SOIL ARCHITECTURE AND PHYSICAL PROPERTIES

INTRODUCTION

- Physical properties related to solid particles of the soil AND the way they are aggregated (arranged)

- Solid particles are the building blocks of the soil
  - Solid particles refer to SAND, SILT and CLAY
  - Soil <u>TEXTURE</u> describes amount of each solid particle in a soil

- The way the building blocks are put together determines the nature of the system of pores and channels in a soil
  - This is the <u>STRUCTURE</u> of the soil
  - Organic matter/other substances act to cement particles

INTRODUCTION

- Soil texture and structure, together, help determine
  - the ability of the soil to hold water
  - conduct (move) water and air through the soil
  - how soils behave when used as construction medium
  - How soils behave under agricultural use

SOIL PHYSICAL PROPERTIES

- *Soil physical properties*
  - Influence how soils function in an ecosystem
  - Determine how soils can best be managed
  - Determine occurrence and growth of many plant species
  - Regulate movement of water, nutrients, chemical pollutants

SOIL PHYSICAL PROPERTIES

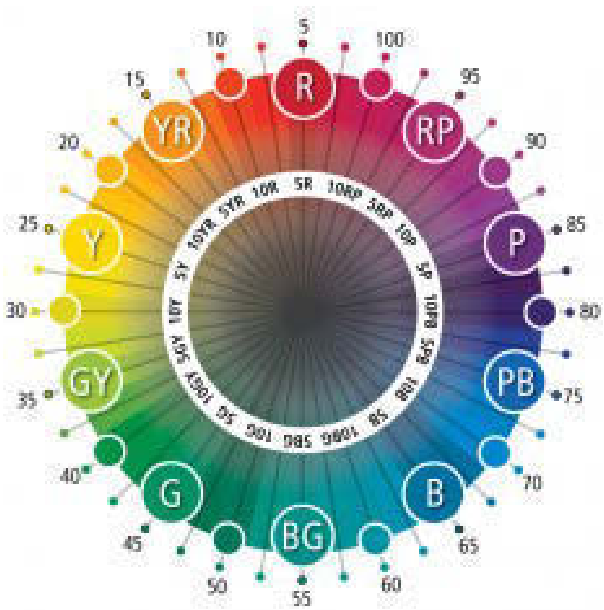
- Texture
- Structure
- Bulk Density
- Porosity
- Strength
- Temperature
- Color

SOIL COLOR

- Soil colors have little effect on behavior and use of soils by themselves
  - Provide valuable clues to nature of other soil properties and conditions
  - Soil color influenced primarily by
    - content of organic matter and water
    - Presence and oxidation state of iron and manganese
      - Influenced by water, may be masked by organic matter

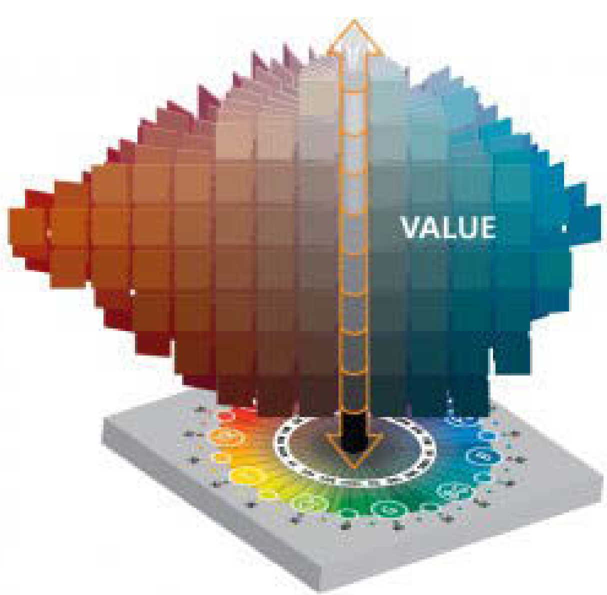
MUNSELL COLOR SYSTEM`

Munsell Hue



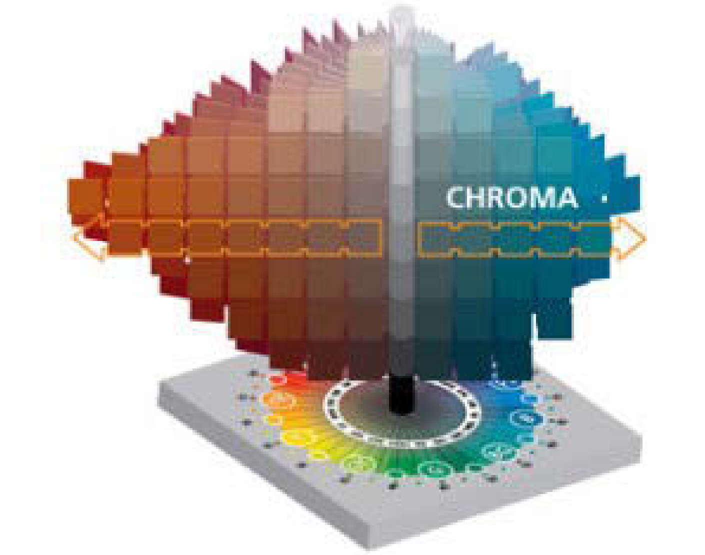
Hue is that attribute of a color by which we distinguish red from green, blue from yellow, etc. There is a natural order of hues: red, yellow, green, blue, purple. One can mix paints of adjacent colors in this series and obtain a continuous variation from one to the other. For example, red and yellow may be mixed in any proportion to obtain all the hues red through orange to yellow. The same is said of yellow and green, green and blue, blue and purple, and purple and red. This series returns to the starting point, so it can be arranged around a circle. Munsell called red, yellow, green, blue, and purple "principal hues" and placed them at equal intervals around a circle. He inserted five intermediate hues: yellow-red, green-yellow, blue-green, purple-blue and red-purple, making ten hues in all. For simplicity, he used the initials as symbols to designate the ten hue sectors: R, YR, Y, GY, G, BG, B, PB, P, and RP.

Munsell Value



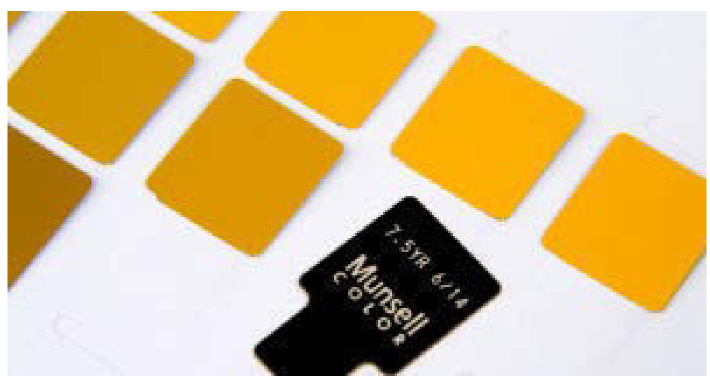
Value indicates the lightness of a color. The scale of value ranges from 0 for pure black to 10 for pure white. Black, white and the grays (as shown in figure at left) between them are called "neutral colors". They have no hue. Colors that have a hue are called "chromatic colors." The value scale applies to chromatic as well as neutral colors. The value scale is illustrated for all neutral colors on the chart labeled Munsell's Nearly Neutral, included in this book of color.

Munsell Chroma



Chroma is the departure degree of a color from the neutral color of the same value. Colors of low chroma are sometimes called “weak,” while those of high chroma (as shown in figure at left) are said to be “highly saturated,” “strong,” or “vivid.” Imagine mixing a vivid red paint, a little at a time, with a gray paint of the same value. If you started with gray and gradually added red until the vivid red color was obtained, the series of gradually changing colors would exhibit increasing chroma. The scaling of chroma is intended to be visually uniform and is very nearly so. The units are constant. The scale starts at zero, for neutral colors, but there is no arbitrary end to the scale. As new pigments have become available, Munsell color chips of higher chroma have been made for many hues and values. The chroma scale for normal reflecting materials extends beyond 20 in some cases. Fluorescent materials may have chromas as high as 30.

How to Read a Munsell Color Chart



The Munsell color system is a means to visually identify and match color using a scientific approach. Albert Munsell was both a scientific thinker and an artist who wanted artists and scientists to have a system that made it easy to express colors in a concrete way. The result was a system that could be used across many disciplines. Here are a few examples of practitioners using Munsell color charts in their workflow…

- A soil scientist accurately assessing the makeup of the soil in the field.
- An artist in the studio replicating colors when mixing paints or materials.
- Quality control experts making sure final product colors match the set standard.
- Electricians staying safe using standard color codes.

- A food scientist using custom colors to bring consistent and reliable results.
- And many more…

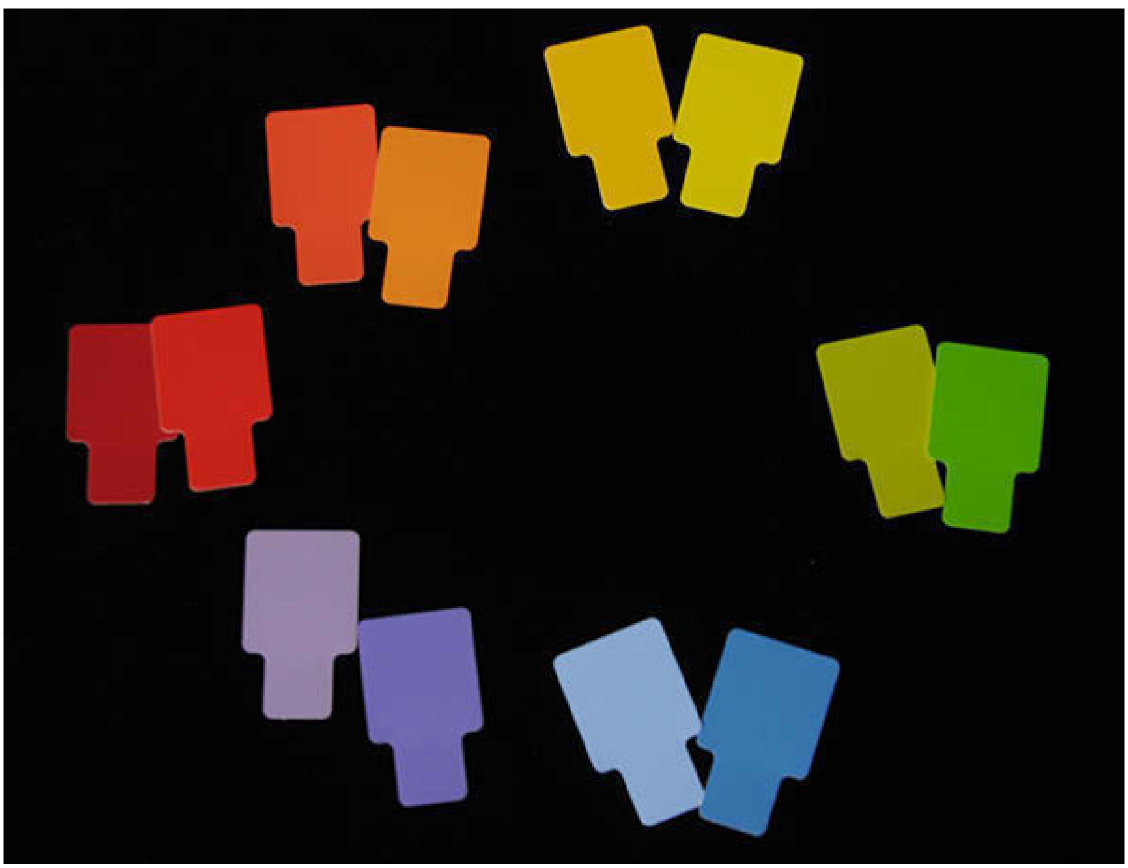
Since color is applicable across so many areas of studies, learning how to read these charts and numbers can be very helpful.

The steps for reading a chart outlined below can be applied to any of the Munsell color charts or books.

Step 1: Understanding Color Attributes

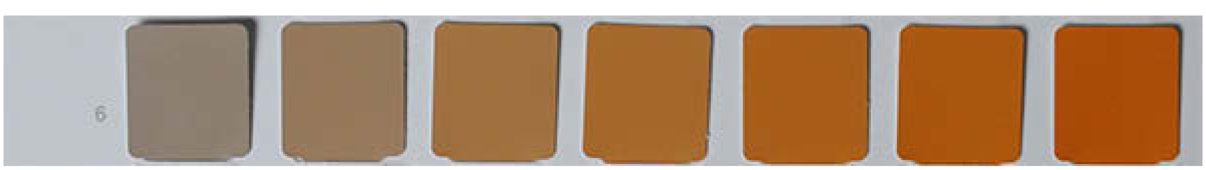
The first step is to understand the three attributes of color… hue, value and chroma (also referred to as HVC).

Hue is the color such as red, green, blue, etc. In the Munsell system these are given letter codes, i.e. Red (R), Yellow-Red (YR), Green (G), Green-Yellow (GY) and so on.



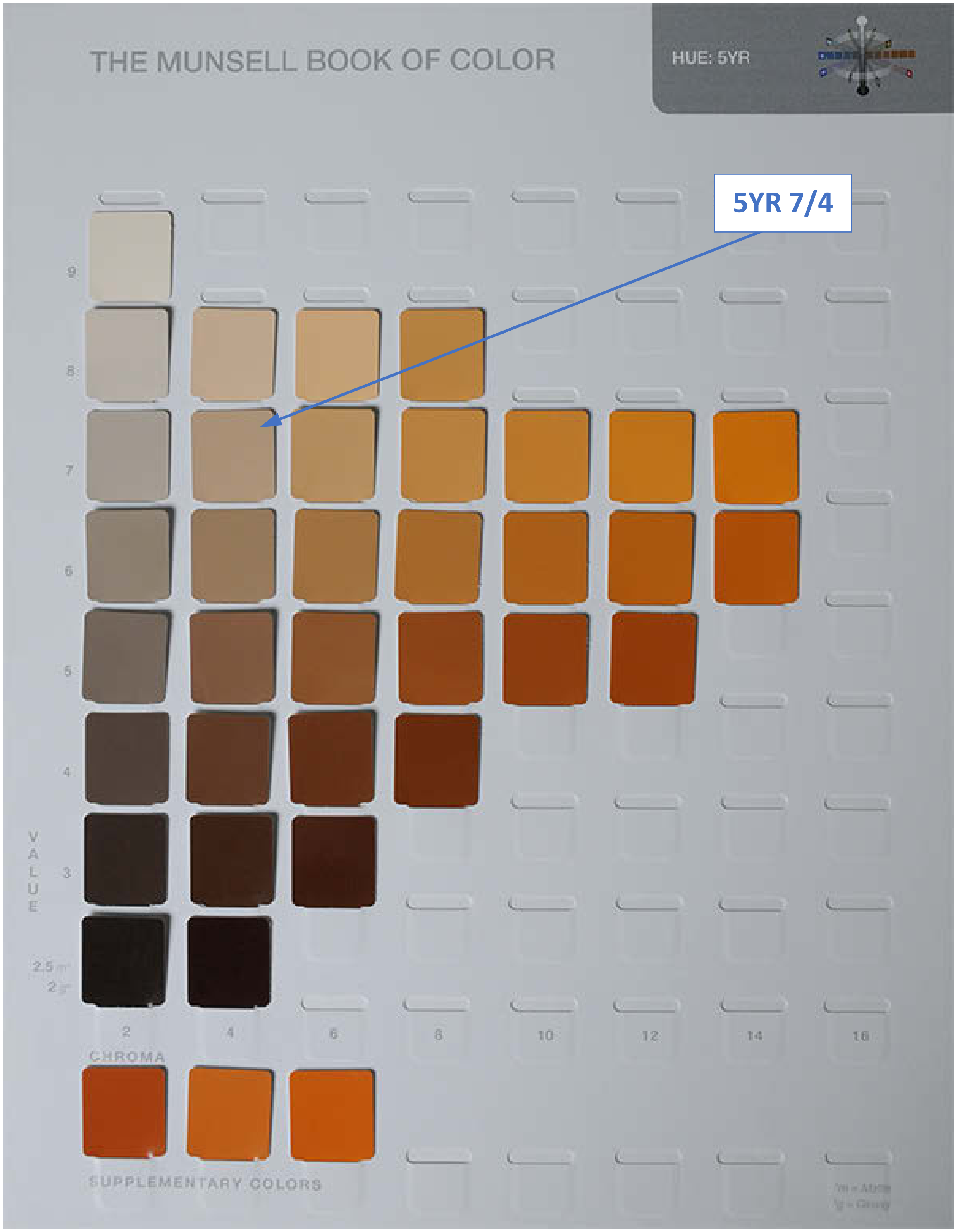
Value is how light or dark a color is. In the Munsell system, value is indicated with a number, i.e. 2, 4, 6 and so on. The value scale runs vertically and moves from lightest (at the top) to darkest (at bottom) in descending order, so a 2 is going to be darker than a 6.the

Chroma is how weak or strong a color is. In the Munsell system, chroma is indicated with a number, typically in the range of 2-14 (upwards of 30 for colors in the fluorescent family). The chroma scale runs horizontally and moves from weak (from the left) to strong (to the right), in ascending order, so a 2 is going to be weaker than a 6.



Step 2: Reading Color Notations

Each color is designated with what is referred to as a color notation; for example, 5YR 7/4. As explained above, each of these indicators refer to the 3 attributes of color. 5YR is the Hue (or color), 7 is the Value (or lightness/darkness) and 4 is the Chroma (weak/strong). These colors can then be referenced on a Munsell color chart to see what the notation looks like.



Once you know the color notation, you know which color is being referenced. This is useful in many ways…

- A soil scientist indicating the colors of the soil layers from a core sample to determine the best uses for the land.
- An artist in the studio matching the blue sky they are painting.
- Quality control experts using a color sheet to make sure the red shoes are the right color that was specified to the manufacturer.
- An electrician knowing which wires are hot, neutral or grounded.
- A food scientist checking that the colors are not outside the normal range, no one wants to eat blue green beans.
- Finding evidence of human activity at an archaeological site and being able to determine age.
- A homeowner making sure the couch they are buying doesn't clash with the paint on the wall.

The ways in which these color charts can be used are endless and we continually are discovering new uses.

http://munsell.com/about-munsell-color/

FIGURE 3-23

An area of very rubbly soil (class 5).

Soil Color

Elements of soil color descriptions are the color name, the Munsell notation, the water state, and the physical state: "brown (10YR 5/3), dry, crushed, and smoothed."

Physical state is recorded as broken, rubbed, crushed, or crushed and smoothed. The term "crushed" usually applies to dry samples and "rubbed" to moist samples. If unspecified, the surface is broken. The color of the soil is recorded for a surface broken through a ped if a ped can be broken as a unit.

The color value of most soil material becomes lower after moistening. Consequently, the water state of a sample is always given. The water state is either "moist" or "dry." The dry state for color determinations is air-dry and should be made at the point where the color does not change with additional drying. Color in the moist state is determined on moderately moist or very moist soil material and should be made at the point where the color does not change with additional moistening. The soil should not be moistened to the extent that glistening takes place as color determinations of wet soil may be in error because of the light reflection of water films. In a humid region, the moist state generally is considered standard; in an arid region, the dry state is standard. In detailed descriptions, colors of both dry and moist soil are recorded if feasible. The color for the regionally standard moisture state is usually described first. Both moist and dry colors are particularly valuable for the immediate surface and tilled horizons in order to assess reflectance.

Munsell notation is obtained by comparison with a Munsell system color chart. The most commonly used chart includes only about one fifth of the entire range of hues.[11] It consists of about 250 different colored papers, or chips, systematically arranged on hue cards according to their Munsell notations. Figure 3-24 illustrates the arrangements of color chips on a Munsell color card.

The Munsell color system uses three elements of color—*hue, value,* and *chroma*—to make up a color notation. The notation is recorded in the form: hue, value/chroma—for example, 5Y 6/3.

Hue is a measure of the chromatic composition of light that reaches the eye. The Munsell system is based on five principal hues: red (R), yellow (Y), green (G), blue (B), and purple (P). Five intermediate hues representing midpoints between each pair of principal hues complete the 10 major hue names used to describe the notation. The intermediate hues are yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red-purple (RP). The relationships among the 10 hues are shown in figure 3-25. Each of the 10 major hues is divided into four segments of equal visual steps, which are designated by numerical values applied as prefixes to the symbol for the hue name.[12] In figure 3-25, for example, 10R marks a limit of red hue. Four equally spaced steps of the adjacent yellow-red (YR) hue are identified as 2.5YR, 5YR, 7.5YR, and 10YR respectively. The standard chart for soil has separate hue cards from 10R through 5Y.

Value indicates the degree of lightness or darkness of a color in relation to a neutral gray scale. On a neutral gray (achromatic) scale, value extends from pure black (0/) to pure white (10/). The value notation is a measure of the amount of light that reaches the eye under standard lighting conditions. Gray is perceived as about halfway between black and white and has a value notation of 5/. The actual amount of light that reaches the eye is related logarithmically to color value. Lighter colors are indicated by numbers between 5/ and 10/; darker colors are indicated by numbers from 5/ to 0/. These values may be designated for either achromatic or chromatic conditions. Thus, a card of the color chart for soil has a series of chips arranged vertically to show equal steps from the lightest to the darkest shades of that hue. Figure 3-24 shows this arrangement vertically on the card for the hue of 10YR.

Chroma is the relative purity or strength of the spectral color. Chroma indicates the degree of saturation of neutral gray by the spectral color. The scales of chroma for soils extend from /0 for neutral colors to a chroma of /8 as the strongest expression of color used for soils. Figure 3-24 illustrates that color chips are arranged horizontally by increasing chroma from left to right on the color card.

The complete color notation can be visualized from figure 3-24. Pale brown, for example, is designated 10YR 6/3. Very dark brown is designated 10YR 2/2. All of the colors on the chart have hue of 10YR. The darkest shades of that hue are at the bottom of the card and the lightest shades are at the top. The weakest expression of chroma (the grayest color) is at the left; the strongest expression of chroma is at the right.

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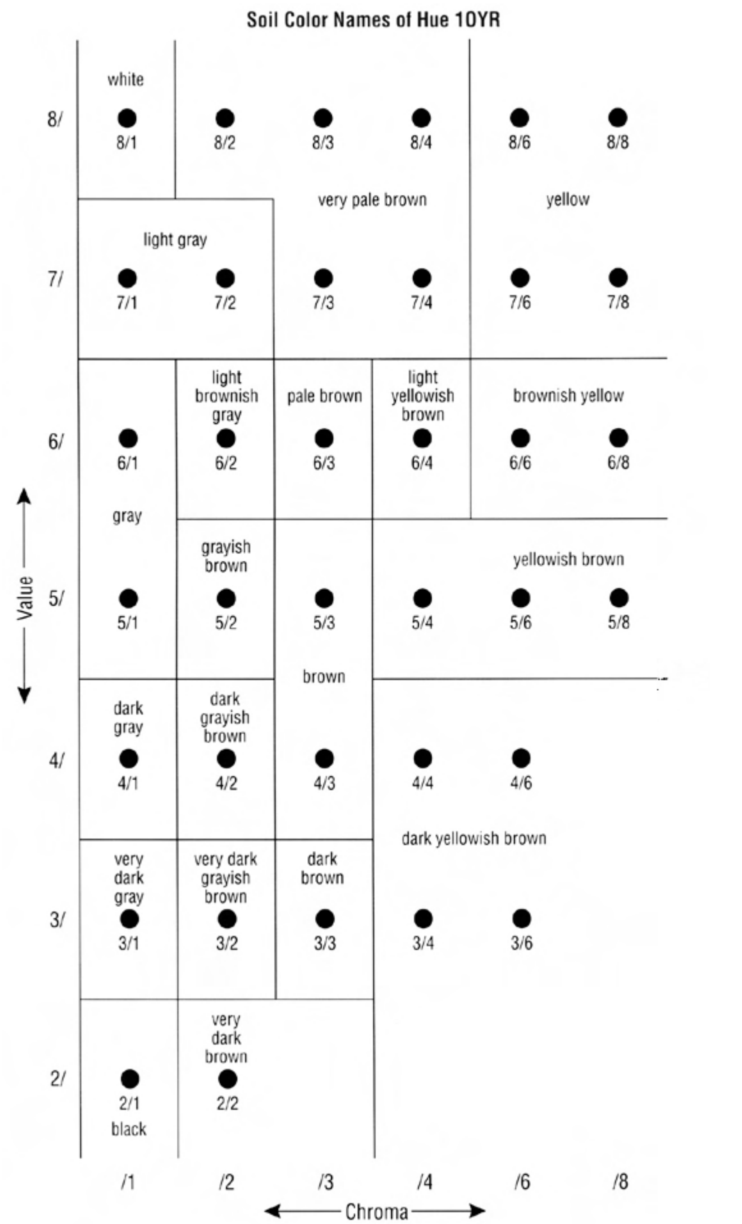
[11] The appropriate color chips, separate or mounted by hue on special cards for a loose leaf notebook, may be obtained from the Munsell Company.

[12] The notation for hue, and for value and chroma, is decimal and could be refined to any degree. In practice, however, only the divisions on the color charts are used.

FIGURE 3-24

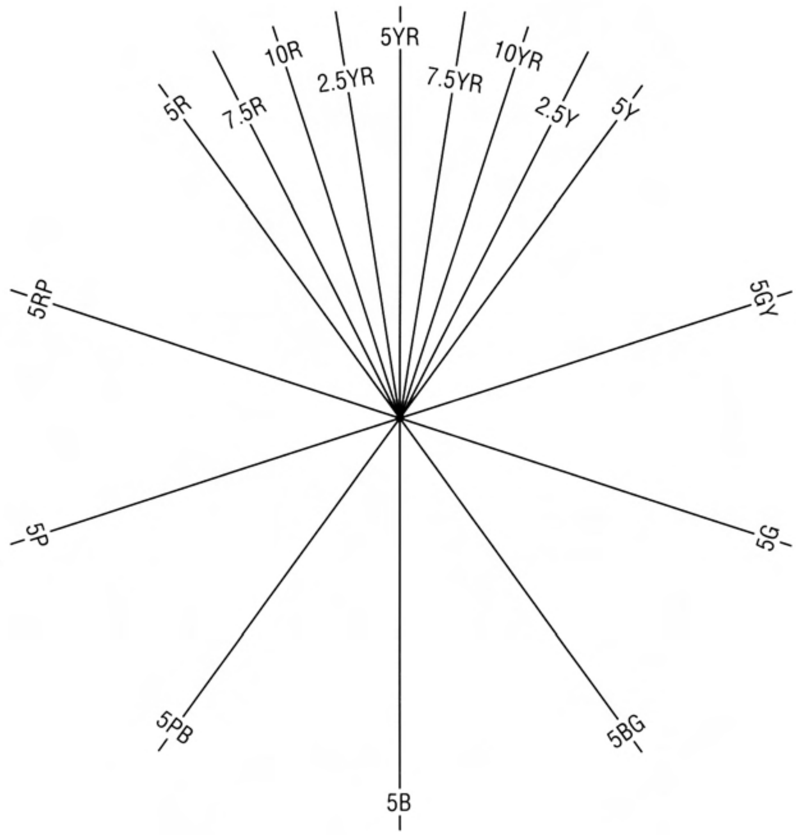


The arrangement of color chips according to value and chroma on the soil-color card of 10YR hue.

At the extreme left of the card are symbols such as N 6/. These are colors of zero chroma which are totally achromatic—neutral color. They have no hue and no chroma but range in value from black (N 2/) to white (N 8/). An example of a notation for a neutral (achromatic) color is N 5/ (gray). The color 10YR 5/1 is also called "gray," for the hue is hardly perceptible at such low chroma.

Conditions for measuring color.—The quality and intensity of the light affect the amount and quality of the light reflected from the sample to the eye. The moisture content of the sample

FIGURE 3-25



A schematic diagram of relationships among the five principal and five intermediate hues of the Munsell Color System and subdivisions within the part used for most soil colors.

and the roughness of its surface affect the light reflected. The visual impression of color from the standard color chips is accurate only under standard conditions of light intensity and quality. Color determination may be inaccurate early in the morning or late in the evening. When the sun is low in the sky or the atmosphere is smoky, the light reaching the sample and the light reflected is redder. Even though the same kind of light reaches the color standard and the sample, the reading of sample color at these times is commonly one or more intervals of hue redder than at midday. Colors also appear different in the subdued light of a cloudy day than in bright sunlight. If artificial light is used, as for color determinations in an office, the light source used must be as near the white light of midday as possible. With practice, compensation can be made for the differences unless the light is so subdued that the distinctions between color chips are not apparent. The intensity of incidental light is especially critical when matching soil to chips of low chroma and low value.

Roughness of the reflecting surface affects the amount of reflected light, especially if the incidental light falls at an acute angle. The incidental light should be as nearly as possible at a right angle. For crushed samples, the surface is smoothed; the state is recorded as "dry, crushed, and smoothed."

Recording Guidelines

Uncertainty.—Under field conditions, measurements of color are reproducible by different individuals within 2.5 units of hue (one card) and 1 unit of value and chroma. Notations are made to the nearest whole unit of value and chroma.

Before 1989, the cards for hues of 2.5YR, 7.5YR, and 2.5Y did not include chips for colors having chroma of 3. These colors are encountered frequently in some soils and can be estimated reliably by interpolation between adjacent chips of the same hue. Chips for chromas of 5 and 7 are not provided on any of the standard color cards. Determinations are usually not precise enough to justify interpolation between chromas of 4 and 6 or 6 and 8. Color should never be extrapolated beyond the highest chip. It should also be rounded to the nearest chip.

For many purposes, the differences between colors of some adjacent color chips have little significance. For such purposes, color notations have been grouped, and the groups have been named (fig. 3-24).

Dominant Color

The dominant color is the color that occupies the greatest volume of the layer. Dominant color (or colors) is always given first among those of a multicolored layer. It is judged on the basis of colors of a broken sample. For only two colors, the dominant color makes up more than 50 percent of the volume. For three or more colors, the dominant color makes up more of the volume of the layer than any other color, although it may occupy less than 50 percent. The expression "brown with yellowish brown and grayish brown" signifies that brown is the dominant color. It may or may not make up more than 50 percent of the layer.

In some layers, no single color is dominant and the first color listed is not more prevalent than others. The expression "brown and yellowish brown with grayish brown" indicates that brown and yellowish brown are about equal and are codominant. If the colors are described as "brown, yellowish brown, and grayish brown," the three colors make up nearly equal parts of the layer.

Mottling

Mottling refers to repetitive color changes that cannot be associated with compositional properties of the soil. Redoximorphic features are a type of mottling that is associated with wetness. A color pattern that can be related to proximity to a ped surface or other organizational or compositional feature is not mottling. Mottle description follows the dominant color. Mottles are described by quantity, size, contrast, color, and other attributes in that order.

Quantity is indicated by three areal percentage classes of the observed surface:

few: less than 2 percent,

common: 2 to 20 percent, and

many: more than 20 percent.

The notations must clearly indicate to which colors the terms for quantity apply. For example, "common grayish brown and yellowish brown mottles" could mean that each makes up 2 to 20 percent of the horizon. By convention, the example is interpreted to mean that the quantity of the two colors *together* is between 2 and 20 percent. If each color makes up between 2 and 20 percent, the description should read "common grayish brown (10YR 5/2) and common yellowish brown (10YR 5/4) mottles."

Size refers to dimensions as seen on a plane surface. If the length of a mottle is not more than two or three times the width, the dimension recorded is the greater of the two. If the mottle is long and narrow, as a band of color at the periphery of a ped, the dimension recorded is the smaller of the two and the shape and location are also described. Three size classes are used:

fine: smaller than 5 mm,

medium: 5 to 15 mm, and

coarse: larger than 15 mm.

Contrast refers to the degree of visual distinction that is evident between associated colors:

Faint: Evident only on close examination. Faint mottles commonly have the same hue as the color to which they are compared and differ by no more than 1 unit of chroma or 2 units of value. Some faint mottles of similar but low chroma and value differ by 2.5 units (one card) of hue.

Distinct: Readily seen but contrast only moderately with the color to which they are compared. Distinct mottles commonly have the same hue as the color to which they are compared but differ by 2 to 4 units of chroma or 3 to 4 units of value; or differ from the color to which they are compared by 2.5 units (one card) of hue but by no more than 1 unit of chroma or 2 units of value.

Prominent: Contrast strongly with the color to which they are compared. Prominent mottles are commonly the most obvious color feature of the section described. Prominent mottles that have medium chroma and value commonly differ from the color to which they are compared by at least 5 units (two pages) of hue if chroma and value are the same; at least 4 units of value or chroma if the hue is the same; or at least 1 unit of chroma or 2 units of value if hue differs by 2.5 units (one card).

Contrast is often not a simple comparison of one color with another but is a visual impression of the prominence of one color against a background commonly involving several colors.

