

12. Available Water Capacity (AWC)
   a) Field capacity: The amount of water the soil can hold against the flow of gravity (1/3 bar or 33 kPa). (Also see Unit 1.5, Irrigation: Principles and Practices.)
   b) Wilting point: The moisture level at which the soil can no longer provide moisture for plant growth. (15 bar or 1500 kPa)
   c) Measurement (inches/inch or inches/foot)
   d) Properties influencing water-holding capacity
      i. Texture
      ii. Salts
      iii. Organic matter
      iv. Compaction
      v. Soil depth
      vi. Coarse fragments
      vii. Estimating AWC

Detailed Lecture Outline: Soils and Soil Physical Properties

for students

A. Introduction

1. What is soil?
   a) Definitions
      i. Different concepts = Different definitions
      - Edaphological (in relation to plant growth)
        A mixture of mineral and organic material that is capable of supporting plant life
      - Engineering
        Mixture of mineral material (sands, gravels and fines) used as a base for construction
      - Pedological (sees soil as a distinct entity)
        The unconsolidated mineral or organic material on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. Geosphere-Biosphere-Hydrosphere-Atmosphere interface.

   b) Functions of soil
      i. Support growth of higher plants
      ii. Primary factor controlling fate of water in hydrologic system
      iii. Nature's recycling system
      iv. Habitat for organisms
      v. Engineering medium

B. How Soil Is Made

1. Soil-forming factors

   At one time it was felt that soils were static. In the late 1800s, Russian soil scientists introduced the concept that soils are dynamic—that they developed to the point where they are now and that they are evolving into what they will be. They 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 used for soil formation is pedogenesis.

Weathering is the term used to refer to the breakdown of rock into smaller and smaller pieces. Two types of weathering are recognized, chemical and mechanical (physical). Mechanical weathering has to do with 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 size particles. (Since quartz is resistant to chemical weathering, it won't get much smaller than this.)

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. 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.

a) Time: How long the soil has been forming
b) Parent material: E.g., rock, alluvium
c) Biotic factors: Plants, animals, microorganisms
d) Topography: Slope position, aspect, shape and amount
e) Climate: Temperature, moisture, seasonal distribution

FIGURE 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

2. Soil profiles and soil development
   a) Soil horizons

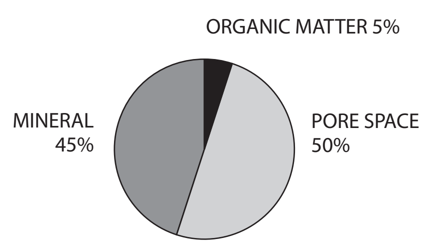
   Soils consist of one or more distinct layers called horizons. These layers are referred to as O, A, E, B, C and R depending on their position and nature

   - O: Layers dominated by organic material. Usually not present under warm-dry conditions.
   - A: The mineral soil horizon that is usually at the surface or below an O horizon. It usually has more organic carbon than underlying layers. Sometimes this layer is missing or truncated due to erosion or 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: A horizon, formed below an A, E, or O horizon, which is dominated by obliteration of all or much of the original rock structure and which shows evidence of soil formation such as illuvial (moved down from an above horizon) concentration of silicate clay, iron, aluminum, humus, carbonates, gypsum, or silica; development of soil color or structure; or brittleness, etc.
   - C: Horizons or layers, excluding hard bedrock, that are little affected by pedogenic (soil forming) processes and that lack properties of O, A, E or B horizons.
   - R: Hard bedrock

   b) Soil horizonation

   (Talk through a possible scenario, use blackboard)
3. What is in soil? (See figure 2)

FIGURE 2. SOIL COMPOSITION: AN IDEALIZED SOIL



a) 40–50% mineral
   i. Gravel, cobbles, stones, boulders
   ii. Sand (0.05–2.00 mm)
   iii. Silt (0.002–0.05 mm)
   iv. Clay (< 0.002 mm)
b) 0–10% biological (See tables 1 and 2)
   i. Flora and fauna
   ii. Live and dead (organic matter)
   iii. Macroscopic and microscopic
c) ~50% pore space

   Pore space consists of the "empty" spaces in the soil. While this might seem to make the pore space unimportant, in reality it is a very important part of the soil. Pore space might be filled with one of two things:
   i. Air
   ii. Water

TABLE 1. SOIL FAUNA AND THEIR EATING HABITS

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

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

TABLE 2. 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	$10 - 10^2$

4. Soil classification: 12 Orders

   Soil scientists have come up with systems for classifying soils, much like 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 this classification is based on genesis—how it is thought the soil developed (plants and animals are also classified by how it is thought they originated—genetics). Also, like plant and animal classification systems, Soil Taxonomy is not static. As more is learned, the system changes somewhat.