Shape, location, and character of boundaries of mottles are indicated as needed. *Shape* is described by common words such as streaks, bands, tongues, tubes, and spots. *Location* of mottles as related to structure of the soil may be significant. *Boundaries* may be described as *sharp* (color gradation is not discernable with the naked eye), *clear* (color grades over less than 2 mm), or *diffuse* (color grades over more than 2 mm).

Moisture state and physical state of the dominant color are presumed to apply to the mottles unless the description states otherwise. An example, for which a standard moist broken state of the sample has been specified, might read "brown (10YR 4/3), brown (10YR 5/3) dry; many medium distinct yellowish brown (10YR 5/6) mottles, brownish yellow (10YR 6/6) dry." Alternatively, the colors in the standard moisture state may be given together, followed by the colors at other moisture states. The color of mottles commonly is given only for the standard state unless special significance can be attached to colors at another state.

A nearly equal mixture of two colors for a moist broken standard state can be written "intermingled brown (10YR 4/3) and yellowish brown (10YR 5/6) in a medium distinct pattern; brown (10YR 5/3) and brownish yellow (10YR 6/6) dry." If a third color is present, "common medium faint dark grayish brown (10YR 4/2) mottles, grayish brown (10YR 5/2) dry" can be added.

If the mottles are fine and faint so that they cannot be compared easily with the color standards, the Munsell notation should be omitted. Other abbreviated descriptions are used for specific circumstances.

Color Patterns

Color, including mottling, may be described separately for any feature that may merit a separate description, such as peds, concretions, nodules, cemented bodies, filled animal burrows, and the like. Color patterns that exhibit a spatial relationship to composition changes or to features such as nodules or surfaces of structural units may be useful to record because of the inferences that may be drawn about genesis and soil behavior. Colors may be given for extensions of material from another soil layer. The fine tubular color patterns that extend vertically below the A horizon of some wet soils, for example, were determined by the environment adjacent to roots that once occupied the tubules. The rim of bright color within an outer layer of lighter color at the surface of some peds relate to water movement into and out of the peds and to oxidation-reduction relationships.

Ground surface color.—The color value of the immediate ground surface may differ markedly from that of the surface horizon. For example, raindrop impact may have removed clay-size material from the surface of sand and silt which results in a surficial millimeter or so of increased color value. In some arid soils, dark rock fragments may have reduced the color value of the ground surface appreciably from that of the fine earth of the surface horizon as a whole. Furthermore, dead vegetation may have color values that differ appreciably from those for the fine earth of the surface horizon. Color information is, therefore, desirable for the actual ground surface inclusive of the vegetation as well as the soil material. Surface color influences reflectivity of light, therefore, the capacity to absorb and release radiant energy.

Surface soil colors commonly range widely at a site, and it may be necessary to array mentally the color values and their areal proportion for the ground surface, whether rock fragments, dead vegetation, or fine earth. Then a single color value is selected for each important ground surface component. From the areal proportion of the components, and their color value, a weighted average color value for the ground surface may be computed. Estimation of the areal proportion of components is discussed in the section on ground cover.

Soil Structure

Soil structure refers to units composed of primary particles. The cohesion within these units is greater than the adhesion among units. As a consequence, under stress, the soil mass tends to rupture along predetermined planes or zones. These planes or zones, in turn, form the boundary. Compositional differences of the fabric matrix appear to exert weak or no control over where the bounding surfaces occur. If compositional differences control the bounding surfaces of the body,

SOIL TEXTURE

Definition: refers to the *size distribution* or proportions of soil particles in a soil

- Most influential (important) property affects:
  - water intake
  - water storage
  - aeration (porosity)
  - ease of working (tilling)
  - soil fertility
- Gives soil its characteristic "feel"
- Difficult to change (basic property)

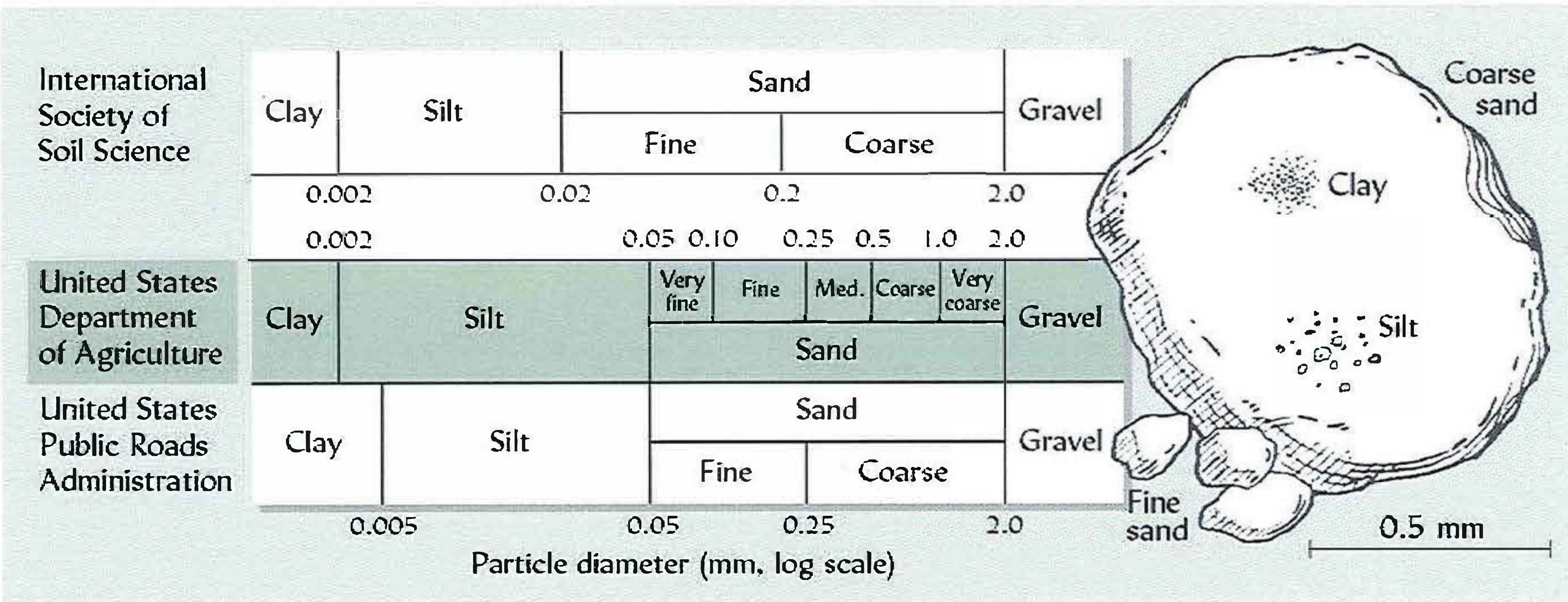
SOIL TEXTURE

- Soil texture influences:
  - Soil-water relations:
    - Drainage, percolation, water holding ability, consistency, plasticity
  - Soil density:
    - Response of soil to manipulation, ability to support desirable uses

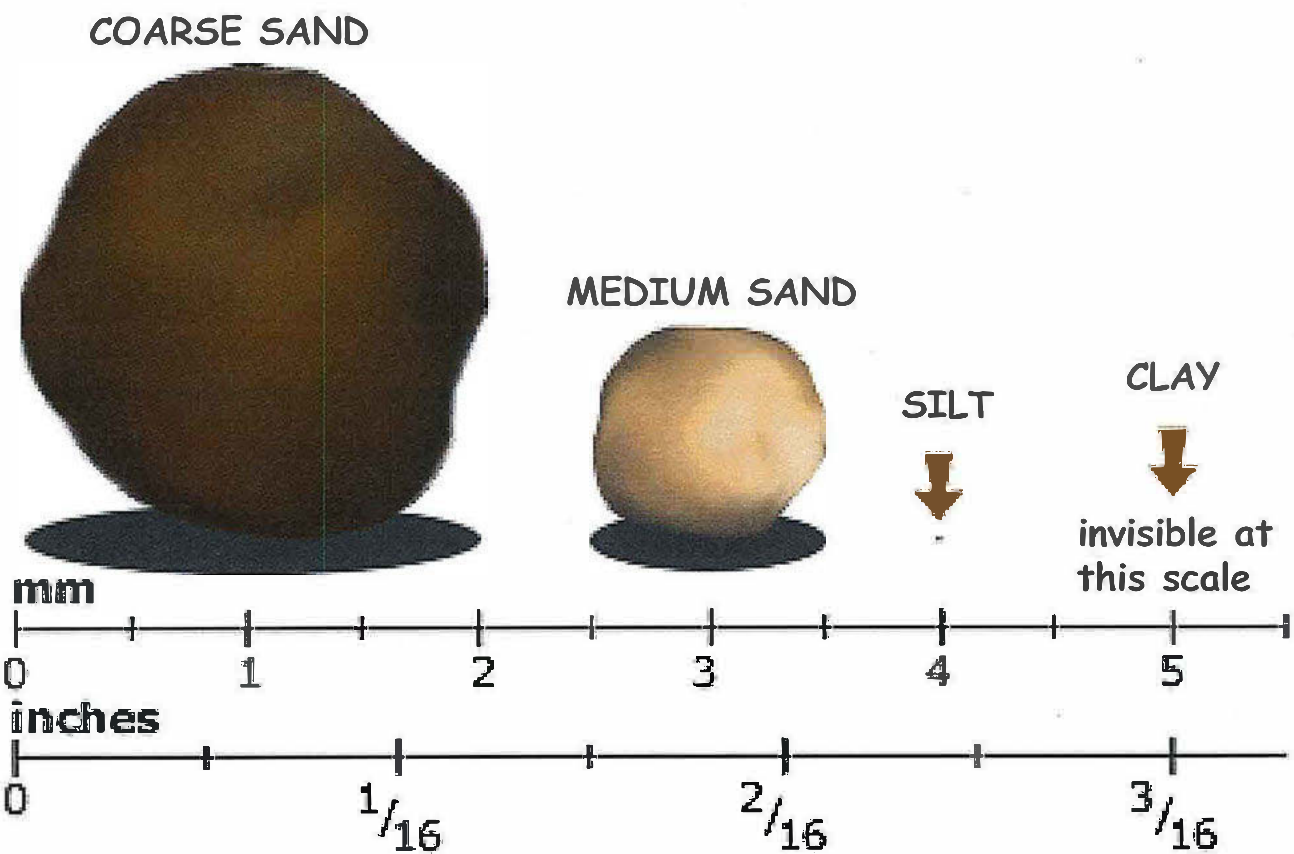
NATURE OF SOIL SEPARATES

- Diameters of individual soil particles range over six orders of magnitude
  - Boulders (>1 meter) to clays (<10^{-6} meters)
- Coarse (rock) fragments greater than 2 mm in diameter are <u>not</u> part of the *fine earth fraction*
- Texture applies only to the *fine earth fraction*… soil separates less than 2 mm in diameter

CLASSIFICATION OF SOIL PARTICLES BY SIZE



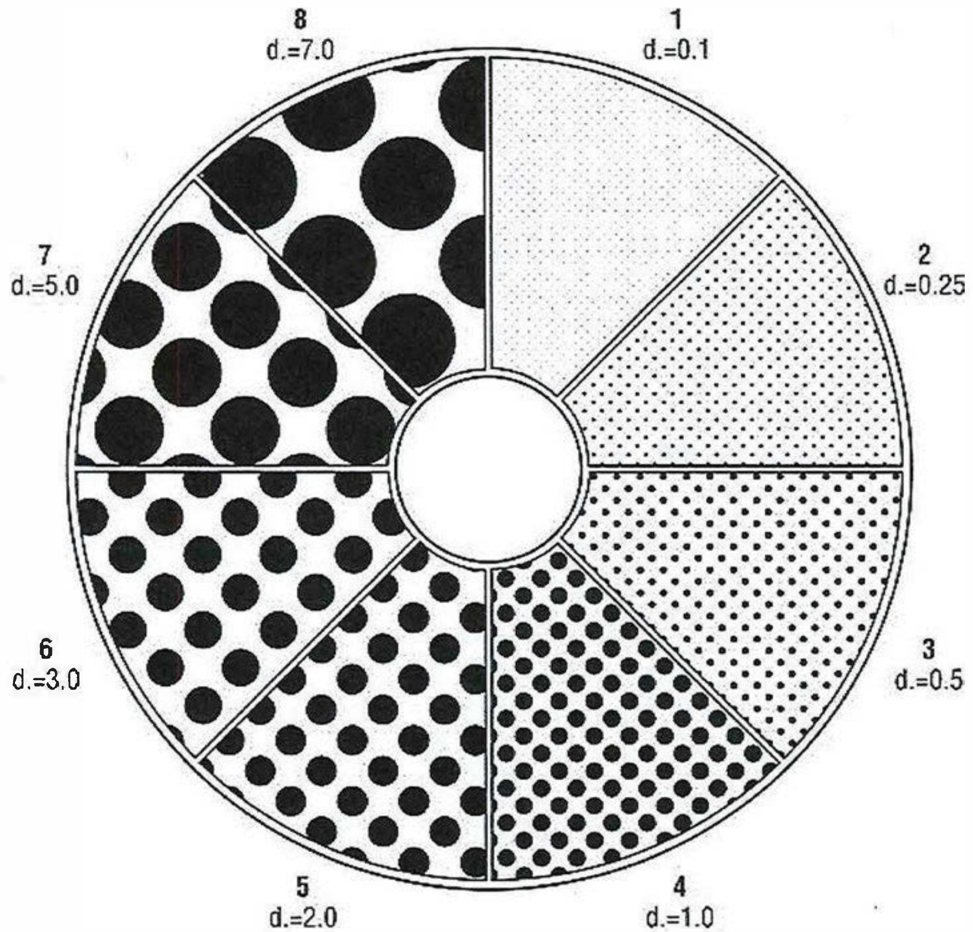
RELATIVE PARTICLE SIZES



SAND-SIZED PARTICLES (0.05 - 2 MM)

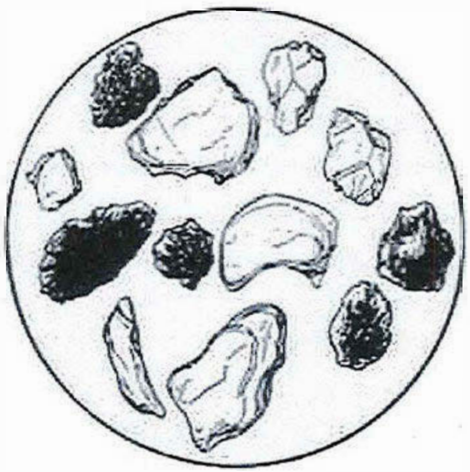
- Generally composed of primary minerals
- Little surface reactivity…low specific surface area
  - Difficult for sands to hold onto water
- Not sticky or plastic
- Often coated with clay or OM
- Pack loosely, leaving large pores
  - Conducts air and water easily
  - Holds little water against pull of gravity
  - Good aeration but will be droughty

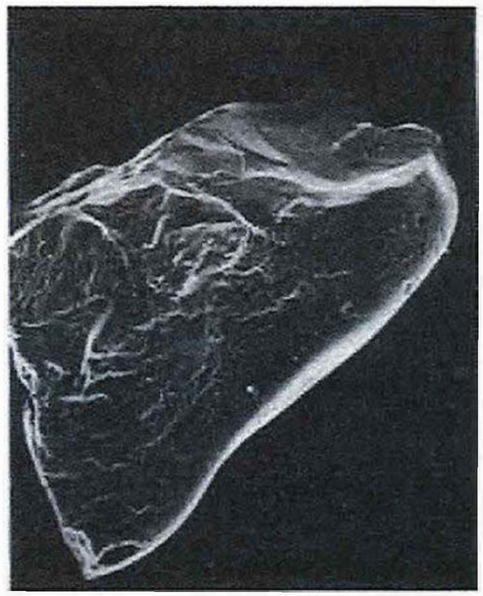
RELATIVE SIZES OF SAND PARTICLES

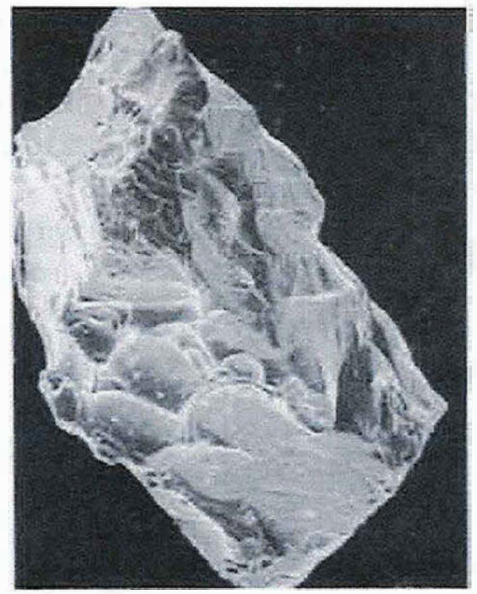


Sizes of particles of indicated diameters (d) in millimeters.

SAND PARTICLES AT 40X MAGNIFICATION


SAND
GRAINS


QUARTZ


FELDSPAR

SILT-SIZED PARTICLES (0.002 - 0.05 MM)

- Essentially very small sand particles
- Irregular in shape but not flat
- Some stickiness, but generally feel floury
- Particles pack together more tightly than sand
  - Voids between particles smaller and more numerous than sand
  - Results in slower water movement thru than sands
  - Provides for more water retention than sands

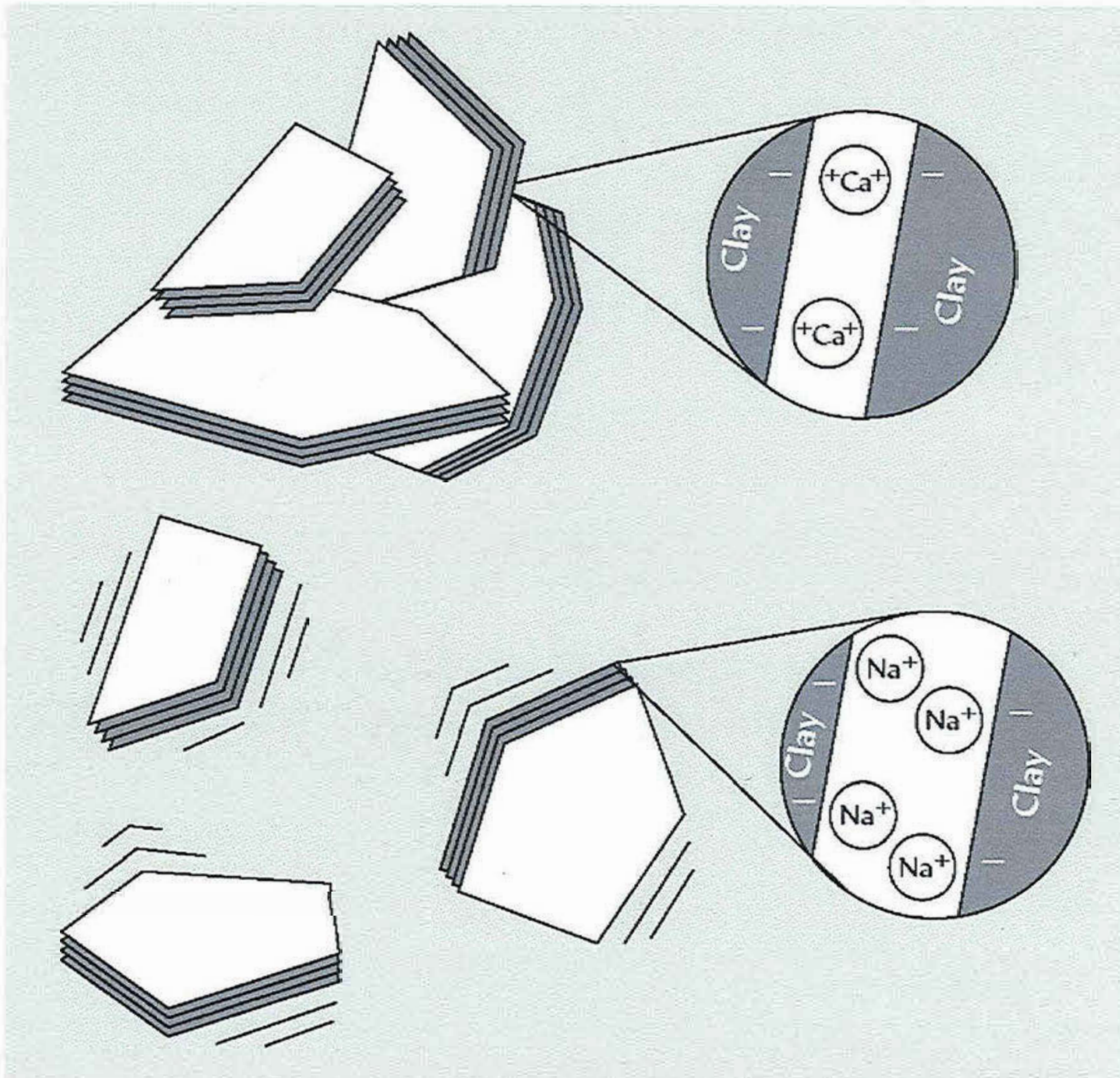
SILT-SIZED PARTICLES (0.002 - 0.05 MM)

- Often coated with clay or OM (like sand)
- More surface activity (chemical reactivity) than sand
  - Naturally more fertile than sand
- Responsible for surface crusts on some soils
  - Can be easily washed away (eroded) by water

CLAY-SIZED PARTICLES (< 0.002 MM)

- Individual particles are invisible to the naked eye
- Usually formed of secondary minerals
- Often plate-like in shape, with stacked layers
- Usually sticky when wet
- Particles pack very tightly
  - Very slow water movement
  - Good water retention, poor availability

CONCEPTUAL DRAWING OF CLAY PARTICLES



CLAY-SIZED PARTICLES (< 0.002 MM)

- Very large specific surface area (surface to volume ratio)
  - 10 to 1000 m^2 per gram of clay
  - 1 spoonful has surface area the size of a football field

- Clays help give soil its structure
  - Organic matter binding
  - Multivalent cation bridging

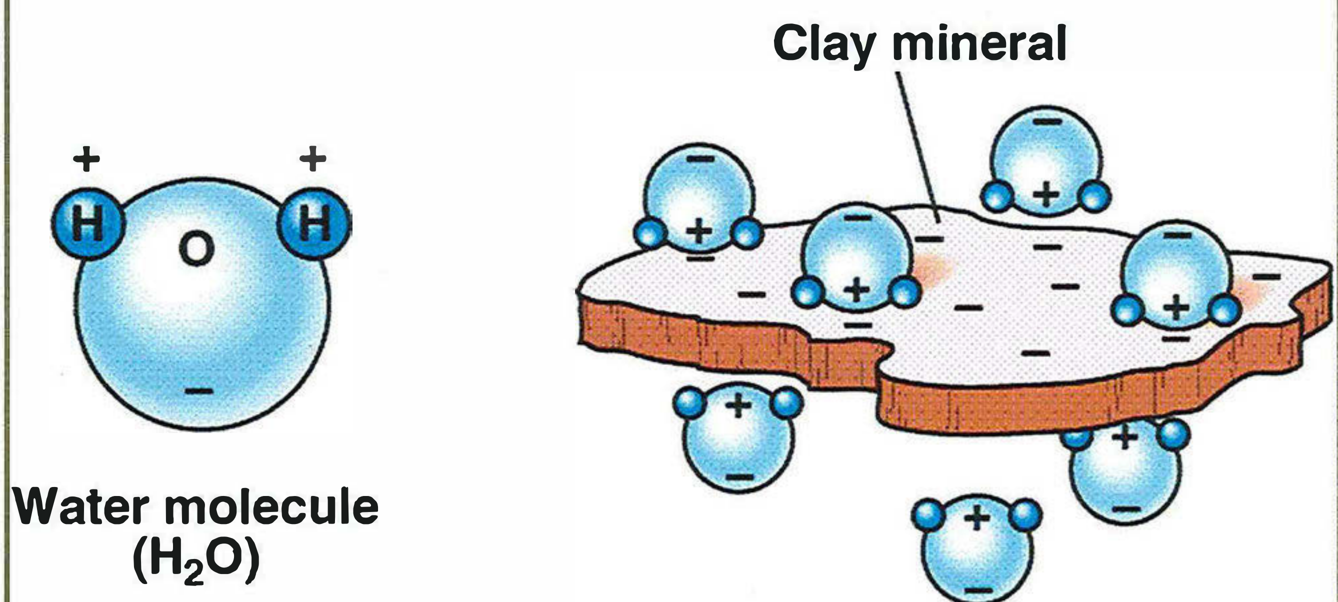
CLAY MINERAL IMAGES

CLAY-SIZED PARTICLES (< 0.002 MM)

- Strong reactive properties
    - Allows water and ion adsorption on surface of clay particles
    - Permits shrink-swell tendencies of some clays
    - Causes clays to stick together (clods) when dry
    - Carry a layer of bound (adsorbed) water

WATER ADSORPTION ON CLAY MINERAL

Clay Mineral



INFLUENCE OF SOIL SEPARATES ON SOIL PROPERTIES AND BEHAVIOR

Property or Behavior	RATING ASSOCIATED WITH THE SOIL SEPARATES		
	Sand	**Silt**	**Clay**
WATER-HOLDING CAPACITY	LOW	MEDIUM to HIGH	HIGH
AERATION	GOOD	MEDIUM	POOR
DRAINAGE RATE	HIGH	SLOW to MEDIUM	VERY SLOW
SOIL ORGANIC MATTER CONTENT	LOW	MEDIUM to HIGH	HIGH to MEDIUM
DECOMPOSITION OF ORGANIC MATTER	RAPID	MEDIUM	SLOW
WARM-UP IN SPRING	RAPID	MODERATE	SLOW
COMPACTABILITY	LOW	MEDIUM	HIGH
SUSCEPTIBILITY TO WIND EROSION	MODERATE (HIGH for FINE SAND)	HIGH	LOW
SUSCEPTIBILITY TO WATER EROSION	LOW (unless FINE SAND)	HIGH	LOW (if aggregated, otherwise HIGH)
SHRINK-SWELL POTENTIAL	VERY LOW	LOW	MODERATE to VERY HIGH
SEALING OF PONDS, DAMS, LANDFILLS	POOR	POOR	GOOD
SUITABILITY FOR TILLAGE AFTER RAINFALL	GOOD	MEDIUM	POOR
POLLUTANT LEACHING POTENTIAL	HIGH	MEDIUM	LOW (unless cracked)
ABILITY TO STORE PLANT NUTRIENTS	POOR	MEDIUM to HIGH	HIGH
RESISTANCE TO pH CHANGE	LOW	MEDIUM	HIGH

SOIL TEXTURAL CLASSES

Grouping of soils according to their relative percentages of SAND, SILT & CLAY

- There are 4 main textural classes....
  - SANDS:
  - generally ≥ 75% sand, < 12% clay
    - *sand, loamy sand, loamy fine sand, loamy coarse sand*
  - SILTS:
  - ≥ 80% silt, < 12% clay
    - *No subclasses*

SOIL TEXTURAL CLASSES

- CLAYS:
- at least 35% clay
  - *clay, sandy clay, silty clay*

- LOAMS:
- sand, silt and clay are present in more or less equal proportions
  - *loam, sandy loam, fine sandy loam, coarse sandy loam, silt loam, silty clay loam, sandy clay loam, clay loam*
  - First word of the class name indicates dominant particle(s)

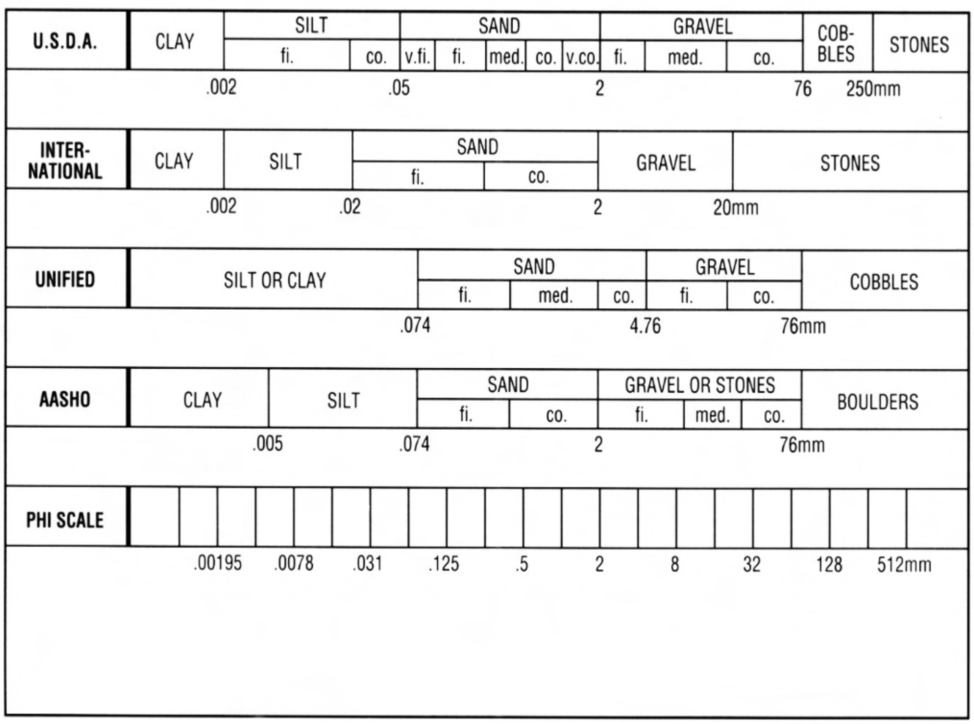
Soil Separates

The United States Department of Agriculture uses the following size separates for the <2 mm mineral material:

Very coarse sand:	2.0-1.0 mm
Coarse sand:	1.0-0.5 mm
Medium sand:	0.5-0.25 mm
Fine sand:	0.25-0.10 mm
Very fine sand:	0.10-0.05 mm
Silt:	0.05-0.002 mm
Clay:	< 0.002 mm

Figure 3-14 compares the USDA system with others.

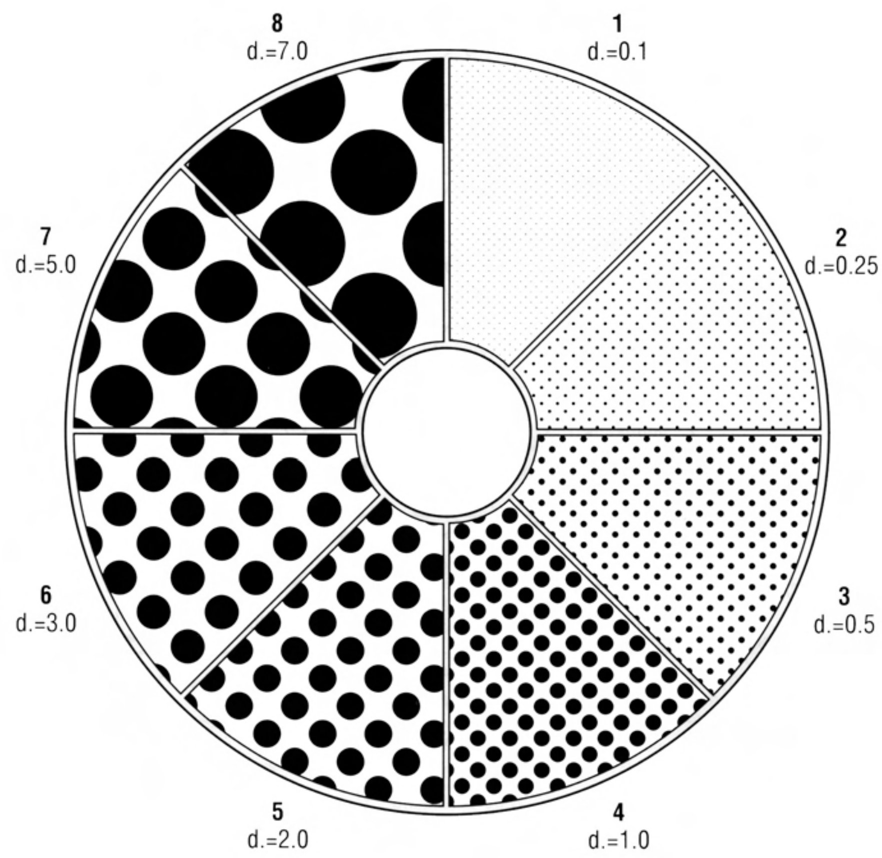
FIGURE 3-14



Relationships among particle size classes of 5 different systems.

Figure 3-15 illustrates classes of soil particles larger than silt.

FIGURE 3-15



Sizes of particles of indicated diameters (d) in millimeters.

Soil Texture

Soil texture refers to the weight proportion of the separates for particles less than 2 mm as determined from a laboratory particle-size distribution. Field estimates should be checked against laboratory determinations and the field criteria should be adjusted as necessary. Some soils are not dispersed completely in the standard particle size analysis. For these, the field texture is referred to as *apparent* because it is not an estimate of the results of a laboratory operation. Apparent field texture is a tactile evaluation only with no inference as to laboratory test results. Field criteria for estimating soil texture must be chosen to fit the soils of the area. Sand particles feel gritty and can be seen individually with the naked eye. Silt particles cannot be seen individually without magnification; they have a smooth feel to the fingers when dry or wet. In some places, clay soils are sticky; in others they are not. Soils dominated by montmorillonite clays, for example, feel different from soils that contain similar amounts of micaceous or kaolintic clay. Even locally, the relationships that are useful for judging texture of one kind of soil may not apply as well to another kind.