   The highest category of this system is called Orders. Currently there are 12 soil orders (see Table 3).

TABLE 3. 12 ORDERS IN SOIL TAXONOMY

Alfisols	high base saturation—areas with low rainfall, but wetter than deserts
Andisols	volcanic ash affected
Aridisols	deserts
Entisols	"young" soils (floodplains, mountains, deserts, etc.)
Gelisols	permafrost-affected soils
Histosols	organic soils, common in wet and cold areas (marshes, muskeg, etc.)
Inceptisols	fairly "young" soils—soil development more advanced than Entisols
Mollisols	thick, dark surfaces—humid and sub-humid grasslands (corn belt)
Oxisols	very low fertility, very "old" soils—humid tropics
Spodosols	humid temperate woodlands, acidic
Ultisols	low base saturation—humid warm-temperate, sub-tropics and tropics; low fertility, acidic
Vertisols	high shrink-swell

   The other categories of the classification system are suborder, great group, subgroup, family, and series. The series corresponds to species in biological classification systems. Series names are usually taken from local geographic features or place names. There are over 20,000 recognized soil series in the U.S. This is an indicator of the tremendous amount of variability there is in soils.

C. Soil Properties

1. Texture

   Non-technical definition: How the soil feels

   Technical definition: An expression that characterizes the relative amounts of sand, silt and clay in the soil.

   a) Soil separates (mineral part of soil)

      i. Sand: gritty

      ii. Silt: floury when dry, greasy when wet

      iii. Clay

      - 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

Some clay minerals are amorphous—without shape. Common in humid temperate woodlands (Spodosols) and volcanic soils (Andisols)

- Properties of clays

  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 to size (block demonstration)

  Cation Exchange Capacity (CEC)

  Clay has net negative charge, attracts cations (positive ions; ions are broken molecules. Certain ions serve as plant nutrients)

- Characteristics of some clay minerals

  Kaolinite 1:1, no shrink-swell, low CEC (3-15 meq/100g), low surface area (5-20 m2/g); prevalent in warm, humid areas such as the southeast US

  Illite (hydrous mica), 2:1, moderate shrink-swell, medium CEC (15-40 meq/100g); medium surface area (100-120 m2/g)

  Smectite (montmorillonite) 2:1 high shrink-swell, high CEC (80-110 meq/100g), high surface area (700-800 m2/g). Found in younger (less weathered) soils. Common in California.

  Iron and Aluminum Oxides: somewhat crystalline, very low CEC (pH dependent), prevalent in tropics and semi-tropics, fixes phosphorus

  Allophane and Imogolite: amorphous, moderate CEC (pH dependent, 10-30 meq/100g), prevalent in volcanic ash derived soils, fixes phosphorus

b) Texture Triangle (see Figure 3, next page)

   i. 12 soil textures (see Table 4)

TABLE 4. 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

2. Structure

   a) What is it?

      i. Arrangement of soil particles into aggregates

      ii. Natural vs. man-made (peds vs. clods)

      iii. Types (shape) (See Figure 4, p. 15)

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

iv. Size: very fine, fine, medium, coarse, very coarse, thick, thin

v. Grade

Weak: Peds barely observable in place, difficult to distinguish from massive or single grain.

Moderate: Peds well formed and evident in undisturbed soil

Strong: Peds distinct in undisturbed soil. Peds have distinctive surface features.

vi. Compound structure

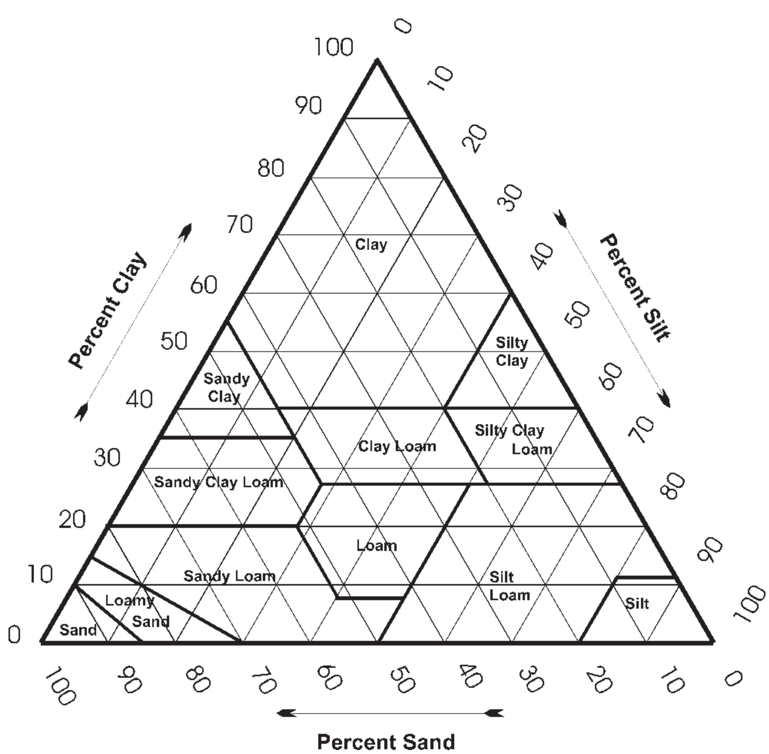
- One structure beside another
- One structure within another ("parts to…")

vii. Persistence upon wetting and drying—"Aggregate stability"

TABLE 5. SIZE CLASSES OF SOIL STRUCTURAL UNITS. THIN AND THICK, RATHER THAN FINE AND COARSE, ARE USED FOR PLATY STRUCTURES.

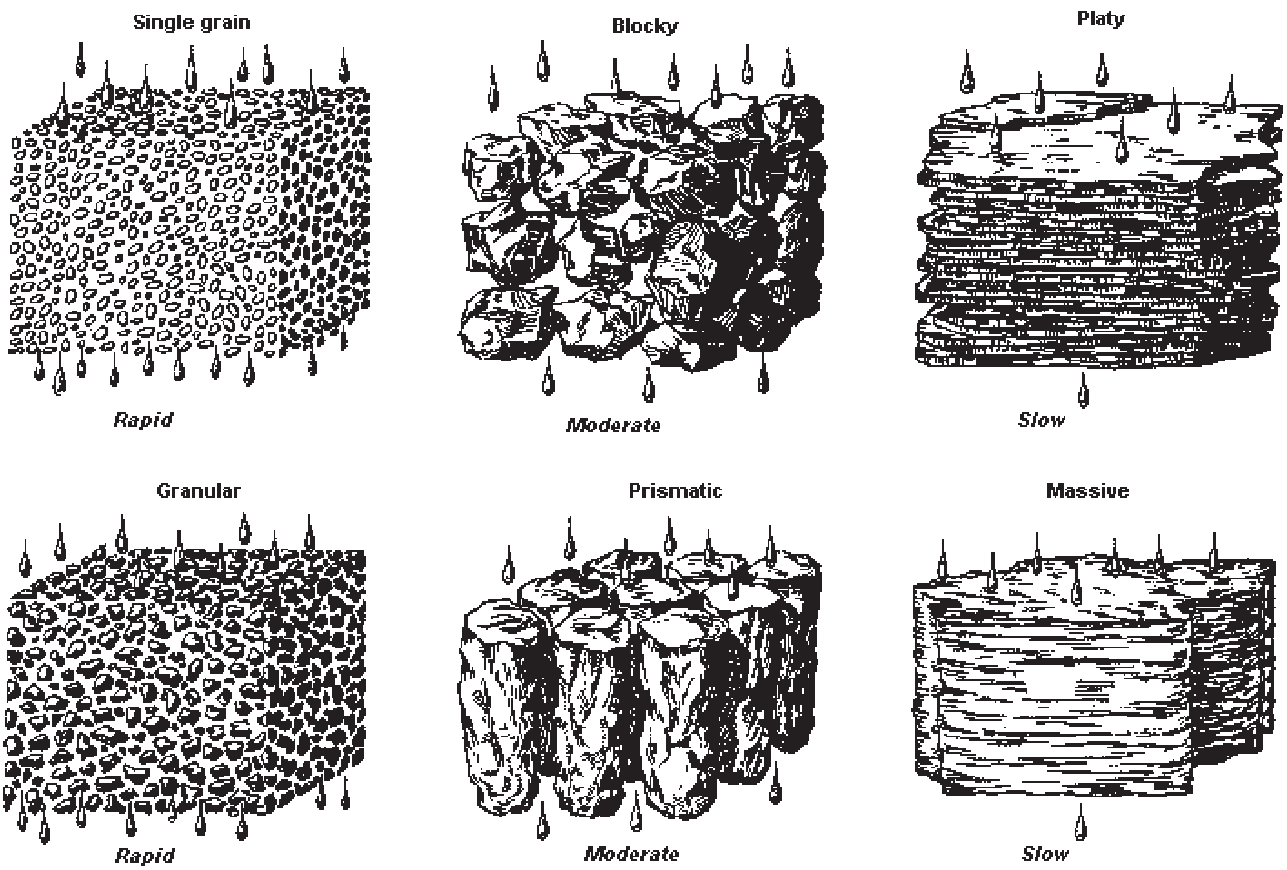
SIZE CLASS	PLATY	COLUMNAR/ PRISMATIC	BLOCKY	GRANULAR
very fine (thin)	<1 mm	<10 mm	<5 mm	<1 mm
fine (thin)	1 – 2 mm	10 – 20 mm	5 –10 mm	1 – 2 mm
medium	2 – 5 mm	20 – 50 mm	10 – 20 mm	2 – 5 mm
coarse (thick)	5 –10 mm	50 –100 mm	20 –50 mm	5 –10 mm
very coarse (thick)	>10 mm	>100 mm	>50 mm	>10 mm