The texture classes (fig. 3-16) are sand, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. Subclasses of sand are subdivided into coarse sand, sand, fine sand, and very fine sand. Subclasses of loamy sands and sandy loams that are based on sand size are named similarly.

Definitions of the soil texture classes follow:

Sands.—More than 85 percent sand, the percentage of silt plus 1.5 times the percentage of clay is less than 15.

Coarse sand. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sand. A total of 25 percent or more very coarse, coarse, and medium sand, a total of less than 25 percent very coarse and coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand.

Fine sand. 50 percent or more fine sand; or a total of less than 25 percent very coarse, coarse, and medium sand and less than 50 percent very fine sand.

Very fine sand. 50 percent or more very fine sand.

FIGURE 3-16

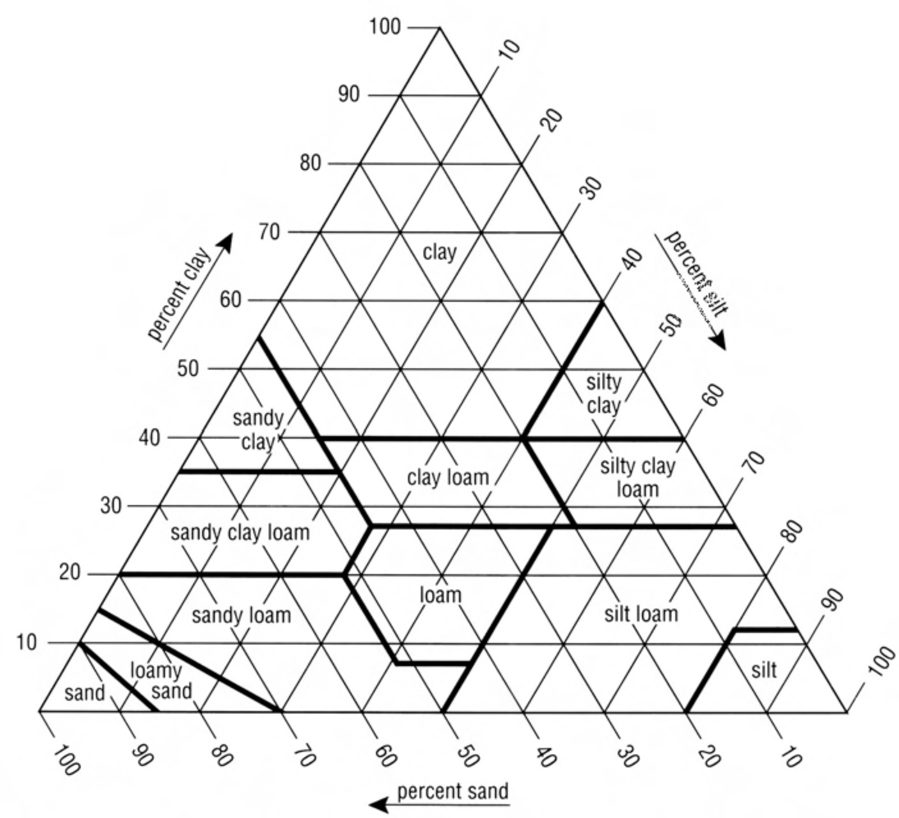


Chart showing the percentages of clay, silt, and sand in the basic textural classes.

Loamy sands.—Between 70 and 91 percent sand and the percentage of silt plus 1.5 times the percentage of clay is 15 or more; and the percentage of silt plus twice the percentage of clay is less than 30.

Loamy coarse sand. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Loamy sand. A total of 25 percent or more very coarse, coarse, and medium sand and a total of less than 25 percent very coarse and coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand.

Loamy fine sand. 50 percent or more fine sand; or less than 50 percent very fine sand and a total of less than 25 percent very coarse, coarse, and medium sand.

Loamy very fine sand. 50 percent or more very fine sand.

Sandy loams.—7 to 20 percent clay, more than 52 percent sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7 percent clay, less than 50 percent silt, and more than 43 percent sand.

Coarse sandy loam. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sandy loam. A total of 30 percent or more very coarse, coarse, and medium sand, but a total of less than 25 percent very coarse and coarse sand and less than 30 percent fine sand and less than 30 percent very fine sand; or a total of 15 percent or less very coarse, coarse, and medium sand, less than 30 percent fine sand and less than 30 percent very fine sand with a total of 40 percent or less fine and very fine sand.

Fine sandy loam. 30 percent or more fine sand and less than 30 percent very fine sand; or a total of 15 to 30 percent very coarse, coarse, and medium sand; or a total of more than 40 percent fine and very fine sand, one half or more of which is fine sand, and a total of 15 percent or less very coarse, coarse, and medium sand.

Very fine sandy loam. 30 percent or more very fine sand and a total of less than 15 percent very coarse, coarse, and medium sand; or more than 40 percent fine and very fine sand, more than one half of which is very fine sand, and total of less than 15 percent very coarse, coarse, and medium sand.

Loam.—7 to 27 percent clay, 28 to 50 percent silt, and 52 percent or less sand.

Silt loam. 50 percent or more silt and 12 to 27 percent clay, or 50 to 80 percent silt and less than 12 percent clay.

Silt. 80 percent or more silt and less than 12 percent clay.

Sandy clay loam. 20 to 35 percent clay, less than 28 percent silt, and more than 45 percent sand.

Clay loam. 27 to 40 percent clay and more than 20 to 46 percent sand.

Silty clay loam. 27 to 40 percent clay and 20 percent or less sand.

Sandy clay. 35 percent or more clay and 45 percent or more sand.

Silty clay. 40 percent or more clay and 40 percent or more silt.

Clay. 40 percent or more clay, 45 percent or less sand, and less than 40 percent silt.

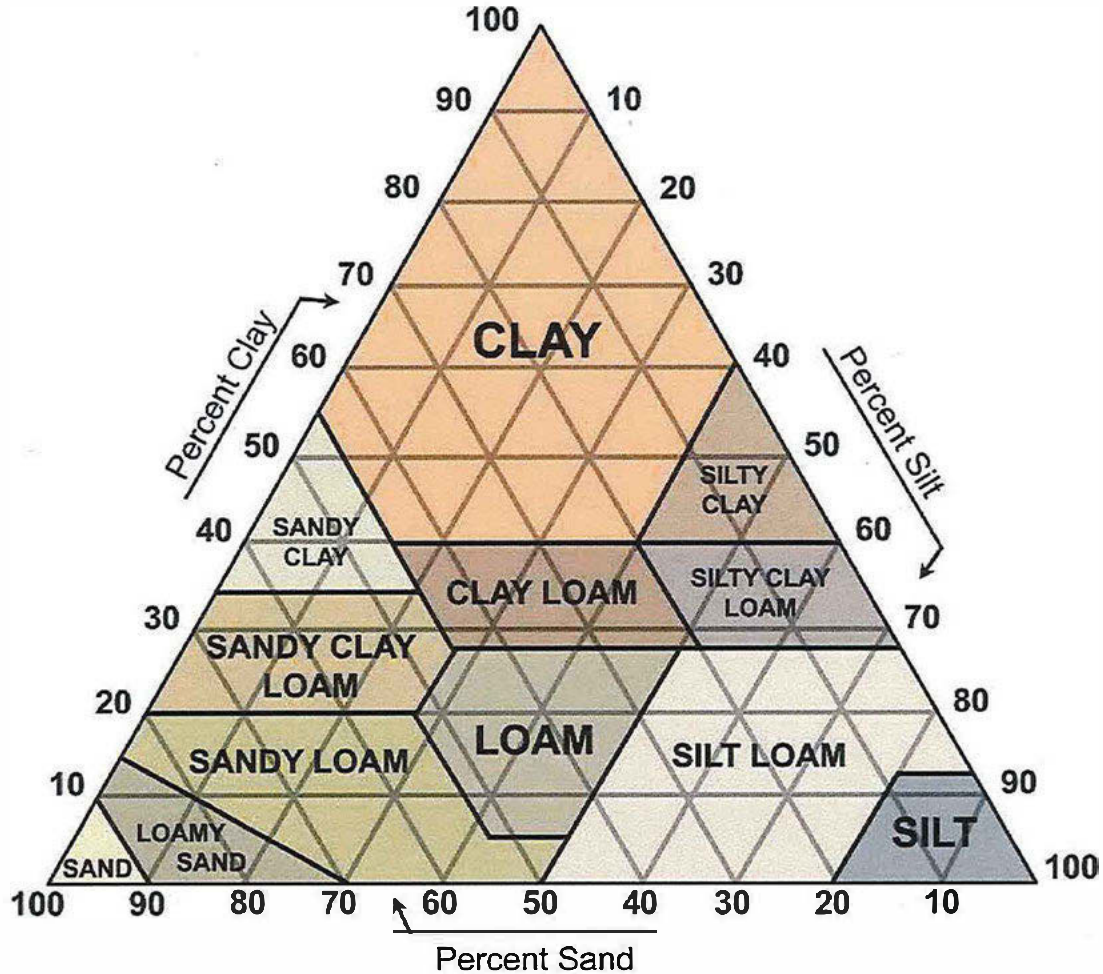
The texture triangle (fig. 3-16) is used to resolve problems related to word definitions, which are somewhat complicated. The eight distinctions in the sand and loamy sand groups provide refinement greater than can be consistently determined by field techniques. Only those distinctions that are significant to use and management and that can be consistently made in the field should be applied.

Groupings of soil texture classes.—The need for fine distinctions in the texture of the soil layers results in a large number of classes of soil texture. Often it is convenient to speak generally of broad groups or classes of texture. An outline of soil texture groups, in three classes and in five, follows. In some areas where soils are high in silt, a fourth general class, silty soils, may be used for silt and silt loam.

General terms [9]	*Texture classes*
Sandy soil materials	
Coarse-textured	Sands (coarse sand, sand, fine sand, very fine sand) Loamy sands (loamy coarse sand, loamy sand, loamy fine sand, loamy very fine sand)
Loamy soil materials:	
Moderately coarse-textured	Coarse sandy loam, sandy loam, fine sandy loam
Medium-textured	Very fine sandy loam, loam, silt loam, silt
Moderately fine-textured	Clay loam, sandy clay loam, silty clay loam
Clayey soils:	
Fine-textured	Sandy clay, silty clay, clay

[9] These are loamy, and clayey texture groups, not the sandy, loamy, and clayey particle-size classes defined in Soil Taxonomy.

SOIL TEXTURAL TRIANGLE



K·STATE
Research and Extension

Estimating Soil Texture By Feel

Department of Agronomy MF2852 Soil Judging

The word *texture* describes the roughness or smoothness of an object. Soil texture is determined by feeling the soil.

- **Soil texture** is the proportion of sand, silt, and clay in the soil.
- **Soil texture** is considered by most soil scientists to be the single most important soil property.
- **Soil texture** affects many land uses and cannot be changed without great cost and effort.

Sand, the largest particle of the soil, is visible to the eye. It is gritty, holds little water, and is not slick or sticky when wet. Sand particles are between 2 and 0.05 millimeters in diameter.

Medium-sized soil particles are called **silt**. Silt feels like flour or talcum powder. It holds moderate amounts of water and has a somewhat sticky feel when wet. Silt particles are between 0.05 and 0.002 millimeters in diameter.

The smallest particles of soil are called **clay**. Most individual clay particles can only be seen with a powerful microscope. Clay feels sticky when wet, and hard when dry. Clay is more chemically active than sand and silt. Clay particles are less than 0.002 millimeters in diameter.

How to determine soil texture by feel

Laboratory analyses of soil texture are costly and take time, while feeling soil texture by hand is quick, free, and, with practice, highly accurate. The two basic steps in the texture by feel method are shown in figures 1 and 2.

After completing these two steps, and following the flow chart diagram, determine the soil textural class for your soil sample. The textural triangle organizes the textures into 12 classes. Notice that the loam textures are toward the middle of the diagram, because they contain a significant amount of sand, silt, *and* clay.

The term coarse-textured is often used for soils that are dominated by sand. Fine-textured refers to soils that are dominated by clay, and medium-textured soils are a more balanced mixture of sand, silt, and clay particles.

Why is soil texture important?

Soil texture is one of the most important properties to know how to measure, as it affects many other chemical, physical, and biological soil processes and properties such as the available water-holding capacity, water movement though the soil, soil strength, how easily pollutants can leach into groundwater, and the natural soil fertility.

Figure 1. *Step 1: Take a handful of soil and break it up in your hand. Add water, and knead the mixture into a ball. The mixture should have the consistency of putty or Play-Doh®. Press the ball of soil between your thumb and forefinger, and try to make a ribbon. See how long you can make the ribbon before it breaks. Measure the ribbon length. Remember, there are 2.5 centimeters in 1 inch.*

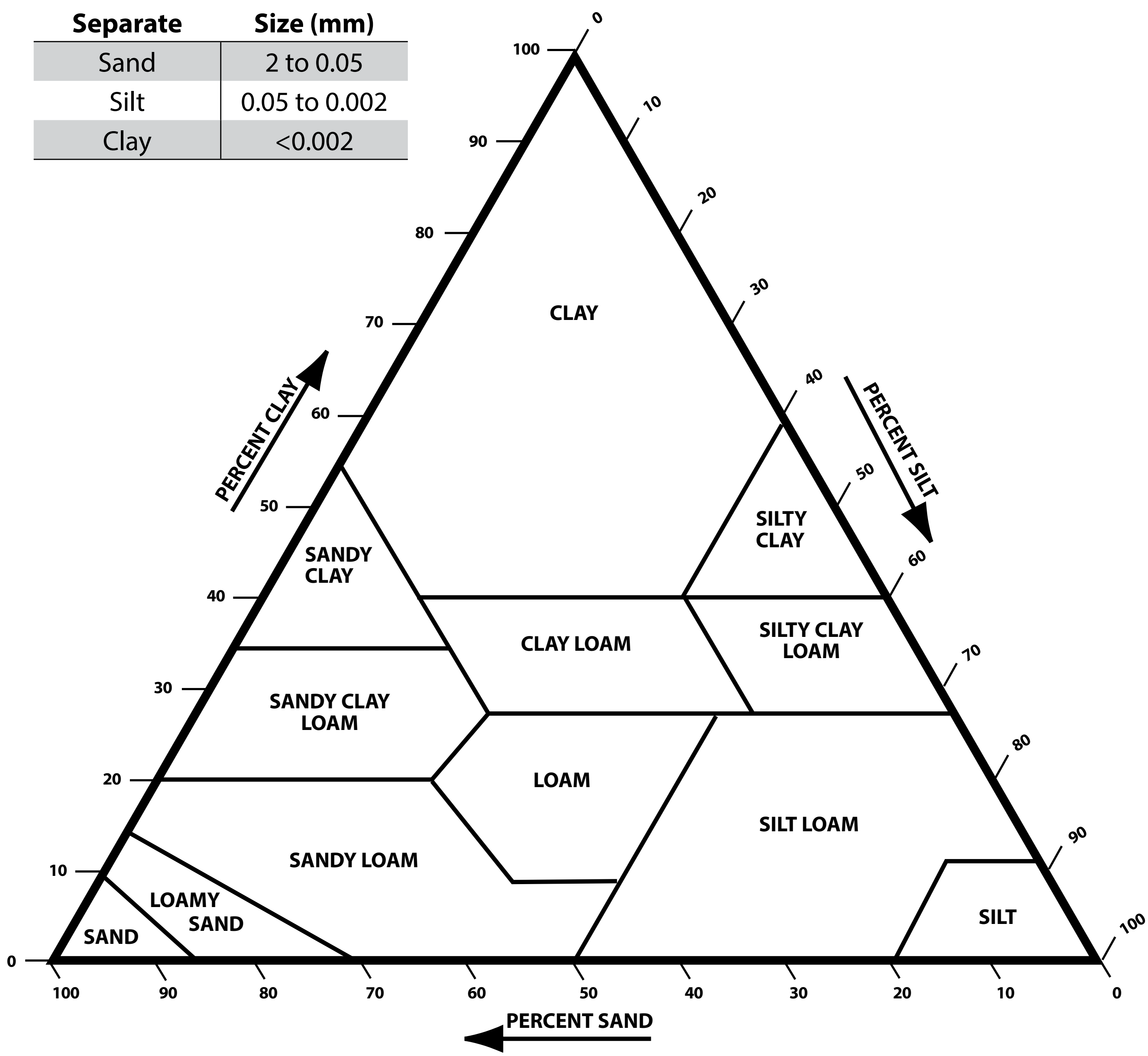
Figure 2. *Step 2: Take a pinch of soil from your texture ball. Place it in the palm of your hand, and add water. Rub the soil and make a muddy puddle in your palm. How gritty does this feel?*

Soil Properties Related to Texture

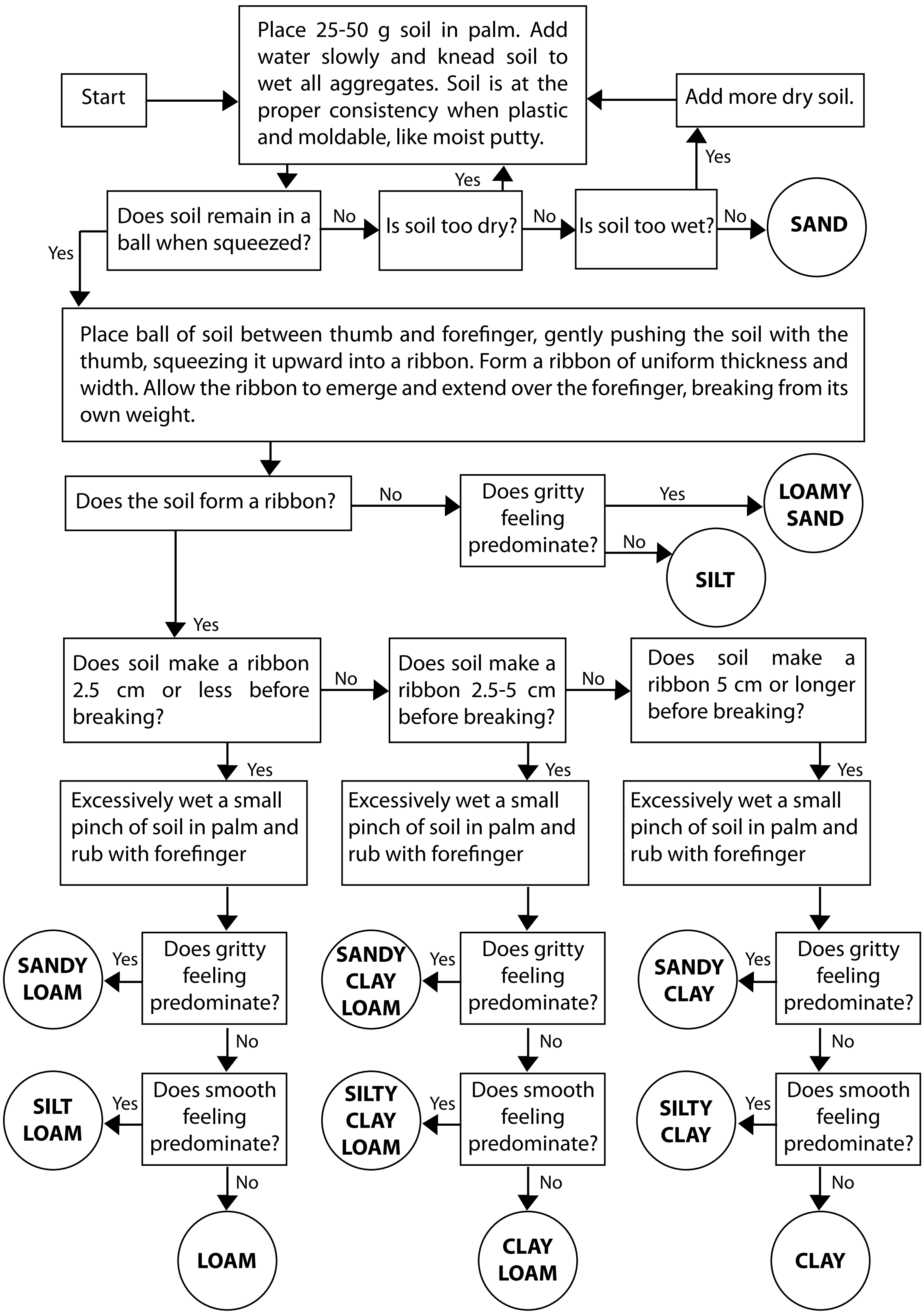
	Coarse	Medium	Fine
Water storage	Low	Medium	High
Water movement	Low	Medium	High
Power needed for digging or tillage	Low	Medium	High
Wind or water erosion (Ease of particle detachment)	High	Medium	Low
Wind or water erosion (Ease of transport)	Low	Medium	High
Plant nutrient storage	Low	Medium	High
Contaminant movement	High	Medium	Low

Soil Textural Classes

Separate	Size (mm)
Sand	2 to 0.05
Silt	0.05 to 0.002
Clay	<0.002



Procedure for Analyzing Soil Texture by Feel



References

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

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Kansas State University Agricultural Experiment Station and Cooperative Extension Service

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PARTICLE DENSITY

- Particle density: determined only by the mass of the solid fraction (sand, silt and clay particles)
- General average particle density for mineral soils is 2.65 g/cm^3 (range between 2.60-2.75 g/cm^3)
- OM has density of 1.1 – 1.4 g/cm^3
- Particle density depends on chemical composition and crystal structure of the particular mineral
- Particle density is NOT affected by pore space

BULK DENSITY

Bulk density:

- includes all pore space in a given volume
- BD less than PD because air and water have lower density than soil solids
- Amount of pore space is major determinant of bulk density
  - More pore space will result in lower density

BULK DENSITY

- BD generally lower in fine-textured (clayey) vs. coarse-textured soils (sandy)
  - Well-structured (clay) produces more pore space
  - Total porosity greater in fine-textured soils
  - More numerous and smaller pores

- Fine-textured soils can be compacted more than coarse-textured soils
  - Smaller particles can be packed more closely

- BD generally varies between 1.0 – 1.5 g/cm^3 in most soils

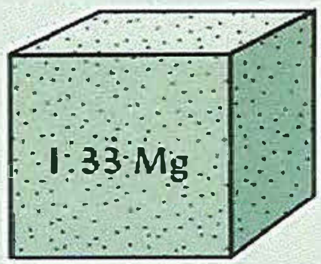
BULK DENSITY

- BD can be increased abnormally by traffic
  - Tractors to cows, traffic squeezes out pore space
- BD can be increased by land clearing/tillage
  - Removes OM (physically or by oxidation)
  - Destroys aggregation
- BD generally increases with depth
  - Less OM deeper in profile
  - Less mechanical activity to promote structure which enhances amount of pore space
  - Weight of overlying soil compresses that below

COMPARISON OF PARTICLE DENSITY AND BULK DENSITY

In the field, one cubic meter of a certain soil appears as...

Solids and pore spaces



To calculate bulk density of the soil:

Volume = 1 m^3 (solids + pores) Weight = 1.33 Mg (solids only)

$$\text{Bulk density} = \frac{\text{Weight of oven dry soil}}{\text{Volume of soil (solids + pores)}}$$

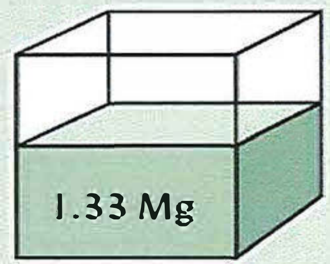
Therefore

$$\text{Bulk density, } D_b = \frac{1.33}{1} = 1.33 \text{ Mg/m}^3$$

If all the solids could be compressed to the bottom, the cube would look like...

1/2 pore spaces

1/2 solids



To calculate solid particle density:

Volume = 0.5 m^3 (solids only) Weight = 1.33 Mg (solids only)

$$\text{Solid particle density} = \frac{\text{Weight of solids}}{\text{Volume of solids}}$$

Therefore

$$\text{Solid particle density, } D_p = \frac{1.33}{0.5} = 2.66 \text{ Mg/m}^3$$

Bulk Density

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm^3.

A three inch diameter ring is hammered into the soil to collect bulk density samples.

Factors Affecting

Inherent - Bulk density is dependent on soil texture and the densities of soil mineral (sand, silt, and clay) and organic matter particles, as well as their packing arrangement. As a rule of thumb, most rocks have a bulk density of 2.65 g/cm^3 so ideally, a medium textured soil with about 50 percent pore space will have a bulk density of 1.33 g/cm^3. Generally, loose, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than that of silt or clay soils. Finer-textured soils, such as silt and clay loams, that have good structure have higher pore space and lower bulk density compared to sandy soils.

Bulk density typically increases with soil depth since subsurface layers have reduced organic matter, aggregation, and root penetration compared to surface layers and therefore, contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them.

The wetting and drying and freeze/thaw cycles that occur in soils naturally, generally do very little to alter soil bulk density.

Dynamic - Bulk density is changed by crop and land management practices that affect soil cover, organic matter, soil structure, and/or porosity. Plant and residue cover protects soil from the harmful effects of raindrops and soil erosion. Cultivation destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to damage caused by water and wind. When eroded soil particles fill pore space, porosity is reduced and bulk density increases. Cultivation can result in compacted soil layers with increased bulk density, most notably a “plow pan” (see Figure 1). Livestock and agricultural and construction equipment exert pressure that compacts the soil and reduces porosity, especially on wet soils.

Relationship to Soil Function

Bulk density reflects the soil’s ability to function for structural support, water and solute movement, and soil aeration. Bulk densities above thresholds in Table 1 indicate impaired function. Bulk density is also used to convert between weight and volume of soil. It is used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems. This increases the validity of comparisons by removing error associated with differences in soil density at time of sampling.

Problems with Poor Function

High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. By reducing water infiltration into the soil, compaction can lead to increased runoff and erosion from sloping land or waterlogged soils in flatter areas. In general, some soil compaction to restrict water movement through the soil profile is beneficial under arid conditions, but under humid conditions compaction decreases yields.

Table 1. General relationship of soil bulk density to root growth based on soil texture.

Soil Texture	Ideal bulk densities for plant growth (g/cm³)	Bulk densities that restrict root growth (g/cm³)
Sandy	< 1.60	> 1.80
Silty	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

The following practices can lead to poor bulk density:

- Consistently plowing or disking to the same depth,
- Allowing equipment traffic, especially on wet soil,
- Using a limited crop rotation without variability in root structure or rooting depth,
- Incorporating, burning, or removing crop residues,
- Overgrazing forage plants, and allowing development of livestock loafing areas and trails, and
- Using heavy equipment for building site preparation or land smoothing and leveling.

Improving Bulk Density

Any practice that improves soil structure decreases bulk density; however, in some cases these improvements may only be temporary. For example, tillage at the beginning of the growing season temporarily decreases bulk density and disturbs compacted soil layers, but subsequent trips across the field by farm equipment, rainfall events, animals, and other disturbance activities can recompact soil.

On cropland, long-term solutions to bulk density and soil compaction problems revolve around decreasing soil disturbance and increasing soil organic matter. A system that uses cover crops, crop residues, perennial sod, and/or reduced tillage results in increased soil organic matter, less disturbance and reduced bulk density. Additionally, the use of multi-crop systems involving plants with different rooting depths can help break up compacted soil layers.

To reduce the likelihood of high bulk density and compaction:

- Minimize soil disturbance and production activities when soils are wet,
- Use designated field roads or rows for equipment traffic,
- Reduce the number of trips across the area,
- Subsoil to disrupt existing compacted layers, and
- Use practices that maintain or increase soil organic matter.

Grazing systems that minimize livestock traffic and loafing, provide protected heavy use areas, and adhere to recommended minimum grazing heights reduce bulk density by preventing compaction and providing soil cover.

Conservation practices resulting in bulk density favorable to soil function include:

- Conservation Crop Rotation
- Cover Crop
- Deep Tillage
- Prescribed Grazing
- Residue and Tillage Management

Measuring Bulk Density

The Cylindrical Core Method is described in the Soil Quality Test Kit Guide, Section I, Chapter 4, pp. 9 - 13. See Section II, Chapter 3, pp. 57 - 58 for interpretation of results.

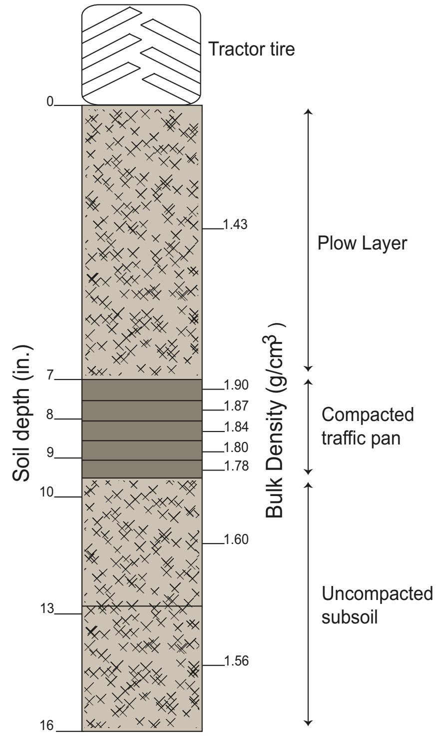
Reference: Arshad MA, Lowery B, and Grossman B. 1996. Physical Tests for Monitoring Soil Quality. In: Doran JW, Jones AJ, editors. Methods for assessing soil quality. Madison, WI. p 123-41.

Specialized equipment, shortcuts, tips:

A microwave or drying oven is required to process samples and a weighing scale is needed to determine the mass of the sample.

Time needed: 30 minutes

Figure 1. Tillage and heavy equipment traffic compacted soil below the plow layer of an Udult soil (Norfolk), inhibiting root penetration and water movement through the soil profile.

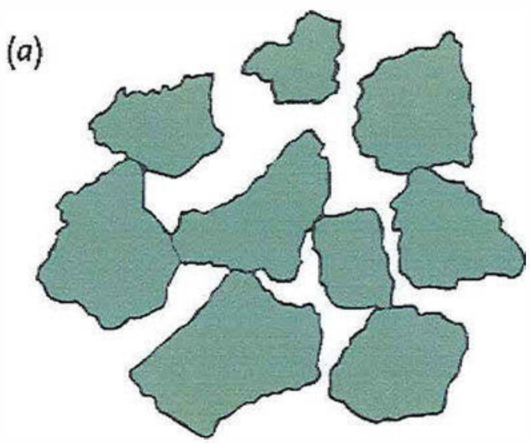


Adapted from: The Nature and Properties of Soils, 10th Edition, Nyle C. Brady, Macmillan Publishing Company.