FIGURE 3. SOIL TEXTURE TRIANGLE



b) What causes structure?
   i. Biological factors/organic matter
      - Bacterial exudates
      - Root activity and exudates
      - Macrofauna activity and waste
   ii. Clay (type and amount)
   iii. Calcium and sodium effects
   iv. Climate (wet/dry, freeze/thaw)

FIGURE 4. SOIL STRUCTURE AND ITS EFFECTS ON PERMEABILITY



3. Pores
   a) What are they and why are they important?
      Pores are the "holes" or voids in the soils. They are important because air and water move through and are stored in pores. Without air, roots cannot live nor can most microbes that are essential to the proper functioning of a healthy soil.
   b) Types of pores: Three types of pores are generally recognized
      i. Interstitial pores: Spaces between mineral grains and peds
      ii. Tubular pores: Pores made by root or animal activity that are or were at one time continuous
      iii. Vesicular pores: Bubble-shaped pores

c) Sizes of pores—two basic size classes of pores are recognized, though 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

   a) What is it?

      The bulk density of the soil (or of anything else) is the (oven dry) weight of a given volume of soil divided by the volume. It is expressed in grams per cubic centimeter. The formula is usually written like this:

      $Db = Ms/Vt$

      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.

      Bulk density is usually determined by coating a mass of soil with a thin layer of plastic; weighing the soil, correcting for moisture content; then determining the volume of that soil by water displacement.

      The bulk density of the soil is a reflection of the amount of pore space in the soil. Other factors affecting the bulk density are they types of minerals present (some are heavier than others), the texture (clays are lighter than silts and sands) and the amount of organic matter (organic matter has a really low bulk density compared to mineral grains).

   b) Importance

      Compacted soils have higher bulk densities than non-compacted soils

5. Organic matter

   Organic matter consists of dead plant parts and animal and microbial waste products in various stages of decomposition. Eventually, these things break down into humus, which is relatively stable in the soil.

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

      i. Structure

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

      ii. Available Water Capacity (AWC)

         Organic matter helps bind water to the soil to keep it from being lost through percolation. This is especially important in sandy soils.

      iii. Cation Exchange Capacity (CEC)

         While the highest CEC you will find in a clay is 160 meq/100g (cmol/kg), humus has a CEC of 100 to 300 meq/100g (cmol/kg) or more

   b) Relationship to climate

      You cannot add large amounts of organic matter to the soil and expect it to persist. There is a maximum equilibrium amount any given soil can hold. This amount is inversely proportional to soil temperature and moisture. That is to say, wetter and colder soils can maintain higher equilibrium amounts of organic matter. Anything added beyond that amount will break down to carbon dioxide and water. The equilibrium amount can be raised to some degree by additions of organic matter, such as in organic gardening situations, but even then it will only go so high. Tropical soils, for example, tend to be nutrient- and organic-matter poor; the nutrient pool tends to be stored in the above-ground biomass (leaves and branches). The muskeg areas of northern Canada, however, contain large amounts of organic matter.

A new practice related to this is being employed to reduce greenhouse gas emissions. Carbon sequestration is the practice of burying organic matter deep in the soil to maximize the amount of organic carbon it contains. To the extent that the soil can hold the organic carbon in equilibrium, it will reduce emissions of CO_2 from the soil.