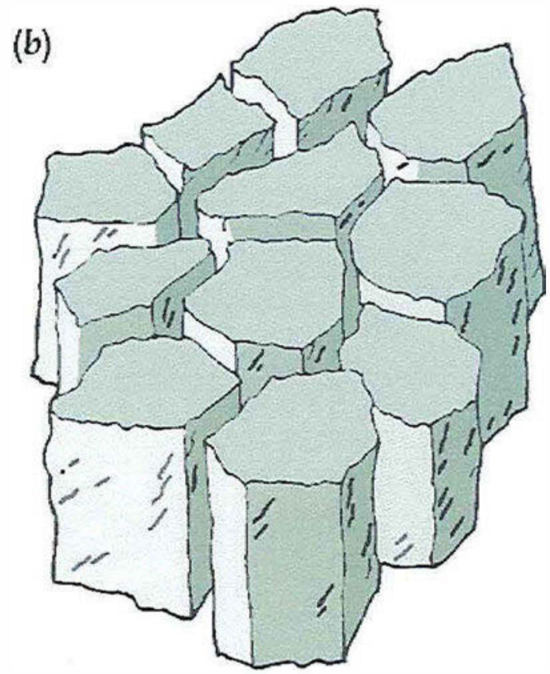
PORE SPACE

- Micropores: retain water against gravity
- Macropores: allow water to flow freely
- Pore space in soils created by:
  - Incomplete interlocking of soil particles
  - Spaces between structural units and aggregates
  - Root and soil animal channels

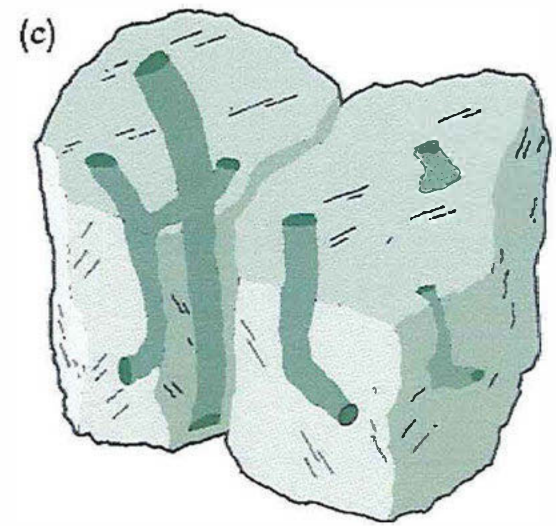
TYPES OF POROSITY



PACKING PORES –
determined by the shape and size of primary particles



INTERPED PORES – spaces between structural units (peds)



BIOPORES – formed by earthworms, insects, and plant roots

PORE SPACE

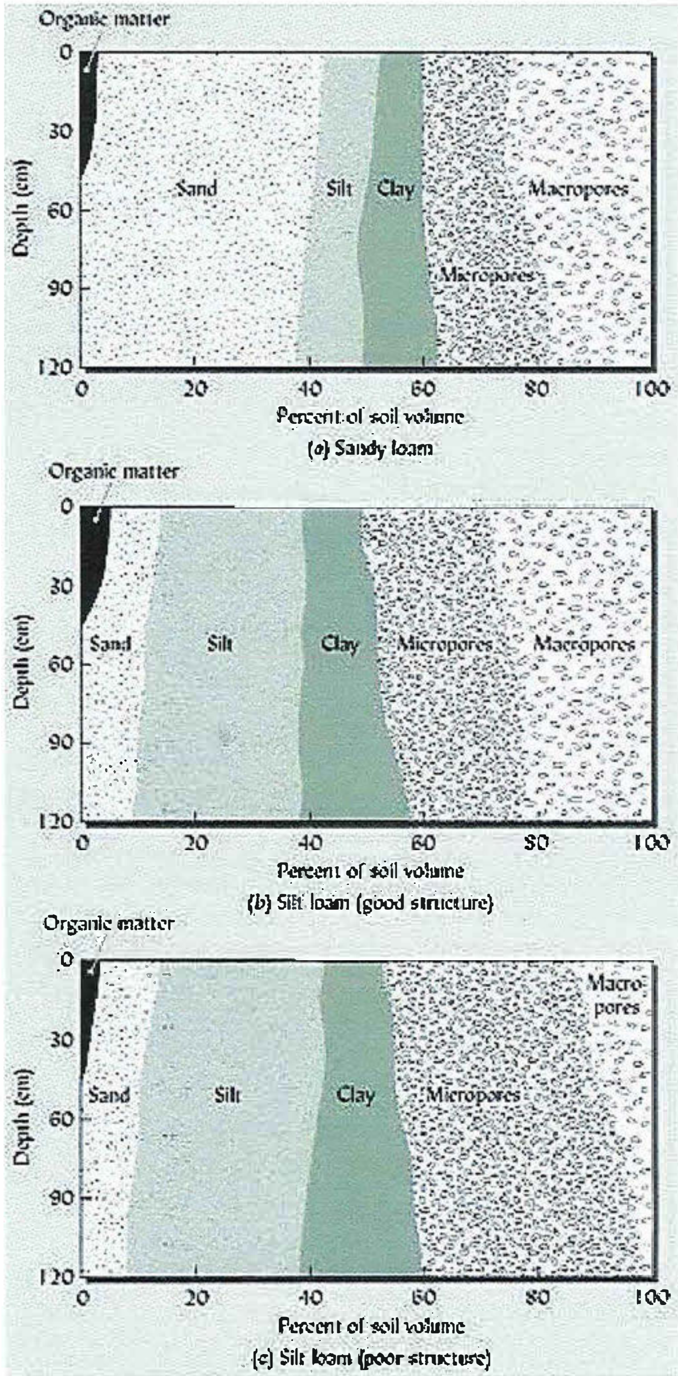
- Coarse textured (sandier) soils dominated by macropores
- Fine textured (clayey) soils dominated by micropores
- Good soils have a balance of both
- Easier to destroy macro than micropore space

DISTRIBUTION OF OM, SAND, SILT AND CLAY, AND POROSITY IN VARIOUS SOILS

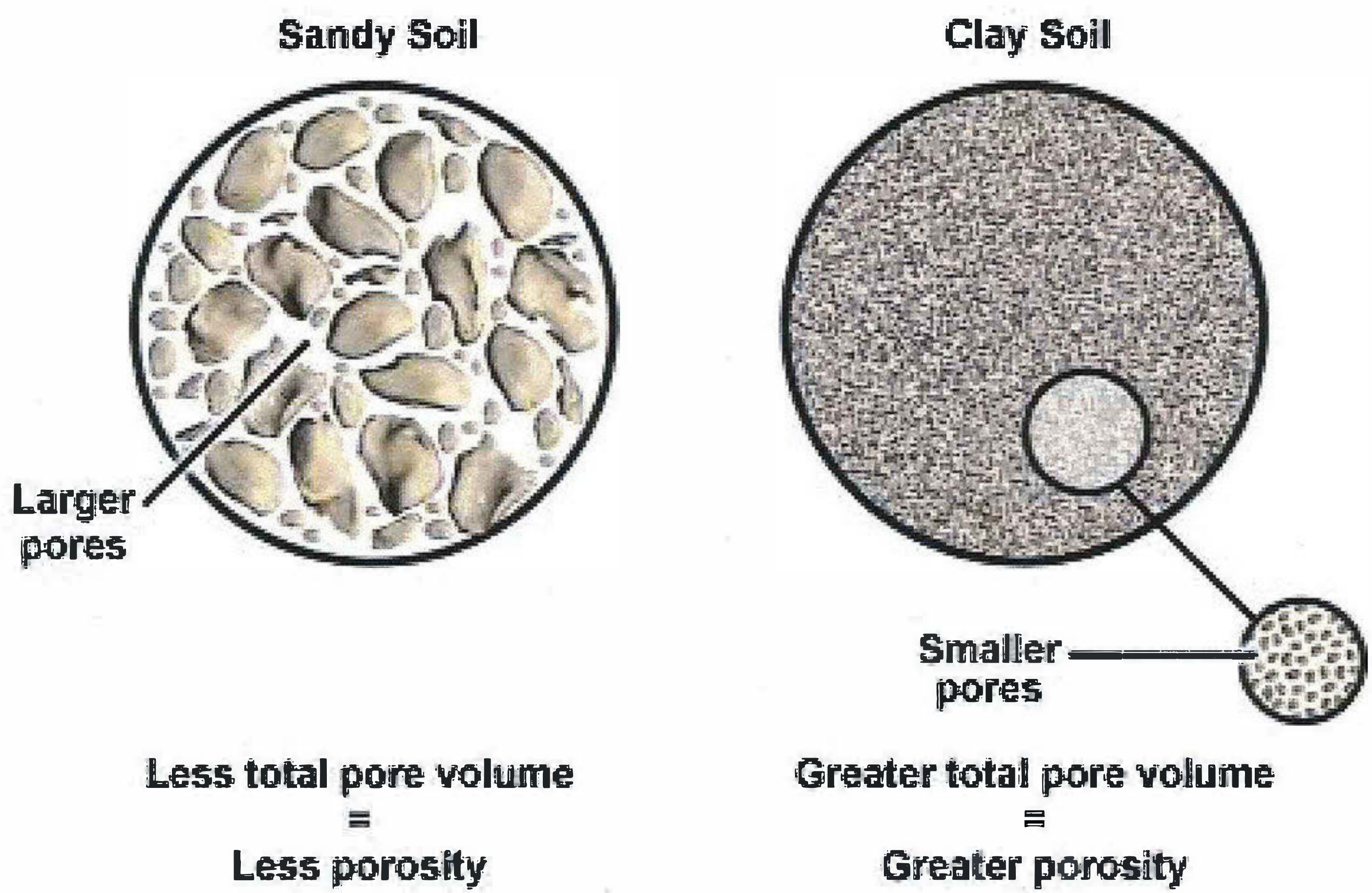
Sandy loam – Dominated by macropores

Silt loam with good structure – more total pore space than sandy loam

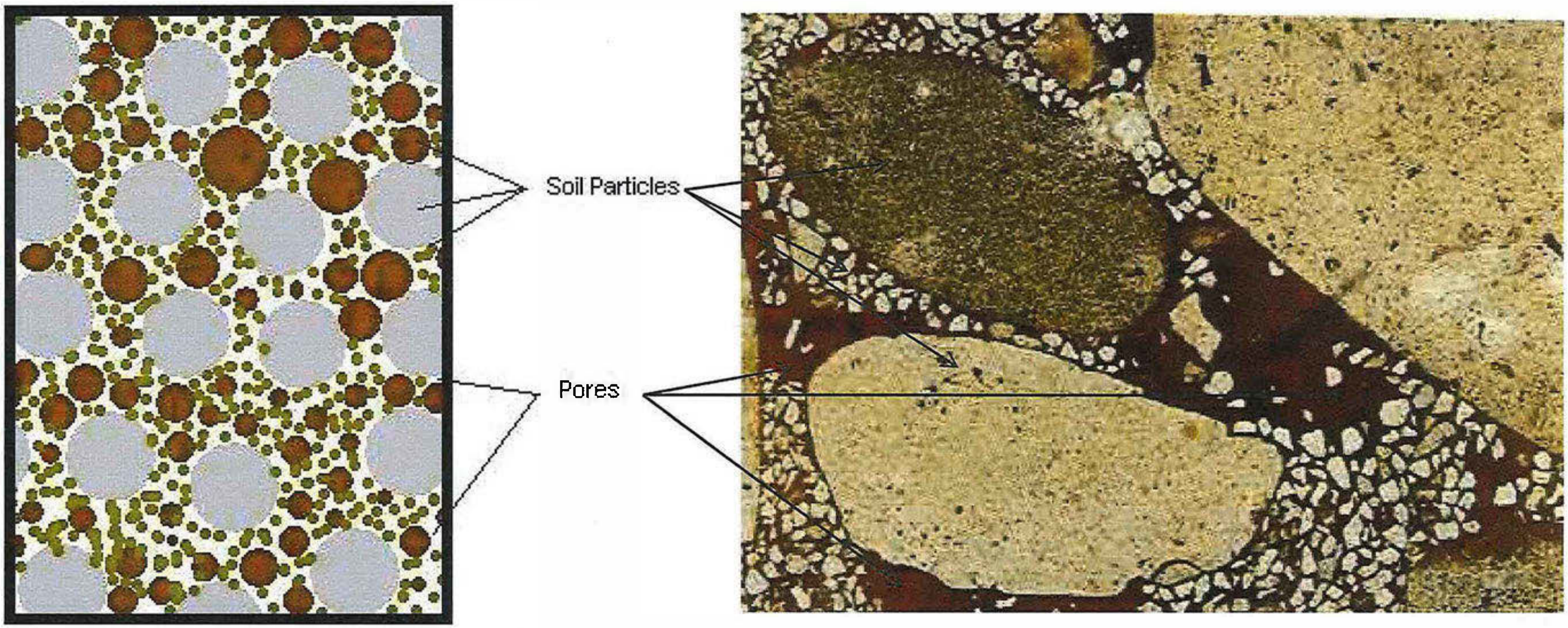
Silt loam with poor structure due compaction – fewer macropores overall

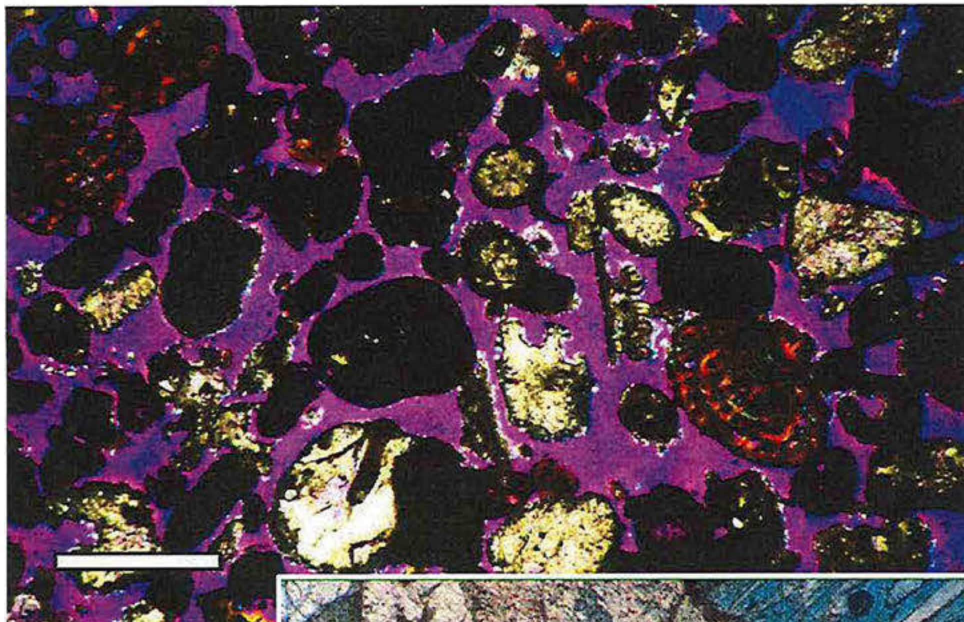


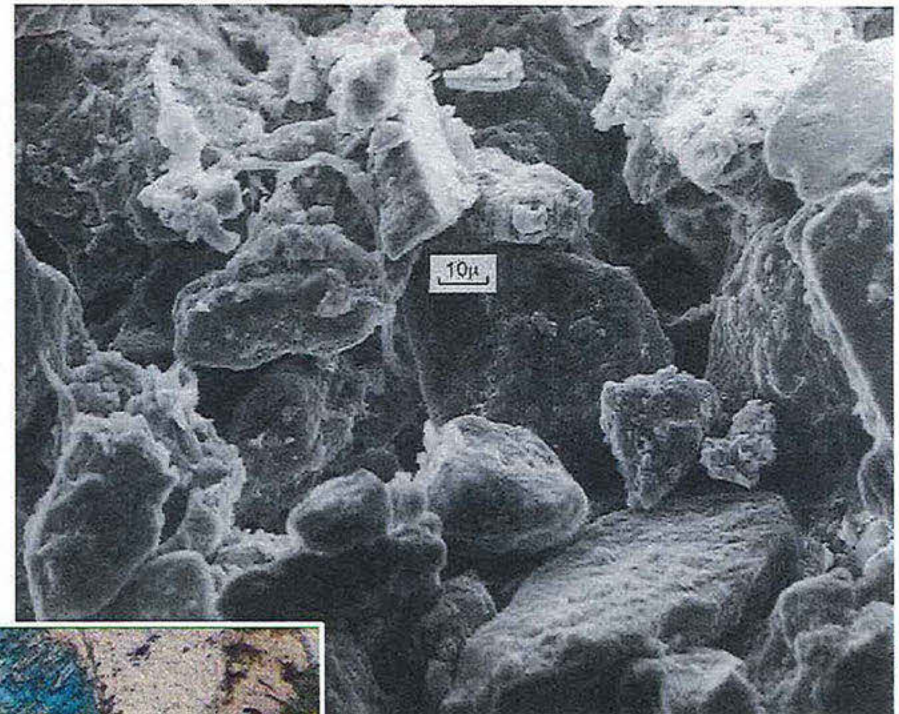
Pore Space in Sandy Soil vs. Clay Soil



POORLY SORTED POROSITY



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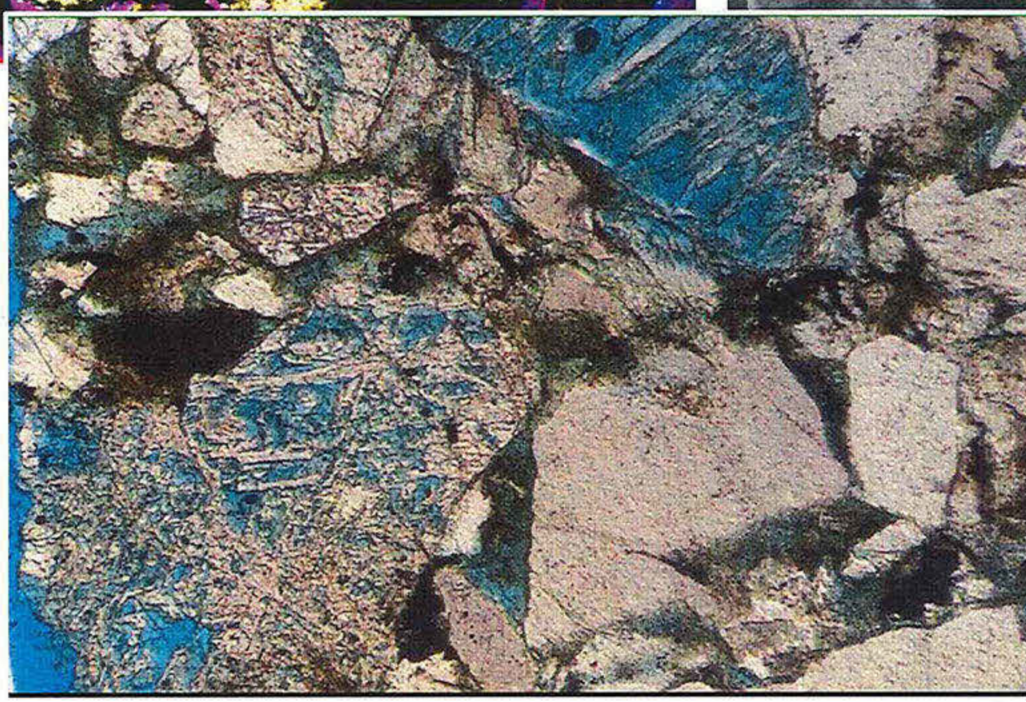


PORE SPACE

- A mixture of pore sizes assures retention of adequate water for plant growth but also allows for drainage of excess water
- A continuous pore system allows more thorough aeration, wetting, and drainage than one with equal pore volume but dominated by dead ends

USDA Natural Resources Conservation Service

Indicator	Test	Function
P	L/O	D

Soil Quality Indicators

Available Water Capacity

Available water capacity is the maximum amount of plant available water a soil can provide. It is an indicator of a soil's ability to retain water and make it sufficiently available for plant use.

Available water capacityis the water held in soil between its *field capacity* and *permanent wilting point*. *Field capacity* is the water remaining in a soil after it has been thoroughly saturated and allowed to drain freely, usually for one to two days. *Permanent wilting point* is the moisture content of a soil at which plants wilt and fail to recover when supplied with sufficient moisture. Water capacity is usually expressed as a volume fraction or percentage, or as a depth (in or cm).

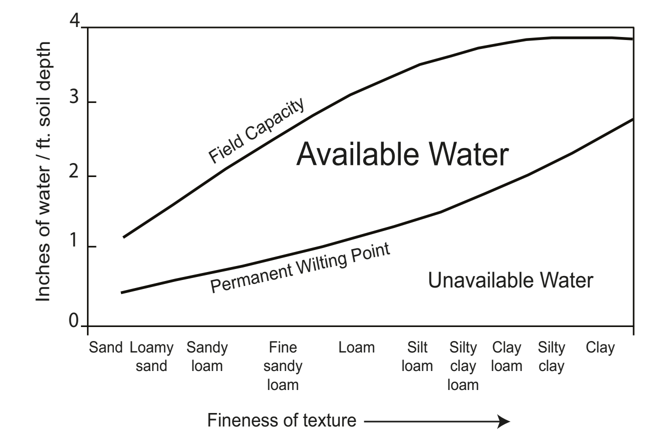


Figure 1. General relationship between soil moisture and texture. Ohio Agronomy Guide, 14th edition, Bulletin 472-05

Factors Affecting

Inherent - Available water capacity is affected by soil texture, presence and abundance of rock fragments, and soil depth and layers.

Available water capacity increases with increasingly fine textured soil, from sands to loams and silt loams. Coarse textured soils have lower field capacity since they are high in large pores subject to free drainage. Fine textured soils have a greater occurrence of small pores that hold water against free drainage, resulting in a comparatively higher field capacity. However, in comparison to well-aggregated loam and silt loam soils, the available water capacity of predominantly clay soils tends to be lower since these soils have an increased permanent wilting point (see Figure 1).

Rock fragments reduce available water capacity of soil proportionate to their volume, unless the rocks are porous. Soil depth and root restricting layers affect total available water capacity since they can limit the volume of soil available for root growth. (Restrictive layers may be naturally occurring or a result of management activities.) Plant rooting characteristics must be considered for a practical understanding of the effects of soil depth and restrictive layers on water available for plant growth. A restrictive layer at 20 inches might have little consequence on the water requirements of a shallow-rooted crop. However, this layer might severely limit the volume of soil a deep-rooted crop can explore for moisture.

Dynamic - Available water capacity is affected by organic matter, compaction, and salt concentration of the soil.

Organic matter increases a soil's ability to hold water, both directly and indirectly. When a soil is at field capacity, organic matter has a higher water holding capacity than a similar volume of mineral soil. While the water held by organic matter at the permanent wilting point is also higher, overall, an increase in organic matter increases a soil's ability to store water available for plant use. Indirectly, organic matter improves soil structure and aggregate stability, resulting in increased pore size and volume. These soil quality improvements result in increased infiltration, movement of water through the soil, and available water capacity (see Figure 2).

Compaction reduces available water capacity through its adverse affects on both field capacity and permanent wilting point. Compaction reduces total pore volume, consequently reducing water storage when the soil is at field capacity. Compaction also crushes large soil pores into much smaller micropores. Since micropores hold water more tightly than larger pores, more water is held in soil at its permanent wilting point.

Salts in soil water result from fertilizer application or naturally occurring compounds. Salt concentration increases as soil water decreases. For soils high in soluble salts, moisture stress results when plants cannot uptake water across an unfavorable salt concentration gradient. Soils with high salt concentration tend to have reduced available water capacity because more water is retained at the permanent wilting point than if water was held by physical factors alone. These effects are most pronounced in soils in dry regions where salts accumulate because of irrigation or natural processes.

Relationship to Soil Function

Soil is a major storage reservoir for water. In areas where rain falls daily and supplies the soil with as much or more water than is removed by plants, available water capacity may be of little importance. However, in areas where plants remove more water than is supplied by precipitation, the amount of water held by the soil may be critical. Water held in the soil may be necessary to sustain plants between rainfall or irrigation events. By holding water for future use, soil buffers the plant – root environment against periods of water deficit.

Available water capacity is used to develop water budgets, predict droughtiness, design and operate irrigation systems, design drainage systems, protect water resources, and predict yields.

Problems with Poor Function

Lack of available water reduces root and plant growth, and it can lead to plant death if sufficient moisture is not provided before a plant permanently wilts. A soil's ability to function for water storage also influences runoff and nutrient leaching.

Agricultural land management practices that lead to poor available water capacity include those that prevent accumulation of soil organic matter and/or result in soil compaction and reduced pore volume and size:

- Conventional tillage operations,
- Low residue crop rotations, and burning, burying, harvesting, or otherwise removing plant residues,
- Heavy equipment traffic on wet soils, and
- Grazing systems that allow development of livestock loafing areas and livestock trails.

As natural areas are permanently converted to homes, roads, and parking areas, the overall amount of water that can be stored in the soil is reduced. This leads to higher total runoff, increased pressure on storm water drainage systems, a higher likelihood of flooding, and generally poorer water quality in streams and lakes.

Improving Available Water Capacity

Farmers can grow high residue crops, perennial sod and cover crops, reduce soil disturbing activities, and manage

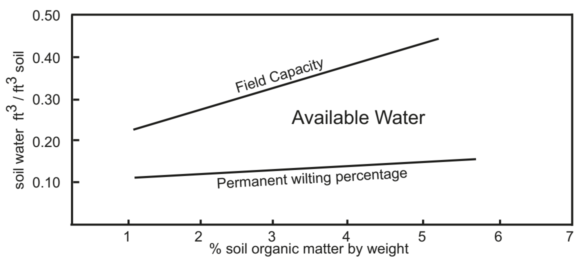


Figure 2. Effect of increasing organic matter on available water capacity of silt loam soils. Adapted from Hudson, SWCS, 1994.

residue to protect and increase soil organic matter to make improvements in a soil's available water capacity. When feasible, tillage, harvest, and other farming operations requiring heavy equipment can be avoided when the soil is wet to minimize compaction; and compacted layers can be ripped to break them and expand the depth of the soil available for root growth.

For soil high in soluble salts, management activities that maintain salts below the root zone can be used. These include irrigation to leach salts below the root zone and practices that promote infiltration, reduce evaporation, minimize disturbance, manage residue, and prevent mixing of salt-laden lower soil layers with surface layers.

Conservation practices resulting in available water capacity favorable to soil function include:

- Conservation Crop Rotation
- Cover Crop
- Prescribed Grazing
- Residue and Tillage Management
- Salinity and Sodic Soil Management

Developers can incorporate the use of permeable parking areas, green roofs, and other practices that minimize the impact of development on soil water storage.

Measuring Available Water Capacity

Reference: U.S. Department of Agriculture, Natural Resources Conservation Service, 2005. National Soil Survey Handbook, title 430-VI. Soil Properties and Qualities (Part 618), Available Water Capacity (618.05). Online at: http://soils.usda.gov/technical/handbook/

Specialized equipment, shortcuts, tips:

Determination of permanent wilting point moisture content requires a pressure membrane apparatus.

Time needed: One to two days is required for free drainage and to allow soil to reach field capacity.

Soil Quality Information Sheet

Soil Quality Resource Concerns:

Available Water Capacity

USDA Natural Resources Conservation Service January 1998

What is available water capacity?

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

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

Why be concerned?

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

How is available water expressed?

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

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

Soil properties affect available water

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

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

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

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

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

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

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

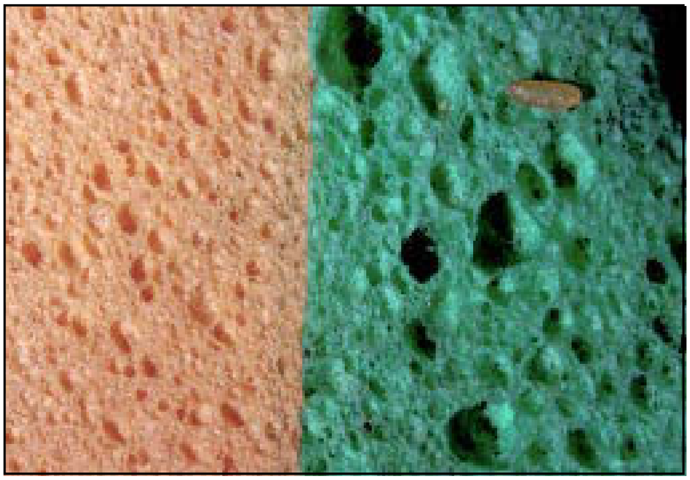


Figure 1: Pore size varies greatly between sponges.

Soil quality and available water

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

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

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

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

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

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

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

Improving the available water

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

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

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

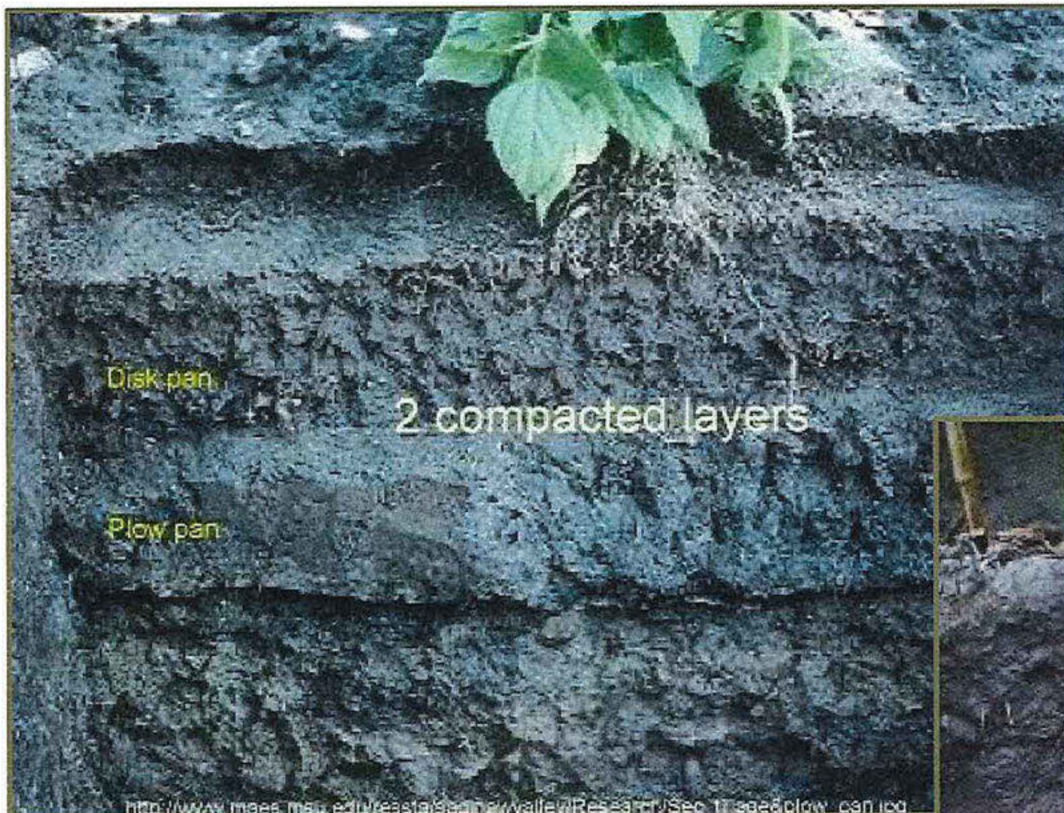
Visit our Web site:
http://soils.usda.gov

SOIL COMPACTION & PORE SPACE

- Compaction often results in loss of macro and increase of micropores
  - Larger pores squeezed out
  - Air exchange reduced
  - Water movement slowed considerably
    - More runoff
    - Less infiltration
    - Slower drainage of excess water in soil (waterlogging)

COMPACTION FROM REPEATED TRAFFIC ON SOIL

MORE EXAMPLES OF PLOW/TILLAGE PANS



IMPACT
OF
CAMPING
ON
BULK DENSITY,
INFILTRATION
AND
RUNOFF
OF A
FOREST SOIL

soil Bulk Density / Moisture / Aeration

Soil Health – Guides for Educators

USDA NRCS United States Department of Agriculture Natural Resources Conservation Service

Bulk density is an indicator of soil compaction. It affects infiltration, rooting depth, available water capacity, soil porosity and aeration, availability of nutrients for plant use, and activity of soil micro-organisms, all of which influence key soil processes and productivity. Bulk density is the oven-dry weight of soil per unit of volume at field moisture capacity or at another specified moisture content. It typically is expressed as grams per cubic centimeter (g/cm^3). Total volume of the surface layer consists of about 50 percent solids, of which about 45 percent is soil particles and 5 percent or less is organic matter, and about 50 percent pore space, which is filled with air or water (fig. 1). Available water capacity is the amount of soil moisture available to plants. It varies with texture (fig. 2) and is reduced when the soil is compacted. Bulk density can be managed by using practices that minimize compaction, improve soil aggregation, and increase soil organic matter content.

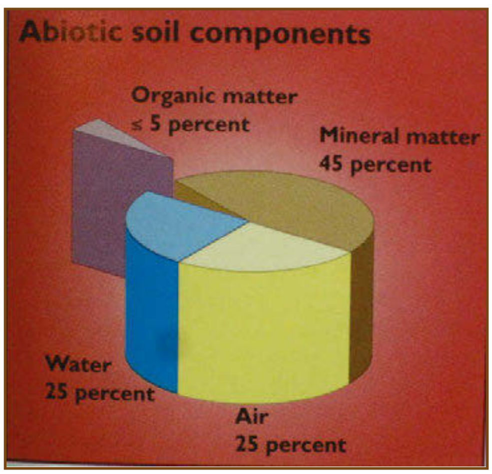


Figure 1.—Four major components of soil volume (Michigan Field Crop Ecology, 1998, E-2646, page 13).

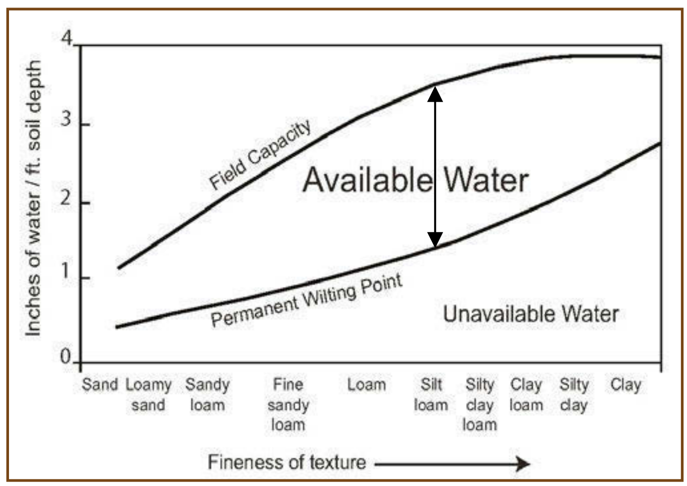


Figure 2.—Relationship between available water and texture (Ohio Agronomy Guide, 14th ed., Bull. 472-05).