6. Color
   a) How it is measured

      Munsell Color Notation (show color book)

   b) Significance of/indicator of:
      i. Drainage and wetness (Redoximorphic features) (show samples)

         Greenish, bluish, and gray colors in the soil indicate wetness. These colors may occur as the dominant color (matrix) or in patches (mottles). The colors are caused by the reduction of iron by bacteria in anaerobic conditions. (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, so they serve as indicators, not proof.

         Bright colors (reds and yellows), on the other hand, indicate well-drained soils. You don't want to have free water (water in excess of the available water capacity) within the rooting depth of your plants during the growing season. It is possible for a soil with bright colors to still have wetness problems if the groundwater is moving fast enough and if it has sufficient oxygen or if it is too cold for biological activity.

      ii. Organic matter

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

7. Soil depth

   It is important to know the depth of the soil. The 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. Some things that may limit depth are:

   a) Bedrock
   b) Densely compacted material (tillage pan)

      Tillage pans are formed when farm implements repeatedly pass through the soil at the same depth. This action 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 that of the soil above and below it.

      A soil may be plowed or ripped to tear up natural or tillage pans and to increase the pore space in the soil. Also, deep-rooted cover crops might be used (see Unit 1.6, Selecting and Using Cover Crops). In a gardening context, double digging might be used (see Unit 1. 2, Garden and Field Tillage and Cultivation).

      The benefits of using some kind of tillage to break up soil compaction don't last forever. And 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. 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.

   c) Natural hardpans (soil cemented by iron, lime, gypsum, silica, etc.) (Show example)
   d) Strongly contrasting textures (pot effect; usually found in floodplain soils)
   e) Water tables

8. Soil temperature

   Soil temperature is important to gardeners, especially when it comes to spring planting. Many seeds need a certain minimum temperature before they will germinate.

   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 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 temperature through transpiration.
      v. Soil color: Darker-colored soils absorb heat more readily than lighted colored soils
      vi. Horticultural practices: Mulching reduces heat by reducing *insolation*—the absorbtion of heat when it's sunny and can also act as an *insulator* —holding in heat in extremely 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.
      iii. Weathering of parent materials: Fluctuating temperatures help break down mineral grains. Warmer temperatures increase chemical weathering.
      iv. Nutrient availability: Many nutrients are unavailable or poorly available at low temperatures, especially phosphorus. (This is primarily related to biological activity.)

9. Drainage

   Soil drainage or drainage classes 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. The U.S. Department of Agriculture recognizes seven natural drainage classes (from the Soil Survey Manual):

   a) Excessively drained

      Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have very high hydraulic conductivity or are very shallow. These soils tend to be droughty.
   b) Somewhat excessively drained

      Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity or are very shallow.
   c) Well drained

      Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

d) Moderately well drained

Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.

e) Somewhat poorly drained

Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.

f) Poorly drained

Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity or nearly continuous rainfall, or of a combination of these.

g) Very poorly drained

Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

10. Odor

a) Indicator of wetness

When soils are waterlogged, bacteria will get their oxygen from sulfur. This will release hydrogen sulfide gas. This accounts for the sulfur smell prevalent around salt marshes.

11. Permeability

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 rates affect the rate at which you can safely apply water to the field. Applying water faster than the permeability and infiltration rates can lead to sealing of the soil surface, which further decreases infiltration rates; it can also cause ponding, which increases the possibility of diseases; and it can lead to runoff, which causes 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 (inches/hour)

Permeability is normally measured in inches per hour. A newer expression you will see is Saturated Hydraulic Conductivity (Ksat). It is measured in μm/sec or cm/hr.

c) Properties influencing permeability

i. Texture

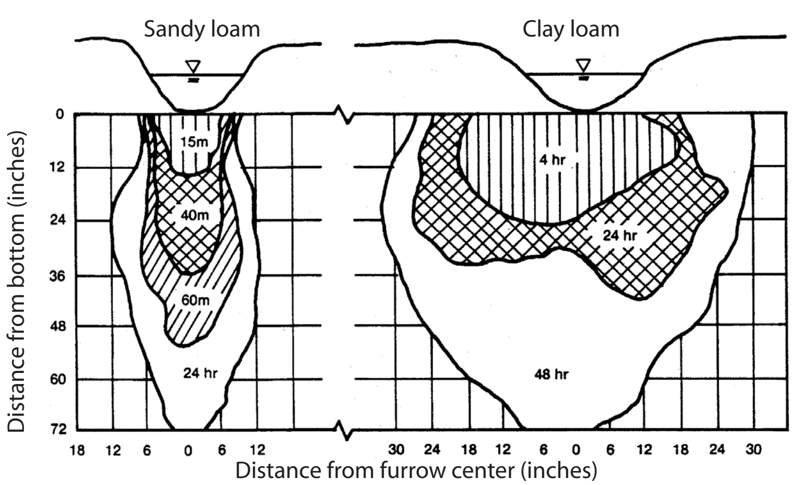
Soil texture is usually the dominant soil property affecting infiltration. Soils that are high in clay content tend to have a slower permeability. Soils that are high in sand content tend to have a faster permeability (see Table 6).