Inherent Factors Affecting Bulk Density and Available Water Capacity

Some inherent factors affect bulk density, such as soil texture. Bulk density is also dependent on the soil organic matter content and density and arrangement of soil minerals (sand, silt, and clay). Generally, rocks have a density of 2.65 g/cm^3. Ideally, silt loam has 50 percent pore space and a bulk density of 1.33 g/cm^3. Loose, well-aggregated, porous soils and soils high in content of organic matter generally have lower bulk density. Sandy soils have relatively high bulk density because they have less total pore space than silty or clayey soils (not applicable to red clayey soils and volcanic ash soils). Bulk density typically increases as soil depth increases. The subsurface layers are more compacted and have less pore space because they have less organic matter, less aggregation, and less root penetration than the surface layer.

Available water capacity (fig. 2) is affected by soil texture, presence and abundance of rock fragments, soil depth, and restrictive layers. It is also affected by management practices that alter soil organic matter content, structure, and porosity.

Bulk Density Management

Bulk density can be altered by using management practices that affect soil cover, organic matter content, structure, compaction, and porosity. Excessive tillage destroys soil organic matter and weakens the natural stability of soil aggregates, making them susceptible to erosion by water and wind. When pore spaces are filled with eroded soil particles, porosity is reduced and bulk density is increased. Tillage and equipment use result in compacted soil layers, such as a plowpan, that have higher bulk density (figs. 3 and 4). Tilling prior to planting temporarily decreases the bulk density of the surface layer, but it increases the bulk density of the layer directly below the plow layer. Making multiple trips across a field with farm equipment, periods of rainfall, trampling by animals, and other disturbances also compact the soil. To minimize soil compaction, decrease soil disturbance and increase soil organic matter content.

Organic matter content and compaction also affect the total water capacity and available water capacity of soil. Organic matter increases the ability of a soil to hold water, both directly and indirectly. Compaction increases bulk density and decreases total pore space, reducing available water capacity.

To increase organic matter content and minimize compaction, improving bulk density and porosity:

- Use a continuous no-till cropping system, grow cover crops, apply solid manure or compost, and use diverse rotations that include high-residue crops and perennial legumes or grass.
- Minimize soil disturbance and avoid operating equipment when the soil is wet.
- Use equipment only on designated roads or between rows.
- Limit the number of times equipment is used on a field.
- Subsoil to disrupt existing compacted layers.
- Use multi-crop systems that include plants with different rooting depths to help break up compacted soil layers.

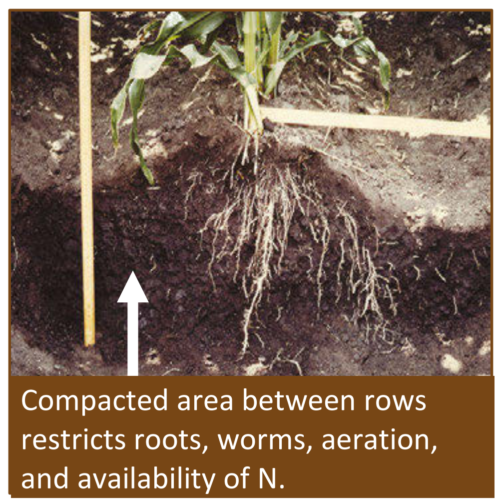


Figure 3.—Compacted soil between rows as a result of wheeled equipment use.

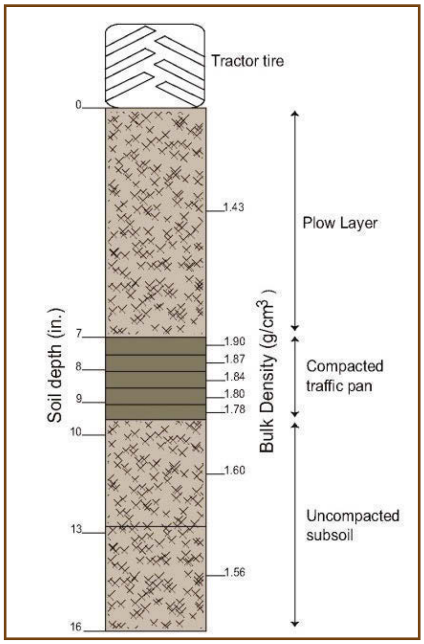


Figure 4.—Compacted plow layer inhibits root penetration and water movement through the soil profile (adapted from *The Nature and Properties of Soils*, 10th edition).

Water-filled pore space and porosity:

If 60 percent or more of the pore space is filled with water, important soil processes are impacted. Soil respiration and nitrogen cycling (ammonification and nitrification) increase as soil moisture increases (fig. 5). In dry soils, the rate of these processes decreases because of a lack of moisture. Poor aeration interferes with the ability of soil organisms to respire and cycle nitrogen.

If more than 80 percent of the pore space is filled with water, soil respiration declines to a minimum level and denitrification occurs. This results in loss of nitrogen as gases, emission of potent greenhouse gases, decreased yields, and an increased need for N fertilizer, which increases cost.

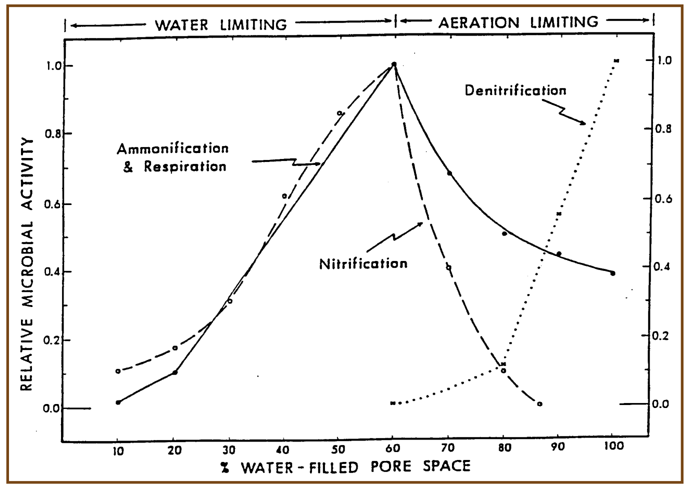


Figure 5.—Relationship of water-filled pore space to soil microbial activity (Linn and Doran, 1984).

Soil Bulk Density Issues and Their Relationship to Soil Function

High bulk density is an indicator of soil compaction and low soil porosity. It impacts available water capacity, root growth (table 1), and movement of air and water through the soil. Compaction reduces crop yields and restricts the growth of plant cover that helps to protect the soil from erosion. By restricting the infiltration of water into the soil, compaction can lead to increased runoff and erosion in sloping areas or to saturated soils in more level areas.

For laboratory analyses to determine organic matter and nutrient content, adjust the volume of the soil sample according to its bulk density. For example, a 30-percent error in organic matter and nutrient content would result if a soil with a bulk density of 1.3 and one with a bulk density of 1.0 were analyzed similarly, or without adjustment for the difference in bulk density.

Table 1.—General relationship of soil bulk density to root growth based on soil texture*

Soil texture	Ideal bulk density for plant growth (grams/cm^3)	Bulk density that affects root growth (grams/cm^3)	Bulk density that restricts root growth (grams/cm^3)
Sand, loamy sand	<1.60	1.69	>1.80
Sandy loam, loam	<1.40	1.63	>1.80
Sandy clay loam, clay loam	<1.40	1.60	>1.75
Silt, silt loam	<1.40	1.60	>1.75
Silt loam, silty clay loam	<1.40	1.55	>1.65
Sandy clay, silty clay, clay loam	<1.10	1.49	>1.58
Clay (>45 percent clay)	<1.10	1.39	>1.47

*Does not apply to red clayey soils and volcanic ash soils.

List some management practices that affect bulk density? Why?

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What impact do these practices have on soil organic matter content and porosity?

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Measuring Bulk Density and Soil Moisture

Materials needed to measure bulk density:

____ 3-inch-diameter aluminum ring

____ Wood block or plastic insertion cap

____ Rubber mallet or weight

____ Flat-bladed knife

____ Resealable plastic bags and permanent marker

____ Scale (1 g precision)

____ 1/8 cup (29.5 mL) measuring scoop

____ Ceramic coffee cup or paper plate

____ 18-inch metal rod, probe, or spade (to check for compaction zone)

____ Access to microwave oven

Considerations:

Bulk density can be measured at the soil surface and/or directly in the plow layer. Samples for measuring bulk density, infiltration, and respiration should be taken from the same locations. It may be possible to use the same sample to measure infiltration and bulk density (same process is used for both). When sampling sticky clay soils, apply penetrating oil to the ring for easier removal of the sample.

Step-by-step procedure:

1. Carefully clear all residue from the soil surface. Drive ring into soil to a depth of 3 inches with a small mallet or weight and block of wood or plastic insertion cap. The top of the ring should extend 2 inches above the surface (figs. 6 and 7).

Figure 6.—Drive ring into soil to a depth of 3 inches.

Figure 7.—Ring extends 2 inches above the surface.

2. Remove the ring by first cutting around the outside edge with a small, flat-bladed knife. Place the trowel underneath the ring (to keep the sample in the ring), and carefully lift the ring out.
3. Remove excess soil from the bottom of the ring with the knife (fig. 8).

Figure 8.—Remove excess soil from bottom of ring.

4. Place the sample in a resealable plastic bag. Label the bag.
5. Weigh the sample, including the bag. Record weight in table 2.
6. Weigh an identical, clean, empty bag. Record weight in table 2.

7. Weigh empty cup or paper plate to be used in step 8. Record weight in table 2.
8. Use the entire soil core (or extract a subsample of soil) to determine water content and dry soil weight.
   a. Mix soil core thoroughly by kneading the plastic bag.
   b. Remove level 1/8-cup scoop of loose soil (not packed down) from bag, and place it in the weighed cup or plate (step 7). To increase accuracy of measurement, use the entire soil core or use more than one scoop of soil if subsample is extracted.
9. Weigh both moist soil removed from plastic bag and cup or plate. Record weight in table 2.
10. Place soil and cup or plate in a microwave. Dry in 4-minute cycles at medium power.
11. Weigh soil and cup or plate after each 4-minute cycle. The soil is dry when the weight no longer changes from one drying cycle to the next. Record weight in table 2.

Interpretations

Complete table 2. Compare the results to the bulk density values given in table 1 for the applicable soil textures to determine the relative restrictions to root growth. Determine soil water content and porosity, and complete tables 3 through 5. Compare results to figures 2 and 5. Answer discussion questions.

Table 2.—Bulk density and soil water content (core method)*

(Refer to calculations following table for details.)

Sample site	**(a)** **Wt. of entire moist soil core and bag (grams)**	**(b)** **Wt. of sample bag (grams)**	**(c)** **Wt. of cup or plate (grams)**	**(d)** **Wt. of moist soil subsample and cup or plate (grams)**	**(e)** **Wt. of moist soil subsample (grams)** **(d-c)**	**(f)** **Wt. of dry soil subsample and cup or plate (grams)**	**(g)** **Dry wt. of soil subsample (grams)** **(f-c)**	**(h)** **Soil water content (grams/ gram of soil)** **(e-g) ÷ g**	**(i)** **Soil bulk density (grams/ cm^3)***
Example	490	5	126	160	34	153	27	0.259	1.2

*Soil bulk density = [(a - b) x (1 + h)] ÷ volume of soil core (volume of soil core = 321 cm^3 for 3-inch core, 2 inches from top of soil to top of ring; refer to volume calculations on following page and to figure 11).

Abbreviations and letters in examples and following tables: Wt = weight; π = 3.14; gr = grams; r = radius of inside diameter of ring/core; single letters in equations refer to entries in table 2

Volume of soil core (cm^3) (see figure 11): πr^2 x height

Example—

$3.14 \times (3.66\ cm)^2 \times (7.62\ cm) = 321\ cm^3$

Soil water content of subsample (gr/gr): $\frac{\text{(weight of moist soil - weight of oven-dry soil)}}{\text{weight of oven-dry soil}}$

Example—

(e - g) ÷ (g)

$\frac{(34\ gr - 27\ gr)}{27\ gr} = 0.259$ gr of water/gr of soil

Dry weight of soil core based on water content of subsample (gr):

Dry wt of soil core = $\frac{\text{[wt of moist soil + bag (gr) - wt of bag (gr)]}}{\text{[1 + soil water content (gr/gr)]}}$

Example—

Dry wt of soil core = [(a - b) ÷ (1 + h)] = $\frac{(490\ gr - 5\ gr)}{(1 + 0.259)} = 385$ gr

Bulk density calculation (gr/cm^3): Dry wt of soil core ÷ volume of soil core

Example—

$385\ gr \div 321\ cm^3 = 1.20\ gr/cm^3$

Soil water content and porosity calculations:

Table 3.—Total soil water content

Sample site	Soil water content (by weight) (grams/gram) (h in table 2)	Bulk density from table 2 (grams/cm^3)	Water content (grams/cm^3)*	Total inches of water/foot of soil depth**
Example	0.259	1.2	0.3108	3.7

*Water content (gr/cm^3) = soil water content (gr/gr) x bulk density (gr/cm^3); 1 gram of water (by volume) = 1 cm^3/cm^3

**Total inches of water/foot of soil depth = water content x 12 inches (1 foot)

Table 4.—Soil porosity

Sample site	Bulk density from table 2 (grams/cm^3)	Calculation: 1 - (soil bulk density ÷ 2.65)*	Soil porosity (percent)
Example	1.2	1 - (1.2 ÷ 2.65)	54.7

*The default value of 2.65 is used as a rule of thumb based on the average bulk density of rock.

Table 5.—Water-filled pore space

Sample site	Water content from table 3 (grams/cm^3)	Soil porosity from table 4	Calculation: (water content ÷ soil porosity) x 100	*Percent of pore space filled with water
Example	0.3108	0.547	(0.3108 gr/cm^3 ÷ 0.547) x 100	56.8

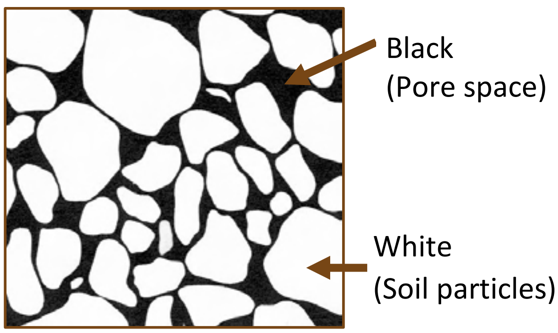

Figure 9.—Soil porosity

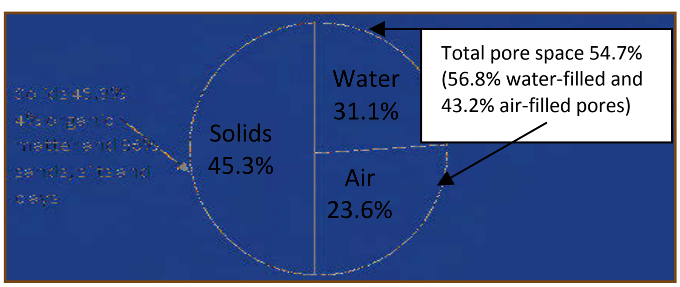

Figure 10.—Example soil core volume, by component (volume = 321 cm^3).

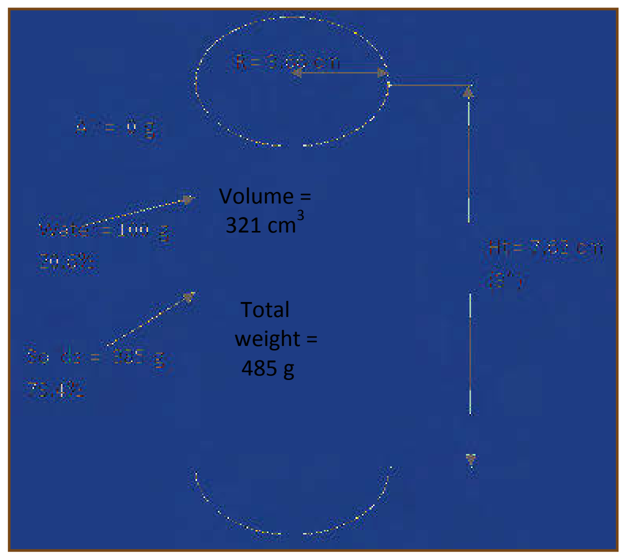

Figure 11.—Example soil core dimensions, volume, and weight, by component.

Were results of bulk density and porosity tests expected? Why or why not?

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Compare results of water-filled pore space calculation to figure 5. Is the ability of the soil organisms to respire and cycle nitrogen impacted? If so, what is the possible impact on production? Are these processes limited by water or aeration?

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Compare bulk density of soil sample to values for the similar soil texture given in table 1. Is bulk density ideal based on the soil texture? Why or why not?

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Compare total water content in table 3 (inches of water per foot of soil depth) to the available water capacity shown in figure 2 for the same soil texture. Is the water content near field capacity?

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Glossary

Ammonification.—Stage of nitrogen cycle in which soil organisms decompose organic nitrogen and convert it to ammonia.

Available water capacity.—Soil moisture available for crop growth (fig. 2). Also defined as the difference between field capacity and wilting point. Typically expressed as inches per foot.

Bulk density.—Weight of dry soil per unit of volume. More compacted soil has less pore space and higher bulk density.

Denitrification.—Conversion and loss of nitrate nitrogen as nitrogen gases when the soil is saturated with water.

Nitrification.—Stage of nitrogen cycle in which soil organisms convert ammonia and ammonium into nitrite and then to nitrate nitrogen, which is available for plant use.

Respiration.—Carbon dioxide (CO_2) release from soil as a result of decomposition of organic matter by soil microbes and from plant roots and soil fauna (aerobes, or organisms that require oxygen).

Soil porosity.—Percent of total soil volume consisting of pore space (fig. 9).

Soil water content, gravimetric.—Weight of soil water per unit of dry soil weight.

Water content.—Amount (weight) of water in soil core expressed as grams/cm^3. One gram of water equals 1 cubic centimeter, by volume.

Water-filled pore space.—Percentage of soil pore space filled with water.

Soil Quality Information Sheet

Soil Quality Resource Concerns: Compaction

USDA Natural Resources Conservation Service **April 1996**

What is compaction?

Soil compaction occurs when soil particles are pressed together, reducing the pore space between them. This increases the weight of solids per unit volume of soil (bulk density). Soil compaction occurs in response to pressure (weight per unit area) exerted by field machinery or animals. The risk for compaction is greatest when soils are wet.

Why is compaction a problem?

Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. It decreases pore size, increases the proportion of water-filled pore space at field moisture, and decreases soil temperature. This affects the activity of soil organisms by decreasing the rate of decomposition of soil organic matter and subsequent release of nutrients.

Compaction decreases infiltration and thus increases runoff and the hazard of water erosion.

How can compacted soils be identified?

- platy or weak structure, or a massive condition,

- greater penetration resistance,

- higher bulk density,

- restricted plant rooting,

- flattened, turned, or stubby plant roots.

The significance of bulk density depends on the soil texture. Rough guidelines for the minimum bulk density at which a root restricting condition will occur for various soil textures are (g/cc stands for grams per cubic centimeter):

Texture	Bulk Density (g/cc)
Coarse, medium, and fine sand and loamy sands other than loamy very fine sand	**1.80**
Very fine sand, loamy very fine sand	**1.77**
Sandy loams	**1.75**
Loam, sandy clay loam	**1.70**
Clay loam	**1.65**
Sandy clay	**1.60**
Silt, silt loam	**1.55**
Silty clay loam	**1.50**
Silty clay	**1.45**
Clay	**1.40**

What causes soil compaction?

Soil compaction is caused by tilling, harvesting, or grazing when the soils are wet.

Soil water content influences compaction. A dry soil is much more resistant to compaction than a moist or wet soil.

Other factors affecting compaction include the texture, pressure exerted, composition (texture, organic matter, plus clay content and type), and the number of passes by vehicle traffic and machinery. Sandy loam, loam, and sandy clay loam soils compact more easily than silt, silt loam, silty clay loam, silty clay, or clay soils.

Compaction may extend to 20 inches. Deep compaction affects smaller areas than shallow compaction, but it persists because shrinking and swelling and freezing and thawing affect it less. Machinery that has axle loads of more than 10 tons may cause compaction below 12 inches. Grazing by large animals can cause compaction because their hooves have a relatively small area and therefore exert a high pressure.

How long will compaction last?

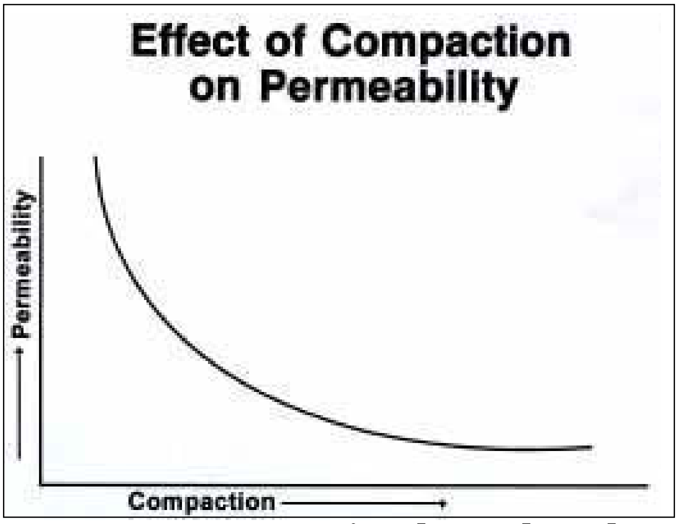
The persistence of soil compaction is determined by the depth at which it occurs, the shrink-swell potential of the soil, and the climate. As the depth increases, the more persistent the condition. The type and percentage of clay determine the shrink-swell potential. The greater the shrink-swell potential and number of wet/dry cycles, the lower is the duration of compaction at a particular depth. Freeze/thaw cycles also help decrease near-surface compaction.

How do organic matter and compaction interact?

Soil organic matter promotes aggregation of soil particles. This increases porosity and reduces bulk density (i.e., compaction). It also increases permeability and may increase plant available water.

Addition of manure, compost, or other organic materials including newspaper, woodchips, and municipal sludge can improve soil structure, helping to resist compaction.

Thick layers of forest litter reduce the impact of machinery, thus reducing compaction.



How can compaction be reduced?

- Reduce the number of trips across the area.

- Till or harvest when the soils are not wet.

- Reduce the pressure of equipment.

- Maintain or increase organic matter in the soil.

- Harvest timber on frozen soil or snow.

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

Soil Quality Information Sheet

Rangeland Soil Quality—**Compaction**

USDA, Natural Resources Conservation Service **May 2001**

What is compaction?

Soil compaction occurs when moist or wet soil aggregates are pressed together and the pore space between them is reduced. Compaction changes soil structure, reduces the size and continuity of pores, and increases soil density (bulk density). Wheel traffic or pressure (weight per unit area) exerted on the soil surface by large animals, vehicles, and people can cause soil compaction. In areas of rangeland, compacted soil layers are generally at the soil surface or less than 6 inches below the surface, although they can be as deep as 2 feet under heavily used tracks and roads. Increases in density can be small to large.

When is compaction a problem?

Compaction changes several structural characteristics and functions of the soil. It is a problem when the increased soil density and the decreased pore space limit water infiltration, percolation, and storage; plant growth; or nutrient cycling.

Water movement and storage.—Compaction reduces the capacity of the soil to hold water and the rate of water movement through soil. It limits water infiltration and causes increased runoff and, in some areas, increased erosion. Compacted wheel tracks or trails can concentrate runoff that can create rills or gullies, especially on steep slopes. When the amount of water that enters the soil is reduced, less water is available for plant growth and percolation to deep root zones. Water entering the soil can perch on a subsurface compacted layer, saturating the soil to or near the surface or ponding on the surface. This water readily evaporates. Compaction can increase the water-holding capacity of sandy soils. An increase in the amount of water stored near the soil surface and a decrease in the amount of water deeper in the soil may favor the shallower rooted annuals over the deeper rooted plant species, such as shrubs.

Plant growth.—Where soil density increases significantly, it limits plant growth by physically restricting root growth. Severe compaction can limit roots to the upper soil layers, effectively cutting off access to the water and nutrients stored deeper in the soil. Anaerobic conditions (lack of oxygen) can develop in or above the compacted layer during wet periods, further limiting root growth. Even in arid climates, anaerobic conditions can occur where water accumulates.

Nutrient cycling.—Compaction alters soil moisture and temperature, which control microbial activity in the soil and the release of nutrients to plants. Anaerobic conditions increase the loss of soil nitrogen through microbial activity. Compaction changes the depth and pattern of root growth. This change affects the contributions of roots to soil organic matter and nutrients. Compaction compresses the soil, reducing the number of large pores. This reduction can restrict the habitat for the larger soil organisms that play a role in nutrient cycling and thus can reduce the number of these organisms.

How can compacted soil layers be identified?

The following features may indicate a compacted soil layer:

- platy, blocky, dense, or massive appearance;
- significant resistance to penetration with a metal rod;
- high bulk density; and
- restricted, flattened, turned, horizontal, or stubby plant roots.

Because some soils that are not compacted exhibit these features, refer to a soil survey report for information about the inherent characteristics of the soil. Each soil texture has a minimum bulk density (weight of soil divided by its volume) at which root-restricting conditions may occur, although the restriction also depends on the plant species.

Texture	Root-restricting bulk density (g/cm^3)*
Coarse, medium, and fine sand and loamy sand other than loamy very fine sand	1.80
Very fine sand, loamy very fine sand	1.77
Sandy loam	1.75
Loam, sandy clay loam	1.70
Clay loam	1.65
Sandy clay	1.60
Silt, silt loam	1.55
Silty clay loam	1.50
Silty clay	1.45
Clay	1.40

* Grams per cubic centimeter.

What affects the ability of soil to resist compaction?

Moisture.—Dry soils are much more resistant to compaction than moist or wet soils. Soils that are wet for long periods, such as those on north-facing slopes and those on the lower parts of the landscape, where they receive runoff, are susceptible to compaction for longer periods than other soils. Saturated soils lose the strength to resist the deformation caused by trampling and wheeled traffic. They become fluid and turn into "mud" when compressed.

Texture.—Sandy loams, loams, and sandy clay loams are more easily compacted than other soils. Gravelly soils are less susceptible to compaction than nongravelly soils.

Soil structure.—Soils with well developed structure and high aggregate stability have greater strength to resist compression than other soils.

Plants and soil organic matter.—Near-surface roots, plant litter, and above-ground plant parts reduce the susceptibility to compaction by helping to cushion impacts. Vegetation also adds soil organic matter, which strengthens the soil, making it more resistant to compaction.

What breaks up a compacted layer?

Natural recovery is often slow, taking years to decades or more. Cycles of wetting and drying and of shrinking and swelling can break down compacted layers, especially in clays and clay loams. Deep compaction occurs in smaller areas than shallow compaction, but it persists longer because it is less affected by the soil expansion caused by freezing. Shallow compaction may be very persistent, however, in areas that are not subject to freezing and thawing.

Roots help to break up compacted layers by forcing their way between soil particles. Plants with large taproots are more effective at penetrating and loosening deep compacted layers, while shallow, fibrous root systems can break up compacted layers near the surface. Roots also reduce compaction by providing food that increases the activity of soil organisms. Large soil organisms, such as earthworms, ants, and termites, move soil particles as they burrow through the soil. Small mammals that tunnel through and mix the soil also are important in some plant communities.

Management strategies that minimize compaction

- Minimize grazing, recreational use, and vehicular traffic when the soils are wet.
- Use only designated trails or roads; reduce the number of trips.
- Do not harvest hay when the soils are wet.
- Maintain or increase the content of organic matter in the soil by improving the plant cover and plant production.

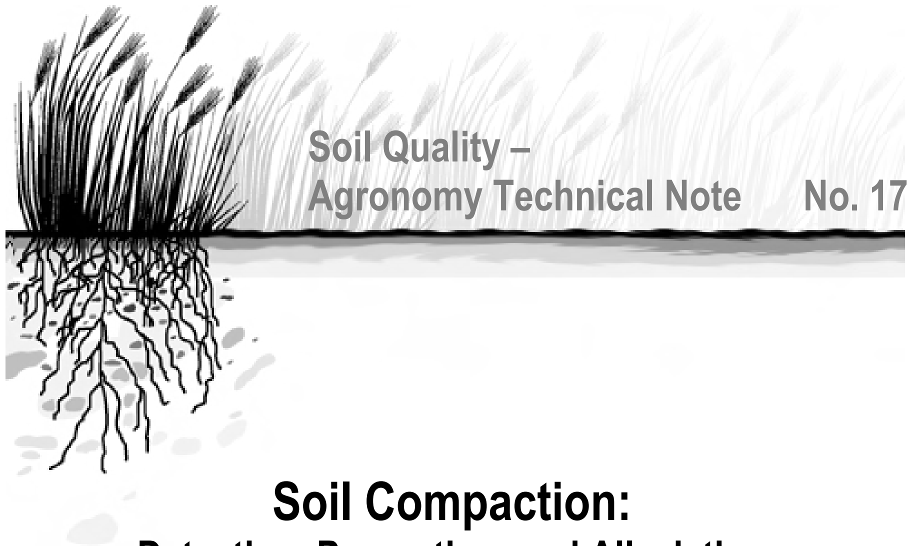
For more information, check the following: http://soils.usda.gov/sqi **and** http://www.ftw.nrcs.usda.gov/glti

(Prepared by the Soil Quality Institute, Grazing Lands Technology Institute, and National Soil Survey Center, Natural Resources Conservation Service, USDA; the Jornada Experimental Range, Agricultural Research Service, USDA; and Bureau of Land Management, USDI)

USDA United States Department of Agriculture

NRCS Natural Resources Conservation Service

Soil Quality Institute



Soil Compaction:
Detection, Prevention, and Alleviation

Technical Note No. 17

June 2003

This is the seventeenth in a series of technical notes about the effects of land management on soil quality.

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Overview

Soil that is excessively compacted is limited in its ability to function. Soil compaction occurs when moist or wet soil particles are pressed together and the pore spaces between them are reduced. Adequate pore space is essential for the movement of water, air, and soil fauna through the soil. The mechanical strength and poor oxygen supply of compacted soil restrict root penetration. Soil moisture is unavailable if layers of compacted soil restrict root growth. Compaction restricts infiltration, resulting in excessive runoff, erosion (Pierce et al., 1983), nutrient loss, and potential water-quality problems. Soil compaction can restrict nutrient cycling, resulting in reduced yields.

Soils in all regions of the country are susceptible to compaction with extreme cases in the upper Midwest, the Pacific Northwest, and the Southeast. Eroded soils are inherently low in content of organic matter and are especially susceptible to compaction.

Compaction is caused primarily by wheel traffic, but it also can be caused by animal traffic or natural processes. Soil is especially susceptible to compaction when it is at field capacity or wetter, has a low content of organic matter, or has poor aggregate stability. Saturated soils lack adequate strength to resist the deformation caused by traffic. Moldboard plowing and excessive tillage break down soil aggregates. After the aggregates are broken down and the soil surface is bare, the soil is more likely compacted by the excessive vehicle passes common in conventional tillage systems. Excessive traffic in forests during thinning and harvesting activities can cause compaction that will be detrimental to the next crop of trees. Grazing on wet soils in a confined area can create compacted layers.

Types of compaction

Surface crusting restricts seedling emergence and water infiltration. It is caused by the impact of raindrops on weak soil aggregates. Soils with cover crops or high-residue cover are less likely to form crusts.

Surface compaction occurs anywhere from the surface down to the normal tillage depth. The compacted layer can be loosened by normal tillage, root growth, and biological activity.

A *tillage pan* is a compacted layer, a few inches thick, beneath the normal tillage depth. It develops when the depth of tillage is the same year to year.

Deep compaction occurs beneath the level of tillage. Ground contact pressure and the total weight on the tire from the axle load significantly affect the amount of subsoil compaction. Deep compaction is difficult to eliminate and may permanently change soil structure. Prevention is important.

Inherent hardpans can form on some soil types because of variations in soil particle sizes, consolidation of particles by rainfall, and certain organo-chemical factors. These pans are aggravated by tillage and traffic.

Detecting Soil Compaction

Generally, compaction is a problem within the top 24 inches of the soil. Signs of compaction are:

- Discolored or poor plant growth.
- Excessive runoff.
- Difficulty penetrating the soil with a firm wire (survey flag) or welding rod (18” long).
- Lateral root growth with little, if any, penetration of roots into compacted layers.
- Platy, blocky, dense, or massive layers.

Quantitative methods of detecting compaction are (Jones, 1983):

- Measuring soil bulk density.
- Measuring penetration resistance with a commercially available cone penetrometer.

Bulk density measurement

Bulk density is defined as the weight of dry soil per volume. The Soil Quality Kit Guide (NRCS Soil Quality Institute, 2001) includes full directions for using the core method to measure bulk density. Table 1 provides interpretations based on soil texture. Samples can be taken from the surface 3 inches or from 3-inch increments beginning at the top of the compacted layer.

Table 1.—General relationship of soil bulk density to root growth based on soil texture (Pierce et al., 1983; R.B. Grossman, personal communication, 1996).

Soil texture	Ideal bulk densities	Bulk densities that may affect root growth	Bulk densities that restrict root growth
	----------	---------- g/cm^3 ----------	----------
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.40	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Soil cone penetrometer

A cone penetrometer allows faster and easier readings than bulk density measurements. The soil penetrometer consists of a cone attached to a rod that is pushed through the soil. The force required to push the cone through the soil divided by the area of the base of the cone is the *cone index*. The cone index is the standard measurement used for soil compaction and is read on the dial indicator of the penetrometer. Cone index is reported in units of pounds/square inch, or psi. Sometimes cone index is reported in bars. A bar is one atmospheric pressure, or about 15 psi. Roots usually cannot penetrate soil compacted to 300 psi or more. This critical value varies with soil type and moisture content of the soil when tested (Schuler et al., 2000). There are potential penetration problems at 145 psi.

The following instructions for using a penetrometer will ensure good results:

- Soil moisture will impact readings and should be near field capacity. If the user is sure there is compaction and is only trying to determine the depth of the compacted layer, then moisture content is not critical.
- Insert the soil penetrometer smoothly without jerking motions. An uneven force will result in a reading that is not representative.
- The penetrometer should be inserted at a constant rate of 1.2 inches/sec (3 cm/sec). Small variations will not affect the reading. Starting and stopping also will not affect the reading.
- Insert the penetrometer until the cone index reads 145 psi, which is an indication of potential penetration resistance. Stop and record the depth.
- Continue insertion. When the cone index is again less than 145 psi, record the depth. This is the bottom of the hardpan or compacted layer.
- If 145 psi or greater is never reached down to 18 inches, stop, record the maximum reading, and remove the penetrometer.
- Repeat the procedure at all sample locations.
- If soil sticks to the penetrometer, clean off the rod and cone with water after use.

Interpreting compaction indicators

The impact of compaction on crop productivity is determined not only by the amount of compaction, but also by the timing and duration of drought, crop type, planting date, crop variety, and other cropping system factors. Thus, indicators of soil compaction, such as bulk density and cone index readings, are not perfect indicators of the *effect* of compaction. For example, crops might show the effects of compaction only during years of high or low rainfall. No-tilled soils can have high compaction, as indicated by bulk density and cone index, but plants may grow well if biopores allow for root growth and water infiltration.

Preventing Soil Compaction

Prevention is important because all compaction is expensive to treat and deep compaction may have permanent, untreatable effects on productivity (Voorhees et al., 1989).

Controlled traffic

A controlled traffic system separates traffic zones from cropping zones within a field. Yields normally improve when traffic is restricted to controlled zones between the rows because the soil directly beneath the rows can retain a loosened structure. A controlled traffic system works well with row crops. If drilled crops are grown, a skip row is required (Reeder and Smith, 2000).

One component of controlled traffic systems is ensuring that all equipment covers the same width or multiples of the same width. A second component is minimizing the number of traffic lanes. Table 2 provides examples of traffic patterns. In the first scenario in table 2, the tractor tire width is 60” and the combine tire width is 120”. Thus, each set of six rows will have four tire paths and 44 percent of the ground will be trafficked. By increasing the tractor tire width to match the combine tire width (as in the second scenario), the number of paths and area trafficked are cut in half.

Permanent high-residue cropping systems, otherwise known as conservation tillage systems, generally work well with controlled traffic systems because previous crop rows are not tilled and thus traffic rows remain visible. Controlled traffic can be an integral part of ridge-till systems and no-till systems with permanent beds.

Mulch tillage systems (systems with tillage across the entire field) require auto-steer technology (Sandusky, 2003) using guidance from a Global Positioning System (GPS) to locate traffic lanes year after year. Auto-steer technology keeps all field operations in the same traffic lanes. Some systems are even capable of 1-inch accuracy. This technology allows controlled traffic with standard agricultural equipment and full-width tillage. Automatic steering and controlled traffic reduce compaction beneath the row, thereby increasing infiltration and reducing the hazard of erosion and the need for subsoiling. Other advantages of auto-steer technology and controlled traffic include the potential to (Sandusky, 2003):

- Extend work time into night hours.
- Plant in spring over fall subsoiling or fall fertilization strips.
- Protect drip-irrigation lines.
- Get improved yields where harvest machines must be kept on rows.

Other strategies to prevent compaction

Other strategies that minimize compaction are (Schuler et al., 2000; Reeves, 1994):

- Avoid working wet soils. Improve drainage if necessary.
- Decrease tire pressure to increase surface area, thus reducing soil compaction.
- Use radial tires in lieu of bias-ply tires to create a larger footprint and more surface area.
- Use duals or triples to replace singles. However, this measure increases the area affected by compaction.
- Maximize the number of axles under grain cars or slurry wagons to decrease the axle load per tire.
- Minimize the use of tractor-trailers or other vehicles with high inflation pressure and small footprints in agricultural fields.

Table 2.—Examples of traffic patterns for controlled traffic systems (Reeder and Smith, 2000).

Number of rows	Tractor (in)	Combine (in)	Number of paths	% Trafficked
--30” row spacing--				
6	60	120	4	44
6	120	120	2	22
8	120	120	2	17
8	60 & 120	120 & 180	6	50
12	60 & 120	120 (6-row)	4	22
16	60 & 120	120 & 180 (8-row)	8	33
24	60 & 120	120& 180 (12-row)	12	33
--36” row spacing--				
6	72	144	4	37
8	72	144	4	28
12	72	144	4	18

- Frequently empty combines and grain carts to minimize field traffic while also minimizing high axle loads that can permanently compact the subsoil.
- Select a tractor with four-wheel drive, front-wheel drive, or a rubber track system, which spreads the load over a larger surface area. However, the extra traction makes it possible to drive on wetter soils, giving the operator the potential to create significant deep compaction.
- Adjust ballast weights for each field operation.
- Reduce the number of trips by using high-residue management systems (conservation tillage).
- Increase the content of organic matter by reducing tillage and using high biomass crop rotations with cover crops. The organic matter improves aggregate stability, which reduces soil compaction.
- Avoid tillage, such as moldboard plowing and disking, which breaks down aggregates and destroys structure.
- Use cover crops and crop residue to conserve moisture. Wetter soils have lower soil strength and thus are less restrictive to root growth.

Alleviating Soil Compaction

Shallow soil compaction caused by natural processes or field operations can usually be alleviated with chisel plowing at shallow depths. However, repeated trafficking by heavy vehicle loads causes deep compaction, which requires more drastic alleviation measures, such as subsoiling. In some regions, combinations of traffic, tillage pans, a low content of organic matter, and natural conditions or processes can lead to deep compacted zones. Subsoiling is recommended if yields are limited by compaction. Subsoiling usually refers to tillage at a depth of at least 35 cm (14 in). Inserting any narrow tool to a depth of less than 35 cm is considered chisel plowing (Raper, 2003).

Although subsoiling or chiseling can alleviate compaction immediately, research shows that a second pass by a single vehicle may nullify the benefits of subsoiling or chiseling (Raper, 2003; Schuler et al., 2000). Before subsoiling is performed, it is important to prevent the recurrence of compaction and prolong the benefits of subsoiling through a controlled traffic system, conservation tillage, crop rotations, cover crops, and in-row tilling (subsoiling or chiseling under the row). Strip tillage is one method of preserving the benefits of subsoiling. It is essentially in-row subsoiling with a no-till planter equipped with row cleaners. The operation consists of pulling a shank directly beneath each row and planting directly behind the in-row subsoiler, thus preventing any traffic compaction. Alternatively, subsoiling and planting can be performed as separate operations.

Subsoiler shank design is an important part of a tillage system. In the 1950s, subsoiler shanks tended to be straight and projected slightly forward. Parabolic shanks soon became popular because they required less draft force. However, when curved shanks are used at deeper or shallower depths than designed, draft forces can increase. Curved subsoiler shanks tend to disrupt the soil in a symmetric manner, leaving soil on either side of the subsoiler shank as it moves forward and causing surface soil disturbance and burial of crop residue (Raper, 2003). The bentleg subsoiler was developed to disrupt the soil in an asymmetric manner, shattering the pan but leaving the surface almost undisturbed. This shank is bent to one side at 45° with the leading edge turned by 25°. For this reason, many farmers interested in high-residue management use this form of tillage as a method of alleviating compaction while maintaining high amounts of residue on the soil surface (Raper, 2003).

Subsoiling and chiseling cost time and energy. They should be performed only when needed. The benefits of chiseling and subsoiling are generally not long lasting. To avoid wasting an expensive trip across the field, consider the following points (Schuler et al., 2000; Raper, 2003):

- Determine the depth and extent of the compaction problem across the field by taking penetrometer readings correctly. Taking readings in dry soil may give the false impression of a compaction problem.
- Use the appropriate equipment (select a proper subsoiler shank for the desired amount of soil mixing and residue cover) and subsoil when the soil is dry enough for the equipment to properly fracture the pan but moist enough for the equipment to pull the shank. Subsoiling when the soil is too dry will disturb more surface soil, and subsoiling when it is too wet will not fracture the compacted layer, thus wasting the trip. A good compromise is near the permanent wilting point.
- Subsoil or chisel to the depth of the compacted layer. Examine the soil profile to determine the depth of the compacted layer and plan to subsoil or chisel 1 inch below the zone. If several observations are made with a penetrometer or by measurement of bulk density, site-specific tillage can focus on certain portions of the field, e.g., eroded areas or a specific soil type.
- Select the proper spacing, such as in-row versus complete field disruption. Complete field disruption spacing should be 60 to 80 percent greater than the operation depth.
- Timing is important. Subsoiling after fall harvest often works well because more time is available and the compaction caused by harvesting operations can be eliminated. Fall subsoiling also allows better infiltration in winter, when rainfall is more plentiful in many climatic regions. In some regions, such as the Southeast Coastal Plain, however, spring subsoiling is preferable because compacted layers will normally reconsolidate over the winter. Many strip-till planters subsoil and plant in one operation.
- Most importantly, have a controlled traffic plan in place to prevent the recurrence of compaction after subsoiling. Again, in some regions, such as the Southeast Coastal Plain, compaction will naturally recur and may require annual subsoiling.
- In permanent stands, such as grazing lands, orchards, and forests, subsoiling may be needed during planting. As a last resort, pastures can be renovated with bentleg subsoilers. Damage to actively growing roots can be reduced by subsoiling during winter or dormancy. Care should also be taken in forests to subsoil only where needed and to the depth of compaction. Rotational grazing and proper planning of watering facilities and permanent lanes may reduce compaction on grazing lands.

Summary

Soil compaction reduces the ability of the soil to function (to regulate infiltration, provide a deep rooting environment, store available water, etc.) and thus reduces crop yields. To locate the depth and position of the compacted layer in a field, such tools as a penetrometer must be used properly. In particular, penetrability should be measured when soil moisture is at field capacity. Preventing compaction avoids the cost of yield losses and the cost of alleviating compaction. Avoid performing field operations when the soil is wet. High-residue management systems, crop rotations, cover crops, and other conservation practices that increase the content of organic matter lessen the effects of compaction. Controlled traffic systems using row spacing or permanent rows lessen compaction in crop-growing areas. Automatic steering helps to reduce traffic, and site-specific tillage helps to economize subsoiling and chiseling. Subsoiling can alleviate soil compaction in some situations. Important issues to be considered before subsoiling include selection of shanks on the basis of the desired amount of soil disruption and surface residue, timing of tillage, depth of tillage, soil moisture, how to keep soil compaction from recurring, and how subsoiling fits within the entire management system.

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Urban Soil Compaction

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United States
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Urban Technical
Note No. 2

March, 2000

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

Introduction

Soil is a crucial component of rural and urban environments, and in both places land management is the key to soil quality. This series of technical notes examines the urban activities that cause soil degradation, and the management practices that protect the functions urban societies demand from soil. This technical note will focus on urban soil compaction.

Healthy soil includes not only the physical particles making up the soil, but also adequate pore space between the particles for the movement and storage of air and water. This is necessary for plant growth, and for a favorable environment for soil organisms to live. Compaction occurs when soil particles are pressed together, thereby reducing the amount of pore space. Examples of compaction in urban settings are traffic pans resulting from repeated trips across lots with trucks and machinery and excessive trampling by people, bicycles, etc. Soils are particularly susceptible to compaction if these activities occur when the soil is wet. The primary impacts of soil compaction are changes in the soil's physical properties (Schuler et al., 2000):

- Strength increases with compaction. Soil strength is the ability to resist penetration by an applied force and is desirable under roads and buildings.
- Bulk density increases with compaction. Bulk density is the weight of soil per volume. It is commonly reported as grams of oven dry soil per cubic centimeter.
- Porosity decreases with compaction. Porosity is the ratio of the volume of pores to the bulk volume of the soil.
- With compaction, the distribution of pores shifts toward smaller pore sizes. Pore size distribution is the array of pores, from very small to large, making up the soil's overall porosity.

  These changes influence the movement of air and water in the soil, ease of root growth, and the biological diversity and activity in the soil. For proper plant growth, void space must be available for air and water movement. Typically a medium textured soil has about 50 % solids and 50 % pore or void space. Compaction increases bulk density and reduces the number of large pores in the soil. (Schuler et al., 2000).

Compared to agricultural land, compaction in urban areas can be more permanent because of the difficulty in bringing in equipment to loosen the soil, due to the presence of utilities and the prevalence of perennial vegetation.

Causes of Soil Compaction in Urban Areas

Causes of compaction in urban areas are generally of two types:

1. Deliberate compaction during construction activities.
   - Compacting of entire areas in order to increase strength for paving and housing foundations without consideration for leaving non-constructed areas (landscaping areas and lawns) in a more natural state.
   - Use of heavy equipment for reshaping and sloping banks along roads and hillsides.
   - Grading lots and placing sod on hard soil or soil denuded of topsoil.
2. Unintentional compaction of the soil after construction is completed.
   - Allowing uncontrolled traffic (both vehicles and foot traffic)
   - Allowing vehicles on lawn areas around homes or businesses, especially when the soil is wet.

Impacts of Soil Compaction

For individual homeowners and businesses, soil compaction makes it difficult to establish and maintain lawns and landscaping due to:

- Restricted root growth.
- Reduced plant uptake of water and nutrients.
- Reduced available water capacity.
- Reduced soil biological activity.

For communities, excessive levels of soil compaction lead to environmental problems due to:

- Increased storm water runoff as a result of low infiltration rates of compacted soils.
- Increased flooding due to runoff.
- Increased erosion from construction sites.
- Increased water pollution potential, especially nitrates and phosphorus, in local rivers, streams, lakes, and ponds.

Detection of Soil Compaction

Generally compaction is a problem within the top 12 inches of the soil surface. Detection of compaction can be by:

- Observing discolored or poor plant growth.
- Probing with a firm wire (survey flag) or welding rod (18” in length) into the compacted area.
- Digging down to plant roots and finding lateral root growth with little if any penetration of compacted layers.
- Taking bulk density samples (Table 2).
- Using commercially available cone penetrometers that indicate force required to penetrate the soil in terms of pressure (pounds per square inch). Roots are unable to penetrate soil compacted to 300 psi or more. This varies with soil type and moisture content of the soil when tested (Schuler et al., 2000).

Table 2. General relationship of soil bulk density to root growth based on soil texture (NRCS Soil Quality Institute, 1999).

Soil texture	Ideal bulk densities (g/cm^3)	Bulk densities that may affect root growth (g/cm^3)	Bulk densities that restrict root growth (g/ cm^3)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Prevention of Urban Soil Compaction

Compaction problems during urban development can be avoided by proper planning. Working with local governments may help prevent total compaction in development areas. Divide large areas into sections to be consciously compacted for roads and foundations, and sections for lawns and landscaping. Disturb only areas needed for construction. Also, only manipulate soil when dry (less than field capacity).

Soil that will support lawns can be protected by subsoiling, and by stockpiling topsoil that will be returned to the site after construction. These two measures can restore water flow functions to near natural conditions. Establishing sod or seeding a lawn is much more successful on a loose soil with topsoil than on a compacted soil without adequate topsoil.

In parks and recreation areas, specific areas can be designated for heavy traffic (paved areas or trails). The remaining vegetated areas will benefit from less compaction because of controlled traffic. During special events, lay down metal or wood mats for better distribution of weight for vehicular traffic or involving high volume of people in concentrated areas. Mesh elements have been used for sporting fields (Beard and Sifers, 1990).

These measures may take a little more time initially, but will pay dividends in the long run. The benefits of planning and wise urban development are:

- Satisfied buyers of homes with soils that function well
- Soils that have good infiltration rates (less frequent irrigation)
- Reduced run-off (less chemical and fertilizer loss to water bodies)
- Lower mortality rates of perennial vegetation (lawns and trees)
- Better plant growth and quality for shrubs, flowers, trees, gardens, and lawns.

Management Practices for Compacted Urban Soil

Although prevention is more effective, the detrimental effects of compaction can be lessened after soils are compacted. Management practices to reduce the effects of urban compaction are:

- Subsoiling to alleviate compacted soils. Always have underground utilities and other underground plumbing or wires located and marked.
- Partial or total soil replacement. Replace dense soil with loose soil or haul in topsoil.
- Increasing organic matter. In gardens, go to residue management/no-till systems and/or cover crops.
- Use of mulch, compost, manures, and amendments.
- Annual aeration of turf grasses to improve infiltration.
- Aeration of soil using a metal tube and air compressor. This is usually used around tree roots. (Personal communication with John Lesenger. Used at the Alabama Shakespeare Festival.)
- Irrigation management. Frequent, low rates of water are necessary because compacted soil holds little water. Over-irrigation wastes water and may lead to environmental pollution from lawn chemicals, nutrients, and sediment.
- Cutting grass at higher heights, which reduces evapotranspiration losses (see local turf grass recommendations–Extension Service).

Summary

Compaction changes important physical properties of the soil. Soils with higher strength, higher bulk densities, and decreased pore space have lower infiltration rates, reduced water holding capacity, and more runoff. This degradation of soil quality results in the need for more irrigation, less healthy plants, higher plant mortality rates, and higher pollution potential from storm water runoff. Urban soil compaction is more complicated than in an agricultural setting. It is less convenient to alleviate urban compaction because soil cannot be disturbed easily around perennial vegetation, underground utilities, buildings, drive ways, etc. Planning will prevent many problems with compaction in developments and subdivisions. Preventive practices, including limiting the extent of disturbed areas, manipulating soil only when dry and restricting traffic, are more effective and less expensive than practices to alleviate compaction after it occurs. Preventing and managing compaction results in soils that function well and that benefit all of society.

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Managing COMPACTED and LAYERED Soils

Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

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Managing Compacted and Layered Soils

Soils consisting of layers varying in compactness or texture often present problems of irrigation, disease and root penetration. These problems may be caused during land grading by placing soils over those of different texture; by compaction from land grading or farm equipment; by naturally-occurring soil layers of varying thickness and depth; or by fine-textured surface clays. Compacted or layered soils often result in wet or dry zones above or beneath the soil in question. Clay soils on the surface present special water infiltration problems.

Symptoms

Indications that a soil is compacted or layered are: decreased vigor in plants, lack of water and root penetration, root and crown rot, plant nutrient deficiencies induced by shallow or sparse root systems, and poor crop production. These symptoms result because compacted or layered soils cause physical barriers to roots, promote wet zones that decrease the necessary flow of air to the roots, and cause the spread of disease organisms.

CONTROLLING COMPACTED SOILS

Man-caused soil compaction results when machinery breaks soil structure and increases its bulk density. Under these conditions the soil aggregates disintegrate, causing collapse of the large pore spaces essential for rapid water percolation and good soil aeration. This can be extensive enough to cause irrigation water to remain on the soil surface for several days after irrigation. Surface clay soils also have slow infiltration rates, and often cause runoff while the sub-soils remain dry.

In recent years, growers have been making deeper cuts and fills during land grading. These operations often bury the original upper soil surfaces and create compacted layers. This results in slow water penetration, wet soil layers, or perched water tables (temporary water tables).

Prevention

Prevention is important, because remedies for compacted soils are costly and results are often only fair at best. The most obvious way to prevent compaction is to till as seldom as possible, and only when soil moisture is relatively low. Till only as necessary for weed control and seedbed preparation. To minimize compacted areas, designate special areas for traffic. Natural or planted sod-cover crops often prevent surface crusting and aid water penetration.

Selection of irrigation systems having minimum land grading requirements can help avert problems in many layered soils. In clay soils, the application rate or frequency of irrigation should be planned to match the irrigation application rate to the basic intake rate of the soil.

Permanent sod

Many long-term experiments have shown that it is possible to increase the size of water-conducting pores in the soil by planting permanent cover crops. Deep-rooted grasses that require no tillage are best, and may increase water intake rates. Extra fertilizer and water often are needed to compensate for the extra vegetation.

Mechanical methods

It is often difficult to reach compacted surface soils that have been buried by land grading. Where the fill is to be 18 inches or deeper, subsoiling before filling has been beneficial. It may be necessary to subsoil after land grading wherever fills will be deeper than 1 foot.

In some areas of deep fills, it is necessary to dig holes for trees or vines several months before planting. Use a backhoe or other excavating equipment. Make the holes about 6 feet square and deep enough to penetrate any layered soils. Cave in the sides of the pit before filling. Do not re-fill the hole with the compacted soil that has been removed—use topsoil instead.

If soil layers are dry enough to shatter, 5-foot subsoilers or rippers may be used. It usually is best to subsoil on 4- to 6-foot centers in two directions. Plan to subsoil before planting: subsoiling in existing crops has been less successful because soils are seldom dry enough to shatter.

It is essential to irrigate both backhoe pits and deeply subsoiled land to sufficiently settle the soil before planting. It is difficult to predict how much settling is needed, but some coarse soils require two irrigations for settling.

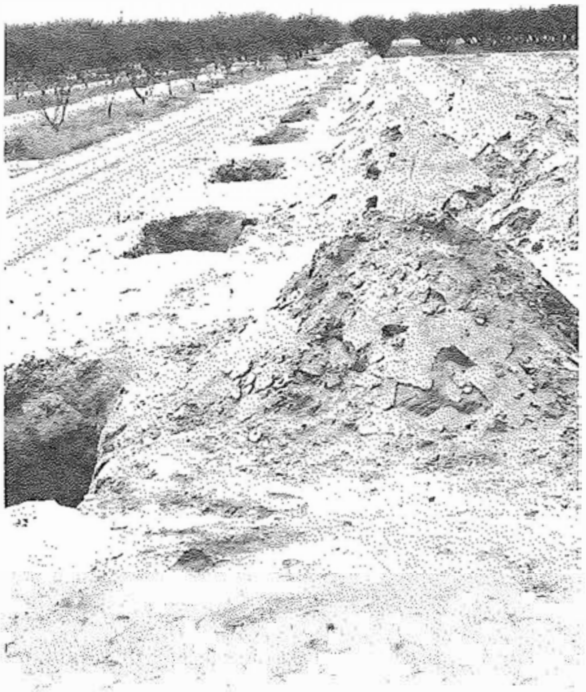

Fig. 1. Holes excavated with backhoe.

Fig. 2. One-year-old almond trees in same field. Left: treated with backhoe before planting. Right: untreated.

CONTROLLING LAYERED SOILS

Many irrigated soils formed from alluvial fills are made up of discontinuous layers (lenses) of various textures—sand, silt, or clay. The sharp boundaries between these layers are called interfaces. Perched water is often a problem in these soils. Saturated conditions can develop when a loamy soil is underlain by sand, and can persist a week or more after irrigation. Such soils have been found to contain two or three distinct water tables in a crop's normal root zone.

Mechanical methods

If the layers are within reach of such equipment, you can successfully use either a mold-board plow or a disc plow. You can also use a backhoe to dig pits.

The slip-plow is a recent development. This plow brings the layer just above the plow point to the surface, and the topsoil tends to fall back into the furrow. The goal is to eliminate soil interfaces by mixing layers of varying textures. However, there is no tillage tool available that creates a completely uniform soil throughout the root zone.

Soil ripping without mixing has not been very successful with stratified clay soils, because the lenses often reseal in a short time.

Water management

Water management is the key to working with layered soils. Deep and sloping layers may produce a basin effect. Install tile to drain the low portion of the basin. This requires soil augering, mapping of lenses, and careful installation of tile.

If soil layers are very deep, apply water carefully. A tensiometer is helpful in predicting depth of moisture penetration and thus avoiding excessive water accumulation. If a tensiometer indicates excessive water on lenses, irrigation should be adjusted accordingly.

In clay soils, water management is the only practical means of controlling problems of excess moisture. Intake rate of the soil should be determined, and an irrigation system specifically designed to apply water at a rate less than the soil intake rate. Sprinklers or drip systems often are the only practical engineering approach to problem clay soils.

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Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the United States Department of Agriculture, James B, Kendrick, Jr., Director, Cooperative Extension, University of California.

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SOIL MANAGEMENT ON HARDPANS AND CLAYPANS

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Hardpans and claypans occur naturally in very old soils that have been modified greatly by weathering. In such soil, fine particles carried downward by percolating water become dense clay subsoil (claypan) and may be cemented (hardpan) by lime, silica, or iron. These layers are an abrupt change from the medium-textured surface soils. Pan layers may vary in thickness from a few inches to several feet and are practically impermeable to roots and water.

WHERE PANS OCCUR

The hardpans occupy the benchlands along the east side of the Central Valley and the mesa land in the southwest corner of California. The claypans are distributed widely in the state, with a concentration along the west side of the Sacramento Valley.

HOW TO CORRECT PANS MECHANICALLY

To eliminate or modify pan conditions with tillage equipment, tools must break completely through the impermeable layers. Often this is impossible in hardpans because the layers are too thick. Ripping becomes difficult where pan thickness exceeds 1 foot.

However, deep ripping has been successful in large areas of the San Joaquin Valley. One-way ripping at 5-foot intervals, 6 feet deep, costs $40 to $75 per acre. When solid chunks are brought to the surface they are hauled away or crushed with a heavy track layer, sheepsfoot roller, or special crushing equipment.

After being ripped, claypans run back together (reseal) when wetted. Therefore, displacement by deep plowing or working with specialized equipment is necessary. A slip plow has been developed for this purpose. Slip plowing to a depth of 5 to 6 feet costs $25 to $50 per acre. Mold-board plowing to a 5-foot depth can cost as much as $50 to $100 per acre.

Because of the high investment required for mechanical control, evaluate the situation carefully before investing in mechanical methods.

HOW TO MANAGE PAN SOILS

Water Management

Crop production on soils over hardpans and claypans is limited chiefly by waterlogging in the root zone rather than by the shallow soil depth. So, living with hardpan and claypan soils is primarily a matter of skillful water management.

Irrigation - The first step is to provide conditions for optimum control of water. Because of the limited water reservoir in the soil, irrigations must be light and frequent. With sprinkler irrigation, controlling the amount and distribution of water applied is simple and fairly accurate. Also, sprinkler irrigation requires a minimum of land grading. This means it is possible to avoid deep cuts that leave areas of very shallow soil.

(Over)

ONE-SHEET ANSWERS

FARM ADVISOR HOME ADVISOR 4-H WORK
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Co-operative Extension work in Agriculture and Home Economics, College of Agriculture, University of California, and United States Department of Agriculture co-operating. Distributed in furtherance of the Acts of Congress of May 8, and June 30, 1914. George B. Alcorn, Director, California Agricultural Extension Servico.

JUNE 1967--3½M Rev.

For surface irrigation, the grade and length of run should be designed to avoid excessive water application. Also, surface drainage for rain and excess irrigation water must be provided.

The initial cost of sprinkler systems is usually greater than for surface systems. In addition, operating costs tend to be higher.

Drainage - One way to remove excess water from soil above the pan is tile drainage. Close spacing of tile is required to provide effective drainage above an impervious layer. Vertical mulching is a possibility for opening drainage channels through pans.

In home gardens, open or gravel-filled post- or utility-pole holes have been successful. Blasting hardpan before planting trees is not helpful unless it establishes a permanent drainage path. The problem is worsened when tree roots grow into an impervious basin, because they drown when the basin fills with water.

Management Aids - Shallow observation wells aid in water management by indicating a build-up of free water over the pan. However, soils can be harmfully wet without showing in an observation well.

Tensiometers are valuable, especially in managing permanent crops. They are sensitive in the high soil-water range, the critical range in managing crops over pans.

Saline and Alkaline Soils - Removing salts from soils over pans presents an especially difficult problem because leaching salts requires drainage. An alkaline soil also requires a soil amendment to free sodium so it can be leached. Although soil amendments will not solve the drainage problem, any material or practice is beneficial if it improves the physical condition of the farmable soil above the pan.

Planting Winter Cover Crops

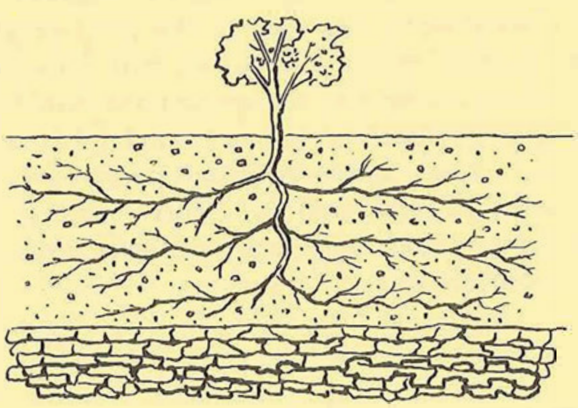
Winter cover crops remove excess moisture following the rainy season. This will permit earlier tillage and reduce the danger of excess moisture in the root zone. Roots of a permanent crop can be damaged if they become active in the spring while the soil is still saturated. Possible additional benefits are improvement of water penetration and addition of nitrogen by legumes.

Choosing Adapted Crops

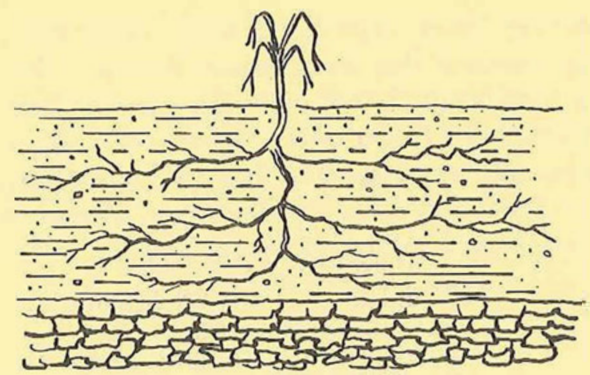
Choosing crops adapted to the soil situation is essential because pan conditions tend to increase cost per unit due to lower yields and higher costs per acre. Under excellent management it is possible to make a profit with citrus and vineyard on 3 feet of soil, deciduous fruit and nuts on 4 feet of soil, and field and vegetable crops on 2 to 4 feet of soil.

Patent Medicines

Soil amendments, bacterial cultures, or special secret or patented compounds will not dissolve the pan or provide the needed drainage through it.



Proper water management will provide drainage over pan layers.

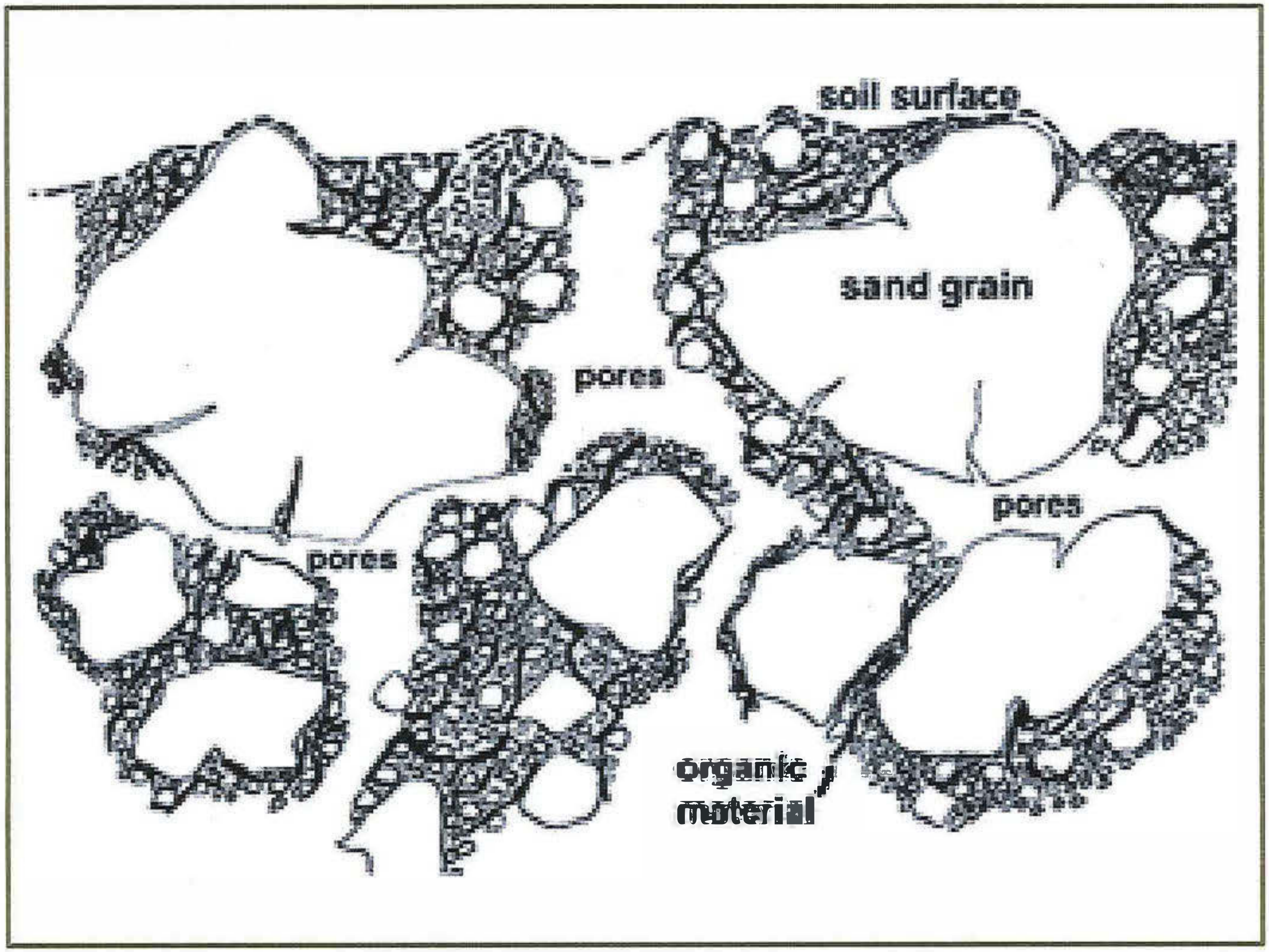


Saturated soil over pan layer drowns plant roots.