TABLE 6. 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	> 20 inches/hour	very rapid
	sand, loamy sand	6 – 20 inches/hour	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 by which water moves through the soil. Water will move almost straight down through a sandy soil, whereas it will have more lateral movement in a heavier soil (one with more clay). (See figure 5)

FIGURE 5. MOVEMENT OF WATER THROUGH SANDY AND CLAY SOILS



ii. Structure

Soil structure has perhaps the greatest effect on permeability. The cracks and pores between aggregates allow for the movement of air and water through the soil. Anything that improves structure improves permeability and vice versa. Tillage and irrigation affect soil structure. 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, providing it is not done while the soil is too wet or too dry.

All of the following properties relate to soil structure:

- 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 slows infiltration and permeability rates drastically.
- Organic matter: Organic matter (decayed plant material) is desirable in the soil, not only because it improves soil fertility, but it also improves soil structure, which has beneficial effects on permeability and infiltration.
- Compaction and pores: All soils contain pores. The pore spaces are occupied by either air or water (plant roots need both air and water). Fine-textured soils (soils with high clay content) contain more total pore space than coarse-textured soils (such as sandy loam and sand), however the pore spaces are smaller. Because of this, water moves more slowly through a fine- textured soil.
- Calcium: Calcium improves soil structure by encouraging aggregation and increasing pore size. As a result it improves permeability and infiltration.
- Soil organisms: Microorganisms (e.g., bacteria and fungi) and macroorganisms (e.g., insects and earthworms) in the soil contribute to improved permeability and infiltration. They have a beneficial effect on soil structure because they encourage the formation of soil aggregates and they make pores 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. (Peat moss demonstration)

ii. Surface fragments: A heavy cover of gravel and stones will prevent water from entering the soil and increase runoff. However, these types of soil are not usually cultivated.

iii. Fire: A hot fire can produce resins and waxy materials that repel water

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

12. Available Water Capacity (AWC)

Definition: Amount of water that the soil can hold that is available for plant growth

AWC 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. (Sponge demonstration)

a) Field capacity: The amount of water the soil can hold against the flow of gravity. (1/3 bar or 33 kPa)

b) Wilting point: The moisture level at which the soil can no longer provide moisture for growth of most agronomic plants. (15 bar or 1500 kPa)

c) Measurement (inches/inch or inches/foot)

AWC is usually measured in inches per foot or inches per inch. If it takes the addition of two inches of water to wet a dry soil (at PWP) to a depth of 1 foot, then the AWC is 2 inches per foot (0.16 inches per inch). The available water 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 a root-restricting layer, whichever is shallower.

d) Properties influencing water holding capacity

i. Texture

Soils that are high in sand content tend to have a lower available water capacity. Soils that are high in clay content tend to have a higher available water capacity. However, if the clay content is too high or the clay particles are too fine, then the AWC might be reduced because the tiny pores may hold onto the water so tightly that the plants can't get it (see examples in Table 7).

TABLE 7. 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. Salts

Salts reduce the Available Water Capacity of the soil. 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 8).

TABLE 8. 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

iii. Organic matter: Organic matter is desirable in the soil, not only because it improves soil fertility, but because it can also improve the Available Water Capacity

iv. Compaction: When a soil is compacted, the soil particles are pressed together, which reduces the pore space. This means there is less space for the water to occupy.

v. Soil depth: Rooting depth is the depth to rock or other layer in the soil that restricts root depth. Natural hard pans as well as man-made pans may restrict root growth. The presence of a root-restricting layer reduces the available water capacity of the soil, since it reduces the amount of soil that is available for plant roots.

One also needs to consider the natural rooting depth of the plants. For example, if the plant roots will only go to a depth of two feet in a soil with no root restrictions, then soil below two feet should not be considered when calculating available water capacity for that crop.

vi. 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 9)

TABLE 9. REDUCTION IN AWC 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%

vii. Estimating AWC: See Example 1

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).