SOIL STRUCTURE

- *Definition:* The grouping or arrangement of individual particles (Soil Architecture!)
- Individual particles make up individual structural units called *aggregates* or *peds*
- Units hold together but separate along planes of weakness

SOIL STRUCTURE UP CLOSE



SOIL STRUCTURE

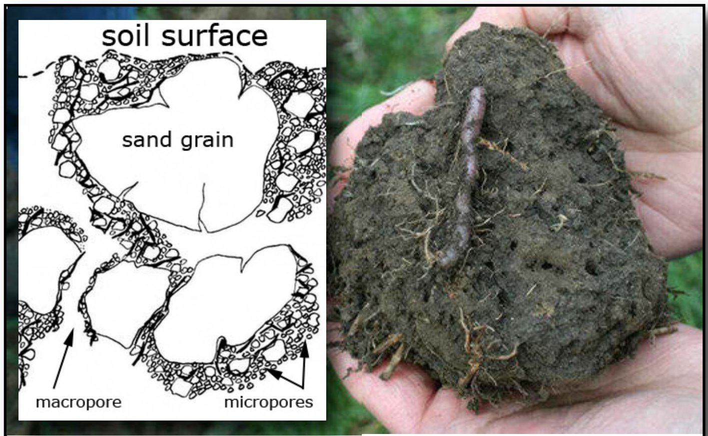
- Provides much of the soil's porosity (micro and macro)
- Allows soil to transmit water and air rapidly
- Allows for better root development
- Nutrients and microorganisms often concentrated along structural boundaries ("cracks")

Soil Quality Indicators

Soil Structure & Macropores

Sand, silt and clay particles are the primary mineral building blocks of soil. Soil structure is the combination or arrangement of primary soil particles into aggregates. Using aggregate size, shape and distinctness as the basis for classes, types and grades, respectively, soil structure describes the manner in which soil particles are aggregated. Soil structure affects water and air movement through soil, greatly influencing soil's ability to sustain life and perform other vital soil functions.

Soil pores exist between and within aggregates and are occupied by water and air. Macropores are large soil pores, usually between aggregates, that are generally greater than 0.08 mm in diameter. Macropores drain freely by gravity and allow easy movement of water and air. They provide habitat for soil organisms and plant roots can grow into them. With diameters less than 0.08 mm, micropores are small soil pores usually found within structural aggregates. Suction is required to remove water from micropores.



High residue and cover crops contribute organic matter to soil, while no-till management helps protect organic matter and allow accumulation. Organic matter provides food for earthworms and other soil biota. All play a role in developing or protecting soil structure and macropores to help soil function at a high level. Inset shows relationship of macro- and micropores to soil aggregates.

Factors Affecting

Inherent - Aggregation of soil particles to develop soil structure is affected by clay particles and shrinking and swelling of clay masses. Clay particles carry a negative charge on their surface that can cause them to repel each other, but that attracts and adsorbs cations present in the soil. Stacks of clay particles can form when their negative surface charge is neutralized by tightly adsorbed polyvalent cations, such as Ca^{2+} and Al^{3+}. Further, Ca^{2+}, Fe^{2+} and Al^{3+} flocculate (clump together) stacks of clay particles, and with humus (negatively charged, highly decomposed, stable organic matter), bind to form small, stable soil aggregates.

In contrast, sodium ions (Na^{+}) are associated with soil dispersion. They are monovalent, relatively large and they are the prominent cation adsorbed to clay particles in some soils in arid and semi-arid regions. Because of their relatively weak charge and large size, sodium ions are ineffective at promoting clay stacking and aggregate formation. Dispersed clay causes the soil to be almost structureless, impervious to water and air, and undesirable for plant growth.

When soil dries out and water is removed, clay stacks move closer together, the soil shrinks in volume, and cracks develop in weakly bonded areas. As soil wetting and drying cycles are repeated with rainfall (or irrigation) and removal by plants, an extensive network of cracks develops and soil aggregates become more defined. Freezing and thawing cycles have a similar shrinking and swelling effect since freezing of soil water to form ice crystals withdraws water from clay structures. Shrinking and swelling breaks apart and compresses soil particles into defined structural aggregates. Certain types of clay particles have shrink-swell properties of their own.

Dynamic - While chemical and physical factors play a prominent role in small aggregate formation in clay soils, biological processes are important for development of large aggregates and macropores, and they are the primary factor for aggregation of sandy soils. Important biological processes include: earthworms burrowing in soil and ingesting soil particles to form casts, development of sticky networks of roots and fungal hyphae, and production of organic glues by fungi and bacteria. Plant roots also contribute to aggregation and development of macropores as they push through the soil while they are growing or by leaving channels when they die. Mycorrhizae, or thread-like fungi, secrete a gooey protein called glomalin that is an effective cementing agent for providing short-term stability of large aggregates. Organic glues are produced by fungi and bacteria as they decompose plant residues. Water-resistant substances produced by roots and microorganisms provide long-term stability of months to a few years of soil aggregates.

Organic matter is the major contributing factor for aggregate formation that can be directly affected by human management. It provides energy for microbial processes that release organic products. The organic products chemically interact with soil particles and iron and aluminum oxides to bind soil particles together into aggregates. Tillage can have favorable and unfavorable effects on aggregation and soil structure. Short-term, tillage breaks clods apart, incorporates organic matter into the soil, and loosens it to increase porosity; however, long-term, tillage increases decomposition of organic matter, prevents accumulation, and reduces its aggregating effects. Tillage of wet soil generally destroys surface soil structure.

Relationship to Soil Function

Important soil functions related to soil structure are: sustaining biological productivity, regulating and partitioning water and solute flow, and cycling and storing nutrients. Soil structure and macropores are vital to each of these functions based on their influence on water and air exchange, plant root exploration and habitat for soil organisms. Granular structure is typically associated with surface soils, particularly those with high organic matter. Granular structure is characterized by loosely packed, crumbly soil aggregates and an interconnected network of macropores that allow rapid infiltration and promote biological productivity. Structure and pore space of subsurface layers affects drainage, aeration, and root penetration. Platy structure is often indicative of compaction.

Problems with Poor Function

Clay soils with poor structure and reduced infiltration may experience runoff, erosion, and surface crusting. On-site impacts include erosion-induced nutrient and soil loss and poor germination and seedling emergence due to crusted soil. Off-site impacts include reduced quality of receiving waters due to turbidity, sedimentation and nutrient enrichment. Water entry into a sandy soil can be rapid, but subsurface drainage of sandy soils with poor structure can also be rapid such that the soil cannot hold water needed for plant growth or biological habitat.

Practices that lead to poor soil structure include:

- Disturbance that exposes soil to the adverse effects of higher than normal soil drying, raindrop and rill erosion, and wind erosion
- Conventional tillage and soil disturbance that accelerates organic matter decomposition
- Residue harvest, burning or other removal methods that prevent accumulation of soil organic matter
- Overgrazing that weakens range and forage plants and leads to declining root systems, poor growth and bare soil
- Equipment or livestock traffic on wet soils
- Production and irrigation methods that lead to salt or sodium accumulation in surface soils

Crumbly structure of surface soil is associated with adequate organic matter content.

Improving Soil Structure & Macropores

Practices that provide soil cover, protect or result in accumulation of organic matter, maintain healthy plants, and avoid compaction improve soil structure and increase macropores.

Practices resulting in improved soil structure and greater occurrence of macropores favorable to soil function include:

- Cover Crop
- Conservation Crop Rotation
- Irrigation Water Management
- Prescribed Grazing
- Residue and Tillage Management
- Salinity and Sodic Soil Management

Evaluating Soil Structure & Macropores

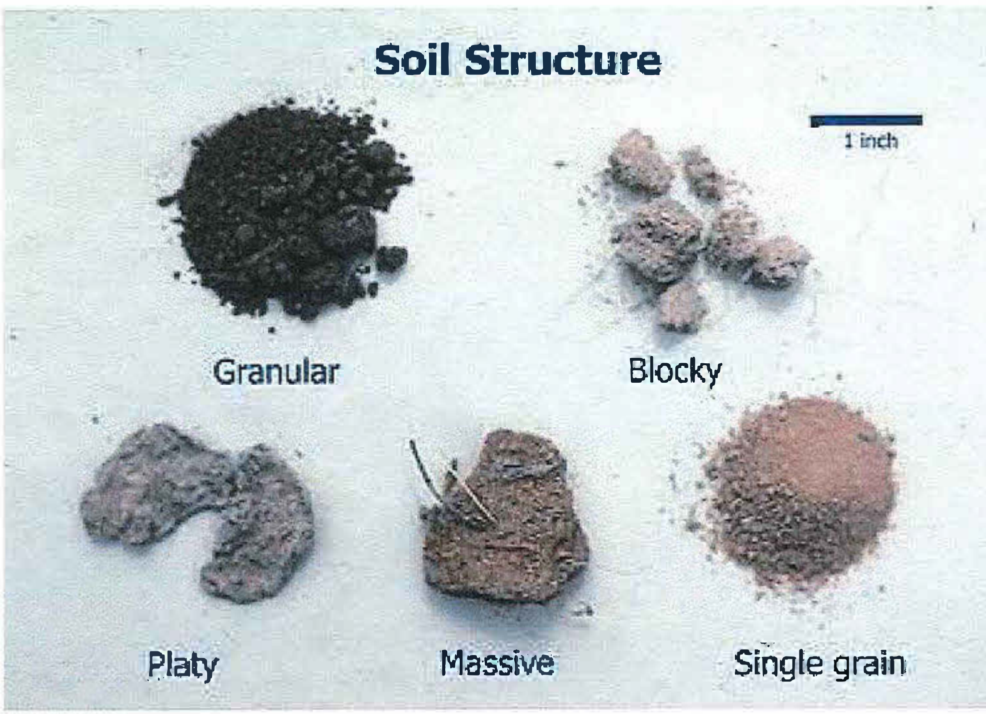
Schoeneberger, PJ, Wysocki, DA, Benham, EC, and Broderson, WD (editors). 2002. Field Book for Describing and Sampling Soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

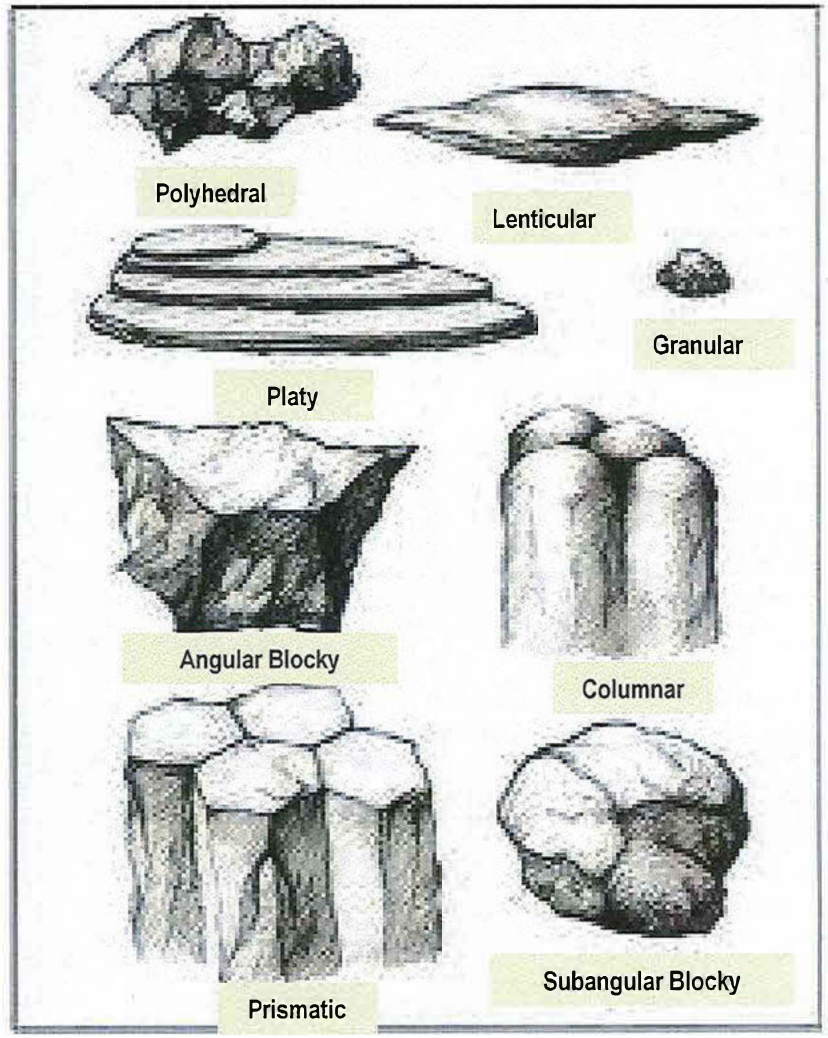
Soil structure is described in the Soil Quality Test Kit Guide, Section I, Chapter 11, pp. 23 – 27. See Section II, Chapter 10, p. 76 for interpretation of observations.

Reference: Brady, NC and Weil, RR. 2002. The Nature and Properties of Soils, 13th Edition. Prentice Hall, NJ.

Time needed: 60 minutes

TYPES OF SOIL STRUCTURE





TYPES OF SOIL STRUCTURE

<u>Granular or crumb</u> (spheroidal)

- Soil exists in small rounded aggregates
- Crumb more porous than granular
- Characteristic of many surface soils
  - Form where high OM or mechanical disturbance
- More common under grassland than forest soils
- Good for root development

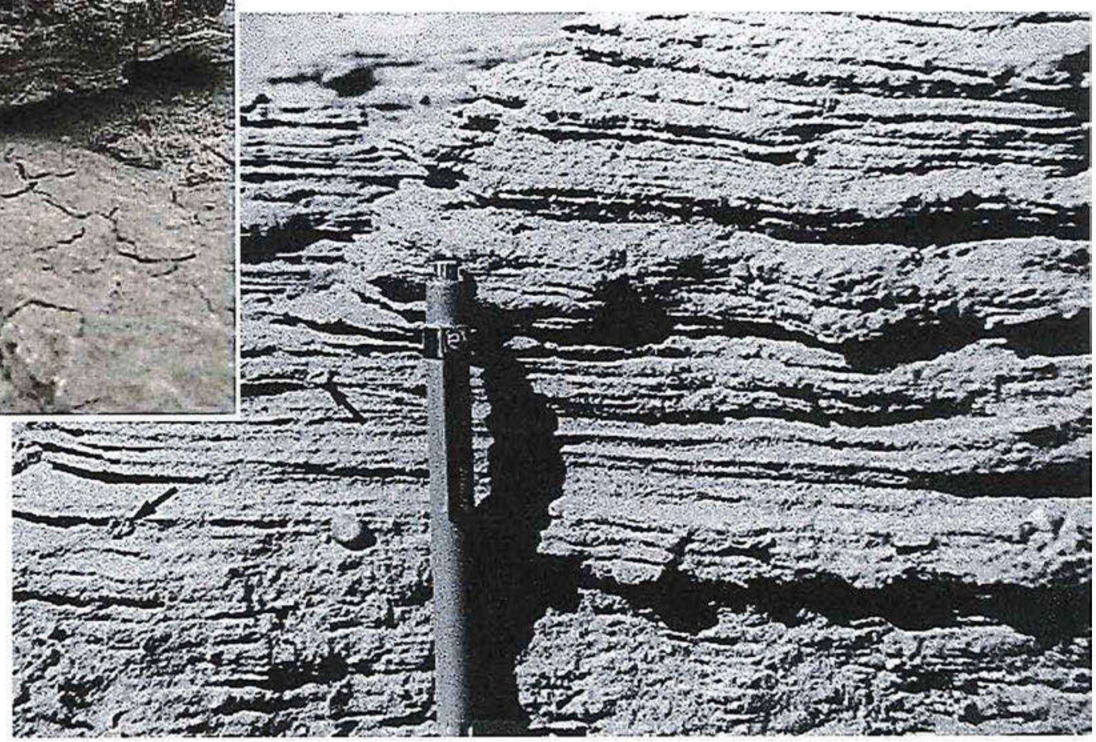
GRANULAR STRUCTURE

TYPES OF SOIL STRUCTURE

<u>Plate-like</u>

- Soil aggregates in thin horizontal plates
- Found in surface or subsurface layers
- More likely under forest soils (and in desert)
- Can slow water and air movement
  - “crusting” similar to plate-like structure

PLATE-LIKE STRUCTURE

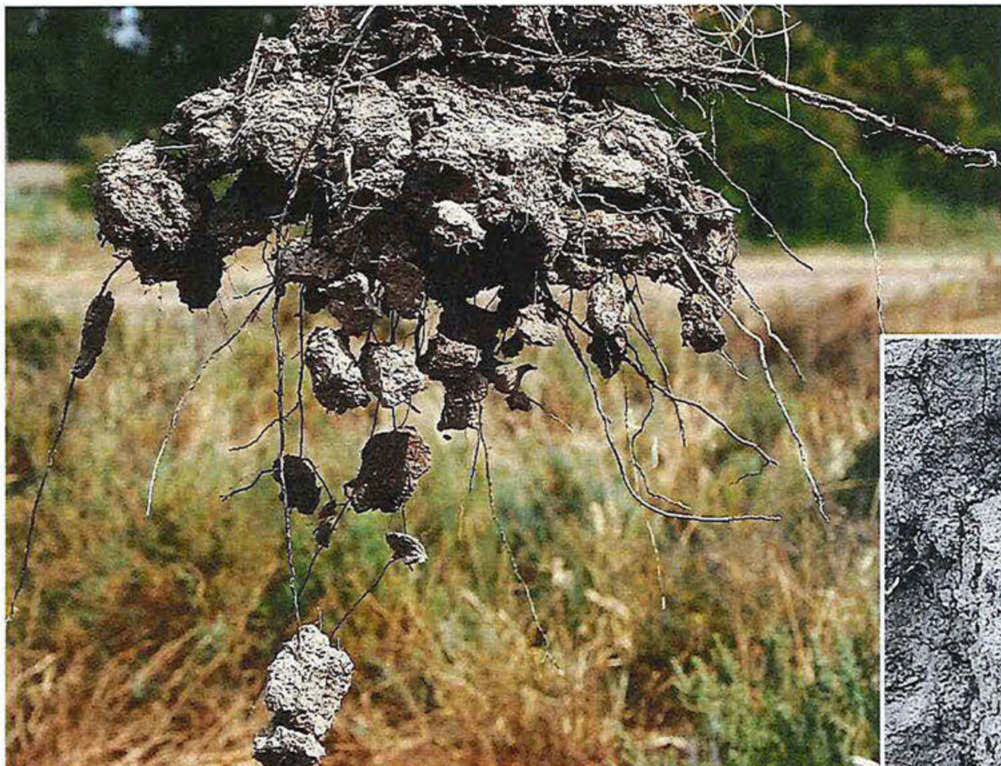


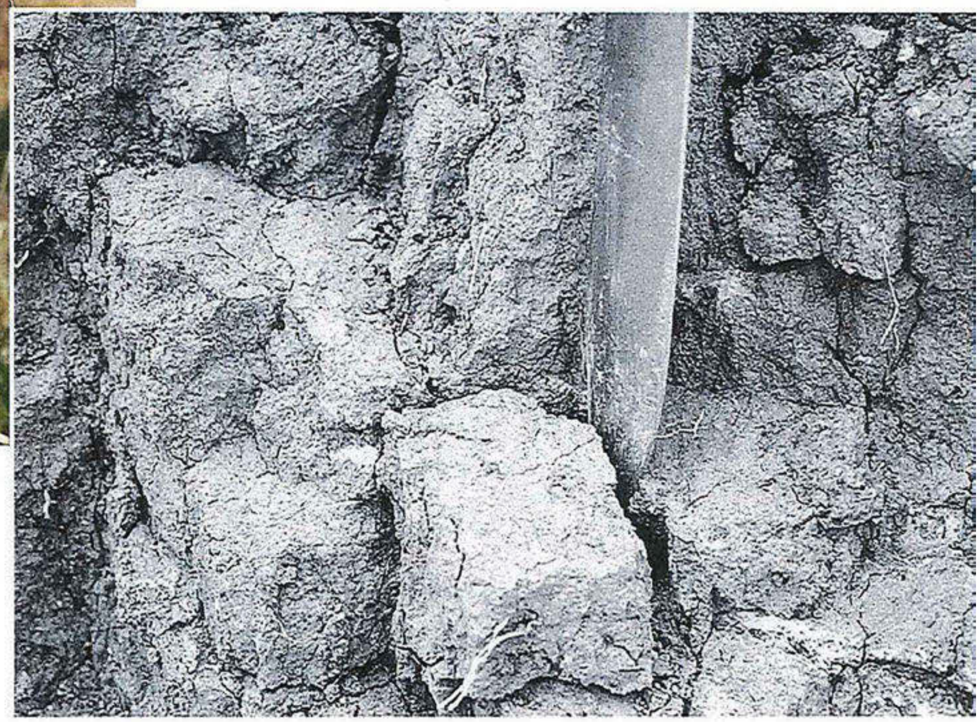
TYPES OF SOIL STRUCTURE

<u>Block-like</u>

- Soil aggregates into 6 sided blocks of some size
- Common in subsurface horizons (particularly Bt)
- Two types of block-like structure:
  - Blocky: block faces are rectangular in shape
  - Subangular blocky: block faces irregular in shape

BLOCKY STRUCTURE





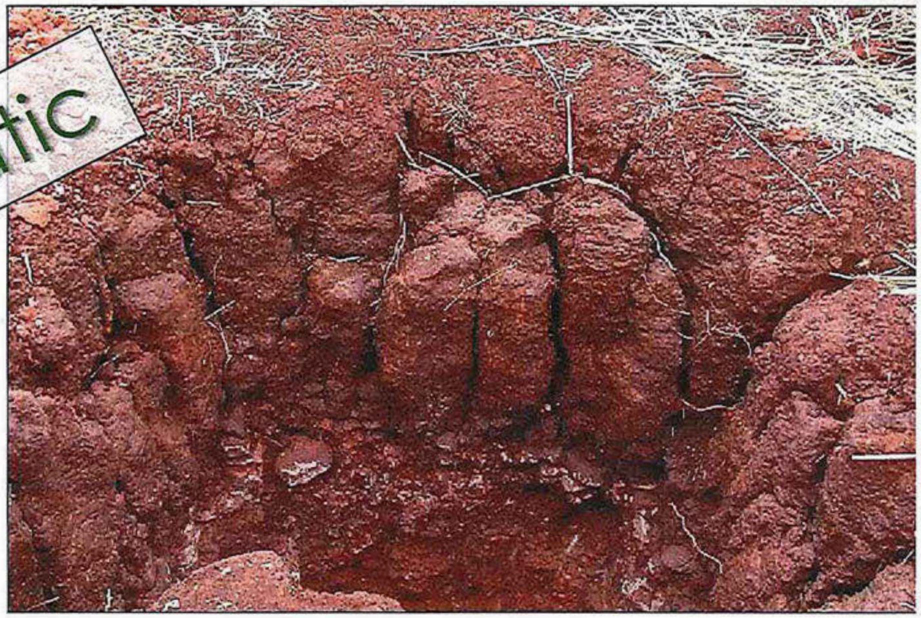
TYPES OF SOIL STRUCTURE

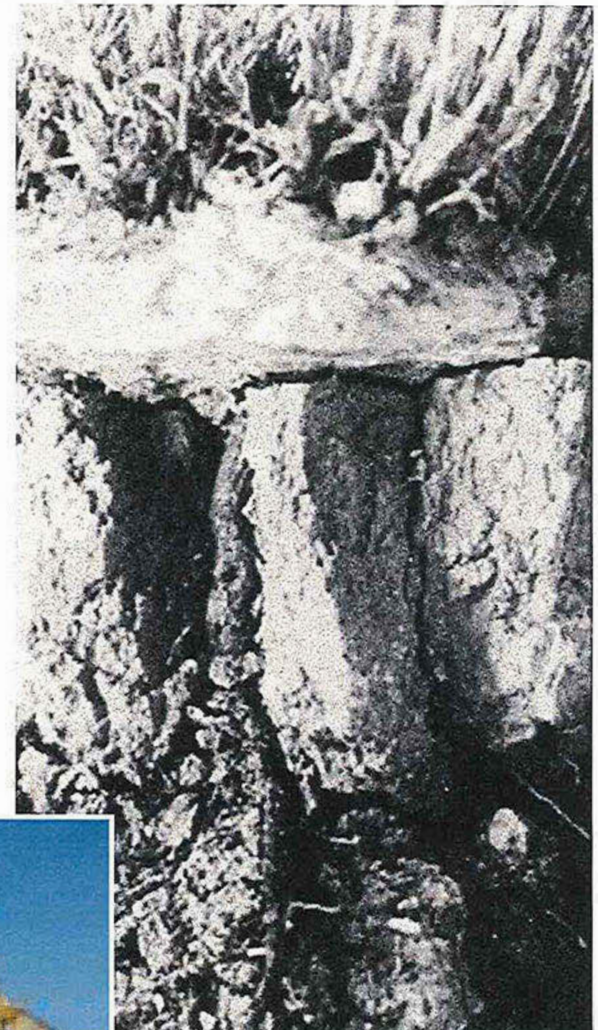
<u>Prism-like</u>

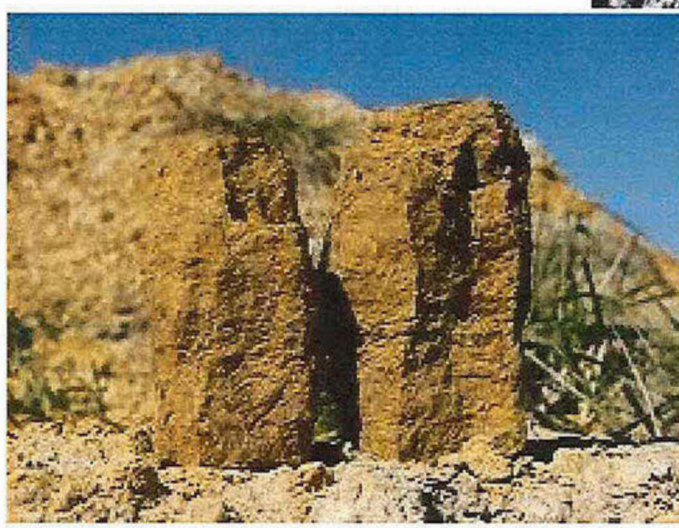
- Soil aggregates into columns or pillars taller than they are wide
- Common in subsurface horizons (particularly Bt)
- Two type of prism-like structure:
  - Prismatic: tops of columns are sharp-edged or level
  - Columnar: tops of columns are rounded (natric horizons)

PRISM-LIKE STRUCTURE

Prismatic







PRISM-LIKE STRUCTURE

Columnar

MASSIVE STRUCTURE

- Massive structure is the absence of one of the principal structural shapes (defined above)

SOIL STRUCTURE

- More than one type of aggregation (or structure) can exist in a given profile
- Structure can be temporarily altered or destroyed by mechanical interference
- Mechanics of soil structure not well understood
  - Takes time, cations and/or OM, external forces

Soil Structure

Soil structure refers to units composed of primary particles. The cohesion within these units is greater than the adhesion among units. As a consequence, under stress, the soil mass tends to rupture along predetermined planes or zones. These planes or zones, in turn, form the boundary. Compositional differences of the fabric matrix appear to exert weak or no control over where the bounding surfaces occur. If compositional differences control the bounding surfaces of the body, then the term "concentration" is employed. The term "structural unit" is used for any repetitive soil body that is commonly bounded by planes or zones of weakness that are not an apparent consequence of compositional differences. A structural unit that is the consequence of soil development is called a *ped*. The surfaces of peds persist through cycles of wetting and drying in place. Commonly, the surface of the ped and its interior differ as to composition or organization, or both, because of soil development. Earthy *clods* and *fragments* stand in contrast to peds, for which soil forming processes exert weak or no control on the boundaries. Some clods, adjacent to the surface of the body, exhibit some rearrangement of primary particles to a denser configuration through mechanical means. The same terms and criteria used to describe structured soils should be used to describe the shape, grade, and size of clods. Structure is not inferred by using the terms interchangeably. A size sufficient to affect tilth adversely must be considered. The distinction between clods and fragments rests on the degree of consolidation by mechanical means. Soil fragments include (1) units of undisturbed soil with bounding planes of weakness that are formed on drying without application of external force and which do not appear to have predetermined bounding planes, (2) units of soil disturbed by mechanical means but without significant rearrangement to a denser configuration, and (3) pieces of soil bounded by planes of weakness caused by pressure exerted during examination with size and shape highly dependent on the manner of manipulation.

Some soils lack structure and are referred to as *structureless*. In structureless layers or horizons, no units are observable in place or after the soil has been gently disturbed, such as by tapping a spade containing a slice of soil against a hard surface or dropping a large fragment on the ground. When structureless soils are ruptured, soil fragments, single grains, or both result. Structureless soil material may be either single grain or massive. Soil material of single grains lacks structure. In addition, it is loose. On rupture, more than 50 percent of the mass consists of discrete mineral particles.

Some soils have *simple structure*, each unit being an entity without component smaller units. Others have *compound structure*, in which large units are composed of smaller units separated by persistent planes of weakness.

In soils that have structure, the shape, size, and grade (distinctness) of the units are described. Field terminology for soil structure consists of separate sets of terms designating each of the three properties, which by combination form the names for structure.

Shape.—Several basic shapes of structural units are recognized in soils. Supplemental statements about the variations in shape of individual peds are needed in detailed descriptions of some soils. The following terms describe the basic shapes and related arrangements:

platy: The units are flat and platelike. They are generally oriented horizontally. Platy structure is illustrated in figure 3-26. A special form, lenticular platy structure, is recognized for plates that are thickest in the middle and thin toward the edges.

prismatic: The individual units are bounded by flat to rounded vertical faces. Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units. Vertices are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat. Prismatic structure is illustrated in figure 3-27.

columnar: The units are similar to prisms and are bounded by flat or slightly rounded vertical faces. The tops of columns, in contrast to those of prisms, are very distinct and normally rounded, as illustrated in figure 3-28.

FIGURE 3-26

Strong thin platy structure

FIGURE 3-27

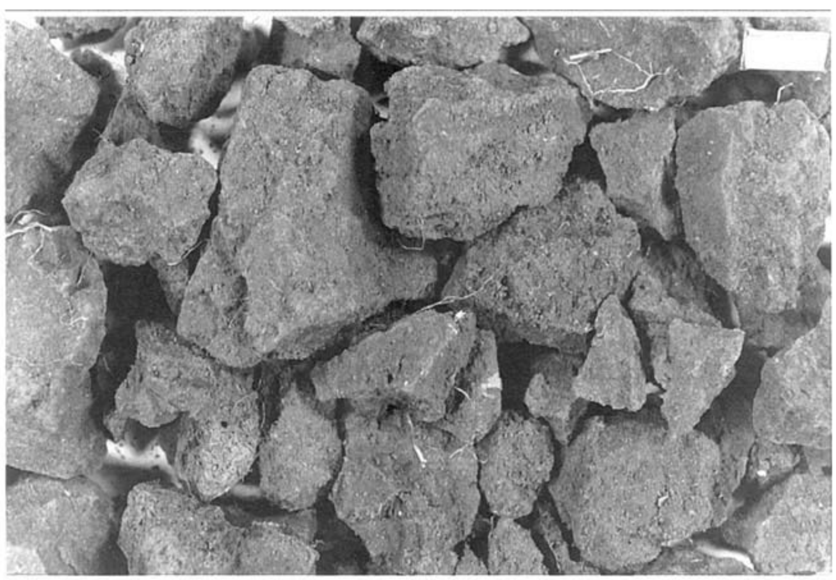
Strong medium platy structure. The prisms are 35 to 45 mm across.

FIGURE 3-28

A cluster of strong medium columnar peds. The cluster is about 135 mm across.

blocky: The units are blocklike or polyhedral. They are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds. Typically, blocky structural units are nearly equidimensional but grade to prisms and to plates. The structure is described as angular blocky if the faces intersect at relatively sharp angles; as subangular blocky if the faces are a mixture of rounded and plane faces and the corners are mostly rounded. Figure 3-29 illustrates angular blocky units.

FIGURE 3-29



Strong medium and coarse blocky peds.

granular: The units are approximately spherical or polyhedral and are bounded by curved or very irregular faces that are not casts of adjoining peds. Granular units are illustrated in figure 3-30.

FIGURE 3-30

Strong fine and medium granular peds.

Size.—Five classes are employed: very fine, fine, medium, coarse, and very coarse. The size limits of the classes differ according to the shape of the units. The size limit classes are given in table 3-13. The size limits refer to the smallest dimension of plates, prisms, and columns. If the units are more than twice the minimum size of "very coarse," the actual size is given: "prisms 30 to 40 cm across."

Grade.—Grade describes the distinctness of units. Criteria are the ease of separation into discrete units and the proportion of units that hold together when the soil is handled. Three classes are used:

Weak. The units are barely observable in place. When gently disturbed, the soil material parts into a mixture of whole and broken units and much material that exhibits no planes of weakness. Faces that indicate persistence through wet-dry-wet cycles are evident if the soil is handled carefully. Distinguishing structurelessness from weak structure is sometimes difficult. Weakly expressed structural units in virtually all soil materials have surfaces that differ in some way from the interiors.

Moderate. The units are well formed and evident in undisturbed soil. When disturbed, the soil material parts into a mixture of mostly whole units, some broken units, and material that is not in units. Peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fractured surfaces.

Strong. The units are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed, the soil material separates mainly into whole units. Peds have distinctive surface properties.

Table 3-13. Size classes of soil structure

	Shape of structure			
Size Classes	***Platy*** [1] mm	***Prismatic and Columnar*** mm	***Blocky*** mm	***Granular*** mm
1	<1	<10	<5	<1
2	1-2	10-20	5-10	1-2
3	2-5	20-50	10-20	2-5
4	5-10	50-100	20-50	5-10
5	>10	>100	>50	>10

[1] In describing plates, "thin" is used instead of "fine" and "thick" instead of "coarse."

The distinctness of individual structural units and the relationship of cohesion within units to adhesion between units determine grade of structure. Cohesion alone is not specified. For example, individual structural units in a sandy loam A horizon may have strong structure, yet they may be less durable than individual units in a silty clay loam B horizon of weak structure. The degree of disturbance required to determine structure grade depends largely on moisture content and percentage and kind of clay. Only slight disturbance may be necessary to separate the units of a moist sandy loam having strong granular structure, while considerable disturbance may be required to separate units of a moist clay loam having strong blocky structure.

The three terms for soil structure are combined in the order (1) grade, (2) size, (3) shape. "Strong fine granular structure" is used to describe a soil that separates almost entirely into discrete units that are loosely packed, roughly spherical, and mostly between 1 and 2 mm in diameter.

The designation of structure by grade, size, and shape can be modified with other appropriate terms when necessary to describe other characteristics. Surface characteristics of units are described separately. Special structural units, such as the wedge-shaped units of Vertisols, are described in appropriate terms.

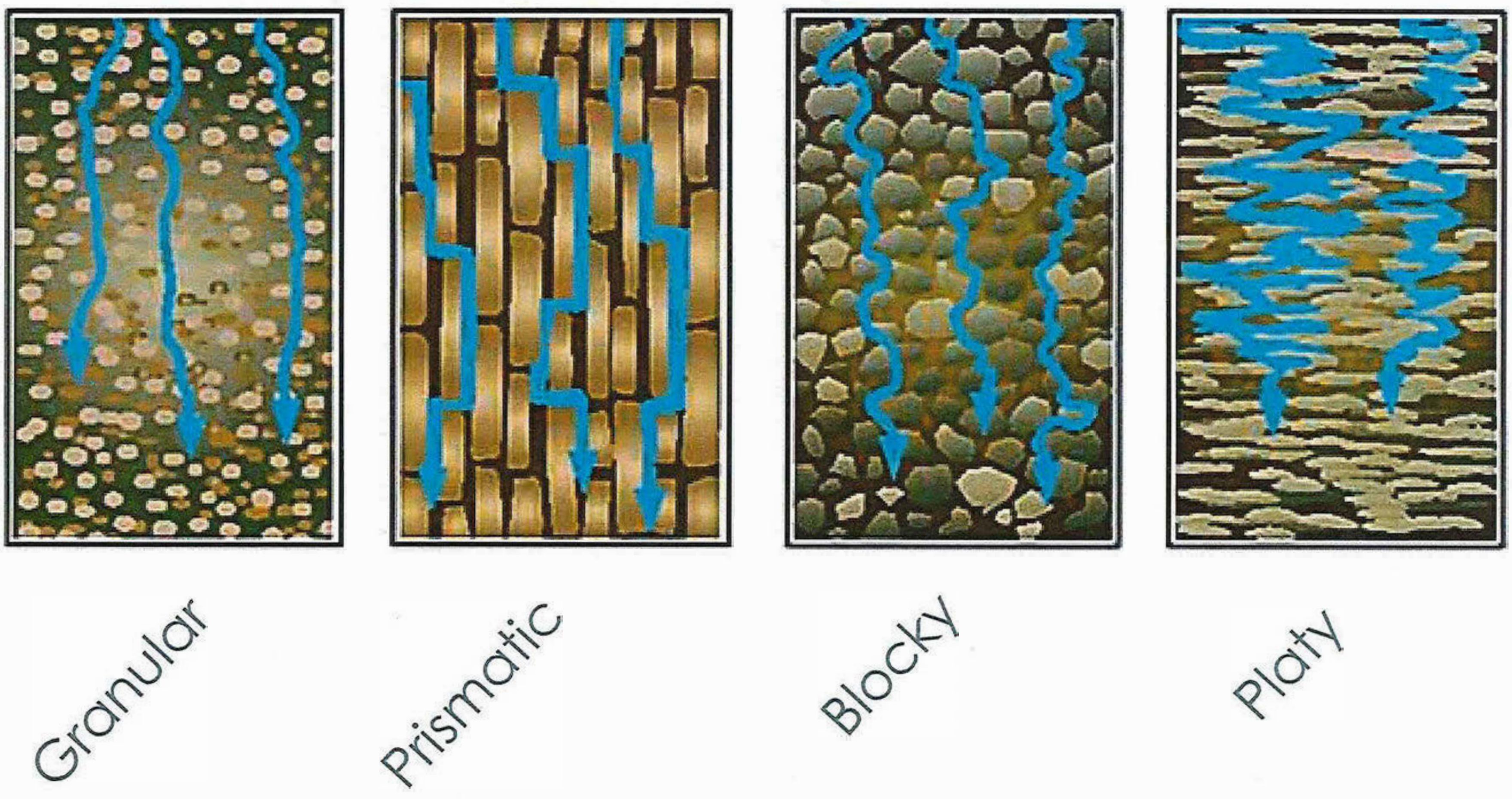
Compound Structure

Smaller structural units may be held together to form larger units. Grade, size, and shape are given for both and the relationship of one set to the other is indicated: "strong medium blocks within moderate coarse prisms," or "moderate coarse prismatic structure parting to strong medium blocky."

Extra-Structural Cracks

Cracks are macroscopic vertical planar voids with a width much smaller than length and depth. A crack represents the release of strain that is a consequence of drying. In many soils, cracks bound individual structural units. These cracks are repetitive and usually quite narrow. Their presence is part of the concept of the structure. The cracks to be discussed are the result of localized stress release which forms planar voids that are wider than the repetitive planar voids between

INFLUENCE OF SOIL STRUCTURE TYPE ON WATER MOVEMENT



soil Infiltration

Soil Health – Guides for Educators

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

Soil infiltration refers to the ability of the soil to allow water to move into and through the soil profile. Infiltration allows the soil to temporarily store water, making it available for use by plants and soil organisms. The infiltration rate is a measure of how fast water enters the soil, typically expressed in inches per hour. For initial in-field assessments; however, it is more practical to express the infiltration rate as the minutes needed for a soil to absorb each inch of water applied to the surface. If the rate is too slow, it can result in ponding in level areas, surface runoff, and erosion in sloping areas and can lead to flooding or inadequate moisture for crop production. Sufficient water must infiltrate the soil profile for optimum crop production. Water that infiltrates through porous soils recharges groundwater aquifers and helps to sustain the base flow in streams.

Unless properly managed, a high infiltration rate can lead to leaching of nitrate nitrogen or pesticides and loss of phosphorus from soils that have a high level of phosphorus. Management practices such as use of no-till cropping systems and use of high residue crops and cover crops can improve infiltration by increasing the soil organic matter content.

Inherent Factors Affecting Soil Infiltration

Soil texture, or the percentage of sand, silt, and clay in a soil, is the major inherent factor affecting infiltration. Water moves more quickly through the large pores in sandy soil than it does through the small pores in clayey soil, especially if the clay is compacted and has little or no structure or aggregation.

Depending on the amount and type of clay minerals, some clayey soils develop cracks from shrinkage as they become dry. The cracks are direct conduits for water to enter the soils. Thus, clayey soils can have a high infiltration rate when dry and a slow rate when moist (cracks close). Clayey soils that do not crack have a slow infiltration rate unless they have a high content of iron oxide (red clayey soils) or they formed in volcanic ash. Management practices that improve soil organic matter content, soil aggregation, and porosity can improve infiltration.

Infiltration Management

Management practices such as using diverse high-residue crops, maintaining residue on the soil surface, using cover crops, and managing equipment traffic to avoid compaction affect infiltration by minimizing surface crusting and compaction and increasing soil organic matter content and porosity. Unless the soil is protected by plant or residue cover, the direct impact of raindrops dislodges soil particles, resulting in runoff and erosion. The rainfall simulator in figure 1 shows that more runoff occurs where there is less residue on the surface, increasing the risk of erosion. Dislodged soil particles fill in the surface pores, contributing to the development of a surface crust, which restricts the movement of water into the soil. Equipment use, especially on wet soils, and tillage can result in compaction. Compacted or impervious soil layers have less pore space, which restricts water movement through the soil profile.

Figure 1.—Rainfall simulator.

As soil moisture content increases, the infiltration rate decreases. Soil moisture is affected by evaporation, water use by plants, residue on surface and plant cover, irrigation, and drainage. Dry soils tend to have pores and cracks that allow water to enter faster. As a soil becomes wet, the infiltration rate slows to a steady rate based on how fast water can move through the saturated soil; the most restrictive layer, such as a compacted layer; or a dense clay layer.

Soil organic matter binds soil particles together into stable aggregates, increasing porosity and infiltration. Soils that have a high content of organic matter also provide good habitat for soil biota, such as earthworms. Soil biota increase pore space and create continuous pores that link the upper soil layer to subsurface layers.

Long-term solutions for maintaining or improving soil infiltration include practices that increase organic matter content and aggregation and minimize runoff, disturbance, and compaction. A higher content of organic matter results in better soil aggregation and improved soil structure, increasing the soil infiltration rate.

To improve the soil infiltration rate:

- Avoid soil disturbance and equipment use when the soils are wet.
- Use equipment only on designated roads or between rows.
- Limit the number of times equipment is used on a field.
- Subsoil to break up compacted layers.
- Use a continuous, no-till cropping system.
- Apply solid manure or other organic material.
- Use rotations that include high-residue crops, such as corn and small grain, and perennial crops, such as grass and alfalfa.
- Plant cover crops and green manure crops.
- Farm on the contour.

Problems Related to Infiltration and Relationship of Infiltration to Soil Function

When rainfall is received at a rate that exceeds the infiltration rate of a soil, runoff moves downslope or ponds on the surface in level areas. Runoff on bare or sparsely vegetated soil can result in erosion. Runoff removes nutrients, chemicals, and sediment, resulting in decreased soil productivity, offsite sedimentation of bodies of water, and diminished water quality.

To determine whether runoff is likely to occur, refer to rainfall data from the nearest location that reflects the amount and duration of rainfall in the sampled area. Compare it to the infiltration rate of the area to determine whether the rate is adequate to minimize runoff. For example, tables 1 and 2 show the likely frequency (1 to 100 years) and duration of rainfall events and the amount of rainfall received during each event at two locations in Nebraska.

Table 1.—Rainfall intensity and duration patterns for Mead, NE*

Frequency of rainfall event	Duration of rainfall event and total rainfall (in)		
	30 minutes	1 hour	2 hours
1 year	1.2	1.1	1.8
2 years	1.3	1.7	1.9
5 years	1.7	2.1	2.4
10 years	2.0	2.5	2.8
100 years	2.8	3.7	4.2

Table 2.—Rainfall intensity and duration patterns for North Platte, NE*

Frequency of rainfall event	Duration of rainfall event and total rainfall (in)		
	30 minutes	1 hour	2 hours
1 year	0.9	1.1	1.2
2 years	1.1	1.4	1.5
5 years	1.5	1.9	2.1
10 years	1.8	2.2	2.5
100 years	2.6	3.4	3.7

* D.M. Herschfield; 1961; *Rainfall Frequency Atlas of the United States*; U.S. Weather Bureau.

Restricted infiltration and ponding result in poor soil aeration. This leads to poor root function, poor plant growth, nitrogen volatilization, reduced availability of nutrients for plant use, and reduced cycling of nutrients by soil organisms.

The soil infiltration rate is most affected by conditions near the soil surface, and the rate can change drastically as a result of management.

Infiltration is rapid through large continuous pores at the soil surface, and it slows as pores become smaller. Steady-state infiltration rates typically occur when the soil is nearly saturated. These rates are given for various textural classes in table 3. They are average values and should not be generalized for all soil types.

Table 3.—Steady-state infiltration rates*

(Soils are wet deep into the profile. Values should be used only for comparing to the infiltration rate of the second inch of water applied.)

Soil type	**Steady-state infiltration rate (in/hr)**
Sand	>0.8
Sandy and silty soils	0.4-0.8
Loam	0.2-0.4
Clayey soils	0.04-0.2
Sodic clayey soils	<0.04

*Hillel, 1982.

What practices are being used that affect the infiltration rate?______________________________

____

____

Do these practices increase or decrease the infiltration rate? Why or why not?

____

____

____

Measuring Infiltration

Materials needed to measure infiltration:

____ 3- or 6-inch-diameter aluminum ring

____ Rubber mallet or weight

____ Block of wood or plastic insertion cap

____ Plastic wrap

____ Plastic bottle marked at 107 mL (3-inch ring) or 444 mL (6-inch ring) for 1 inch of water, or graduated cylinder

____ Distilled water or rainwater

____ Stopwatch or timer

Considerations:

Select representative test locations. For comparison, select locations under different management. For example, select an area where wheeled equipment has been used and one where it has not been used. For greater accuracy, make multiple measurements (3 or more) at each representative location.

The test should not be conducted when the surface layer is unusually dry. If needed, add water and then allow the water to soak into the soil before conducting the test. The measurement can also be taken after the soil has been moistened by rain or irrigation water. The infiltration rate will vary depending on the initial moisture content; therefore, the estimated initial moisture state should be documented. Avoid areas that are not typical of the area, such as animal burrows.

Infiltration test:

1. Clear all residue from the soil surface. Drive the ring into the soil to a depth of 3 inches using a rubber mallet or weight and a plastic insertion cap or block of wood. Take care to drive the ring downward evenly and vertically. Gently tamp down the soil inside the ring to eliminate gaps.
2. Cover the inside of the ring with plastic wrap, and drape it over the rim.
3. Pour 107 or 444 mL of distilled water or rainwater into the plastic-lined ring (fig. 2).

Figure 2.—Water is poured into plastic-lined ring.

4. Gently pull plastic wrap away. Record the time it takes for the water to infiltrate the soil. Stop timer when the soil “glistens.”
5. Repeat steps 2, 3, and 4 to determine the steady-state infiltration rate. Several measurements may be needed.
6. Record the results in table 4.
7. Remove the ring with the soil intact. This intact soil core can be used indoors for the respiration and bulk density tests.

Interpretations

In table 4, record the infiltration rate for the first and second inches of water applied and record the steady-state infiltration rate. Answer discussion questions. The infiltration rate is an indication of the susceptibility of the soil to runoff or ponding. Compare the rate for soils in different fields, soils of different types, and soils under different management systems.

Table 4.—Infiltration data sheet

Date: May 1, 2012									
Location	**Soil texture**	**First inch of water applied**		**Infiltration time for first inch (minutes)**	**Infiltra-tion rate (in/hr)**	**Second inch of water applied**		**Infiltration time for second inch (minutes)**	***Steady state (in/hr)**
		Start time	**End time**			**Start time**	**End time**		
Area tracked by wheeled equipment	Silty clay loam	2:00	5:00	180	0.33	5:00	8:20	200	0.30
Area not tracked by wheeled equipment	Silty clay loam	2:00	2:01	1	N/A	2:02	4:02	120	0.5
Notes:									

*Three or more measurements (inches of water) may be needed to achieve steady-state infiltration rate.

Did the infiltration rate change from the first inch of water applied to the second inch applied? Why or why not? Would a steady-state infiltration rate be achieved if a third inch of water was applied?

____

____

____

Determine the rainfall patterns for your specific geographical area (tables 1 and 2 are example rainfall patterns for two locations in Nebraska and thus should not be used for all areas). How does the infiltration time compare to the expected amount of rainfall in your geographical area? Is the soil susceptible to runoff?

____

____

____

How do the infiltration rates compare to the steady-state infiltration rates given in table 3? Are the rates higher, lower, or similar to those for a similar soil type? Explain.

____

____

____

Glossary

Infiltration rate.—Measure of how fast water enters the soil. It typically is expressed as inches per hour, but it is recorded as minutes needed for each inch of water applied at the surface to move into the soil.

Restrictive layer.—Compacted layer or layer of dense clay, bedrock, or other restrictive material that limits infiltration below the surface of the soil.

Sodic soil.—Soil that has a high sodium content and thus a very low infiltration rate.

Soil aggregates.—Soil particles held together by organic matter and related substances. Well aggregated soils have a higher infiltration rate and a lower risk of erosion.

Soil porosity.—Amount of pore space in the soil. Soils with higher porosity have more pore space and a higher infiltration rate than those with lower porosity.

Steady-state infiltration.—The condition in which the infiltration rate does not increase or decrease as more water is added. It typically occurs when the soil is nearly saturated.

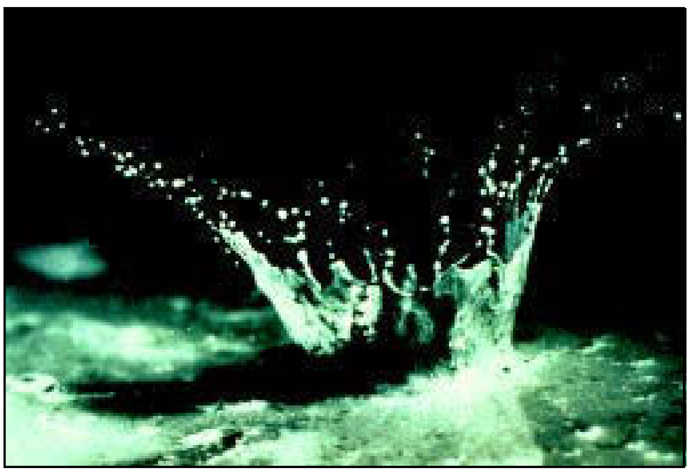
Soil Quality Information Sheet

Soil Quality Indicators: Infiltration

USDA Natural Resources Conservation Service **January 1998**

What is Infiltration?

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



Why is infiltration a concern?

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

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

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

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

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

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

What factors influence infiltration?

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

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

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

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

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

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

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

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

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

How can infiltration be increased?

A number of management options can help increase soil infiltration:

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

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http://soils.usda.gov

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

Soil Quality Indicators

Infiltration

Infiltration is the downward entry of water into the soil. The velocity at which water enters the soil is infiltration rate. Infiltration rate is typically expressed in inches per hour. Water from rainfall or irrigation must first enter the soil for it to be of value.

A one inch layer of water is added to a six inch diameter ring to measure infiltration rate.

Factors Affecting

Inherent - Infiltration rate is dependent on soil texture (percentage of sand, silt, and clay) and clay mineralogy. Water moves more quickly through the large pore spaces in a sandy soil than it does through the small pores of a clayey soil, especially if the clay is compacted and has little or no structure or aggregation (see Table 1).

Depending on the amount and type of clay minerals, many clayey soils develop shrinkage cracks as they dry, creating a direct conduit for water to enter the soil. These clay soils have high infiltration capacities as water moves into the shrinkage cracks, although at other times, when cracks are not present, their infiltration rate is characteristically slow.

Dynamic - A reflection of climate and landscape position, as well as management practices and crop demand, existing soil water content affects the ability of the soil to pull additional water into it. Pores and cracks are generally open in a dry soil. Many of them are filled in by water or swelled shut as the soil becomes wet, so infiltration rate is generally highest when the soil is dry. As the soil becomes wet, the infiltration rate slows to the rate at which water moves through the most restrictive layer, such as a compacted layer or a layer of dense clay.

Infiltration is affected by crop and land management practices that affect surface crusting, compaction, and soil organic matter. Without the protective benefits of vegetative or residue cover, bare soil is subjected to the direct impact and erosive forces of raindrops that dislodge soil particles. Dislodged soil particles fill in and block surface pores, contributing to the development of surface crusts that restrict water movement into the soil.

Compaction results from livestock and equipment traffic, especially on wet soils, and continuous plowing to the same depth, e.g. the creation of a plow pan below the tillage depth. Compacted or impervious soil layers have reduced pore space and restricted water movement through the soil profile.

Soil organic matter affects infiltration through its positive affect on the development of stable soil aggregates, or crumbs. Highly aggregated soil has increased pore space and infiltration. Soils high in organic matter also provide good habitat for soil biota, such as earthworms, that through their burrowing activities, increase pore space and create continuous pores linking surface to subsurface soil layers.

Management that reduces soil cover, disrupts continuous poor space, compacts soil, or reduces soil organic matter negatively impacts infiltration. Since tillage negatively affects all of these properties, it plays an important role in a soil’s infiltration rate.

Table 1. Steady infiltration rates for general soil texture groups in very deeply wetted soil. (Hillel, D. 1982. Introduction to soil physics. Academic Press, San Diego, CA)

Soil Type	Steady Infiltration Rate (in/hr)
Sands	> 0.8
Loams	0.2 - 0.4
Clays	0.04 - 0.2

Relationship to Soil Function

Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile. Soil temporarily stores water, making it available for root uptake, plant growth and habitat for soil organisms.

Problems with Poor Function

When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves downslope as runoff on sloping land or ponds on the surface of level land. When runoff occurs on bare or poorly vegetated soil, erosion takes place. Runoff carries nutrients, chemicals, and soil with it, resulting in decreased soil productivity, off-site sedimentation of water bodies and diminished water quality. Sedimentation decreases storage capacity of reservoirs and streams and can lead to flooding.

Restricted infiltration and ponding of water on the soil surface results in poor soil aeration, which leads to poor root function and plant growth, as well as reduced nutrient availability and cycling by soil organisms. Ponding and soil saturation decreases soil strength, destroys soil structure, increases detachment of soil particles, and makes soil more erodible. On the soil surface rather than in the soil profile, ponded water is subject to increased evaporation, which leads to decreased water available for plant growth.

A high infiltration rate is generally desirable for plant growth and the environment. In some cases, soils that have unrestricted water movement through their profile can contribute to environmental concerns if misapplied nutrients and chemicals reach groundwater and surface water resources via subsurface flow.

Conservation practices that lead to poor infiltration include:

- Incorporating, burning, or harvesting crop residues leaving soil bare and susceptible to erosion,
- Tillage methods and soil disturbance activities that disrupt surface connected pores and prevent accumulation of soil organic matter, and
- Equipment and livestock traffic, especially on wet soils, that cause compaction and reduced porosity.

Improving Infiltration

Several conservation practices help maintain or improve water infiltration into soil by increasing vegetative cover, managing crop residues, and increasing soil organic matter. Generally, these practices minimize soil disturbance and compaction, protect soil from erosion, and encourage the development of good soil structure and continuous pore space. As a short-term solution to poor infiltration, surface crusts can be disrupted with a rotary hoe or row cultivator and plow plans or other compacted layers can be broken using deep tillage.

Long-term solutions for maintaining or improving infiltration include practices that increase soil organic matter and aggregation, and reduce soil disturbance and compaction. High residue crops, such as corn and small grains, perennial sod, and cover crops protect the soil surface from erosion and increase soil organic matter when reduced tillage methods that maintain surface cover are used to plant the following crop. Application of animal manure also helps to increase soil organic matter. Increased organic matter results in increased aggregation and improved soil structure leading to improved infiltration rates. Conservation tillage, reduced soil disturbance, and reducing the number of trips across a field necessary to produce a crop help leave continuous pore spaces intact and minimize the opportunity for soil compaction.

Conservation practices resulting in infiltration rates favorable to soil function include:

- Conservation Crop Rotation
- Cover Crop
- Prescribed Grazing
- Residue and Tillage Management
- Waste Utilization

Measuring Infiltration

The Single Ring (Flooded/Ponded) Infiltrometer Method is described in the Soil Quality Test Kit Guide, Section I, Chapter 3, pp. 7 - 8. See Section II, Chapter 2, pp. 55 - 56 for interpretation of results.

Reference: Lowery B, Hickey WJ, Arshad MA, and Lal R. 1996. Soil water parameters and soil quality. In: Doran JW, Jones AJ, editors. Methods for assessing soil quality. Madison, WI. p 143-55.

Specialized equipment, shortcuts, tips:

To accurately assess infiltration and compare rates for different soils, the soils should be at similar moisture content when taking the measurement. It is recommended that measurements be taken at field capacity, defined as the water content of the soil root zone at which drainage (by gravity) becomes negligible. If the soil is already saturated, infiltration will not occur; wait for one or two days to allow for drying to measure infiltration rate.

Time needed: 60 minutes or more depending on soil conditions

Soil Quality Information Sheet

Rangeland Soil Quality—**Infiltration**

USDA, Natural Resources Conservation Service **May 2001**

What is infiltration?

The process of water soaking into the soil is infiltration. "Infiltration rate" is simply how fast water enters the soil and is usually measured in inches or millimeters per hour. This rate depends on soil texture (amount of sand, silt, and clay) and on soil structure. Soils in good condition have well developed structure and continuous pores to the surface. As a result, water from rainfall or snowmelt readily enters these soils.

Why is infiltration important?

Soil is a reservoir that stores water for plant growth. The water in soil is replenished by infiltration. The infiltration rate can be restricted by poor management. Under these conditions, the water does not readily enter the soil and it moves downslope as runoff or ponds on the surface, where it evaporates. Thus, less water is stored in the soil for plant growth, and plant production decreases, resulting in less organic matter in the soil and weakened soil structure that can further decrease the infiltration rate.

Runoff can cause soil erosion and the formation of gullies. It also carries nutrients and organic matter, which, together with sediment, reduce water quality in streams, rivers, and lakes. The sediment reduces the capacity of reservoirs to store water. Excessive runoff can cause flooding, erode streambanks, and damage roads. Runoff from adjacent slopes can saturate soils in low areas or can create ponded areas, thus killing upland plants. Evaporation in the ponded areas reduces the amount of water available to plants.

What factors affect infiltration?

The proportion of water from rainfall or snowmelt that enters the soil depends on "residence time" (how long the water remains on the surface before running off) and the infiltration rate. These are affected by vegetation and many soil properties.

Residence time

The length of time that water remains on the surface depends on the slope, the roughness of the soil surface, and obstructions to overland flow, such as plant bases and litter. Consequently, plant communities with large amounts of basal area cover, such as grasslands, tend to slow runoff more than communities with small amounts of basal cover, such as shrub lands.

Infiltration rate

The infiltration rate is generally highest when the soil is dry. As the soil becomes wet, the infiltration rate slows to the rate at which water moves through the most restrictive layer, such as a compacted layer or a layer of dense clay. Infiltration rates decline as water temperature approaches freezing. Little or no water penetrates the surface of frozen or saturated soils.

Vegetation

A high percentage of plant cover and large amounts of root biomass generally increase the infiltration rate. Different plant species have different effects on infiltration. The species that form a dense root mat can reduce the infiltration rate. In areas of arid and semiarid rangeland, the infiltration-limiting layer commonly is confined to the top few millimeters of the soil, particularly in the open spaces between plant canopies. These areas receive few inputs of organic matter, which build soil structure. Also, the impact of raindrops in these areas can degrade soil structure and form physical crusts.

Soil properties

The properties that affect infiltration and cannot be readily changed by management include:

Texture.—Water moves more quickly through the large pores and spaces in a sandy soil than it does through the small pores in a clayey soil. Where the content of organic matter is low, texture plays a significant role in the susceptibility of the soil to physical crusting.

Clay mineralogy.—Some types of clay develop cracks as they dry. These cracks rapidly conduct water to the subsurface and seal shut once the soil is wet.

Minerals in the soil.—High concentrations of sodium tend to inhibit the development of good structure and promote the formation of surface crusts, which reduce the infiltration rate. Calcium improves soil structure.

Soil layers.—Subsurface soil, including a subsoil of dense clay, cemented layers, and highly contrasting layers, such as coarse sand over loam, can slow water movement through soil and thus limit infiltration.

Depth.—Soil depth controls how much water the soil can hold. When soil above an impermeable layer, such as bedrock, becomes saturated, infiltration ceases and runoff increases.

The properties that affect infiltration and can be readily changed by management or a shift in vegetation are:

Organic matter and soil biota.—Increased plant material, dead or alive, generally improves infiltration. As organic matter is broken down by soil organisms, it binds soil particles into stable aggregates that enhance pore space and infiltration.

Aggregation and structure.—Good soil structure improves infiltration. Soils with good structure have more pores for the movement of water than soils with poor structure. If aggregates are stable, the structure remains intact throughout a rainstorm.

Physical crusts.—Physical crusts form when poorly aggregated soils are subject to the impact of raindrops and/or to ponding. Particles broken from weak aggregates can clog pores and seal the surface, thus limiting water infiltration.

Biological crusts.—Biological crusts can either increase or reduce the infiltration rate. Their effect on the infiltration rate depends on many other factors, including soil texture.

Pores and channels.—Continuous pores connected to the surface convey water. Such organisms as earthworms, ants, and termites increase the number of pores. Termites, however, can decrease the infiltration rate by reducing the amount of litter cover, and some ant species seal the surface around their nests.

Soil density.—A compacted zone close to the surface restricts the entry of water into the soil and often results in surface ponding. Increased bulk density reduces pore space and thus the amount of water available for plant growth.

Water-repellent layer.—As shrubs and an underlying thick layer of litter burn in a hot fire, very high temperatures can occur directly beneath the shrubs. The heat forces a gas from the burning plant material into the soil. When it cools, the gas forms a water-repellent layer that limits infiltration. This feature is temporary, although it may persist for a number of years. Some soils can be slightly water repellent when dry.

Management strategies

The soil and vegetation properties that currently limit infiltration and the potential for increasing the infiltration rate must be considered in any management plan. Where waterflow patterns have been altered by a shift in vegetation, such as a shift from grassland to open-canopy shrub land, restoration of higher infiltration rates may be difficult or take a long period, especially if depletion of organic matter and/or soil loss have occurred. Excessive grazing of forage can impair infiltration. Management strategies include:

- Increase the amount of plant cover, especially of plants that have positive effects on infiltration.
- Decrease the extent of compaction by avoiding intensive grazing and the use of machinery when the soils are wet.
- Decrease the formation of physical crusts by maintaining or improving the cover of plants or litter and thus reducing the impact of raindrops.
- Increase aggregate stability by increasing the amount of organic matter added to the soil through residue decomposition and vigorous root growth.

For more information, check the following: http://soils.usda.gov/sqi **and** http://www.ftw.nrcs.usda.gov/glti

(Prepared by the Soil Quality Institute, Grazing Lands Technology Institute, and National Soil Survey Center, Natural Resources Conservation Service, USDA; the Jornada Experimental Range, Agricultural Research Service, USDA; and Bureau of Land Management, USDI)

AGGREGATE FORMATION & STABILIZATION

Formation

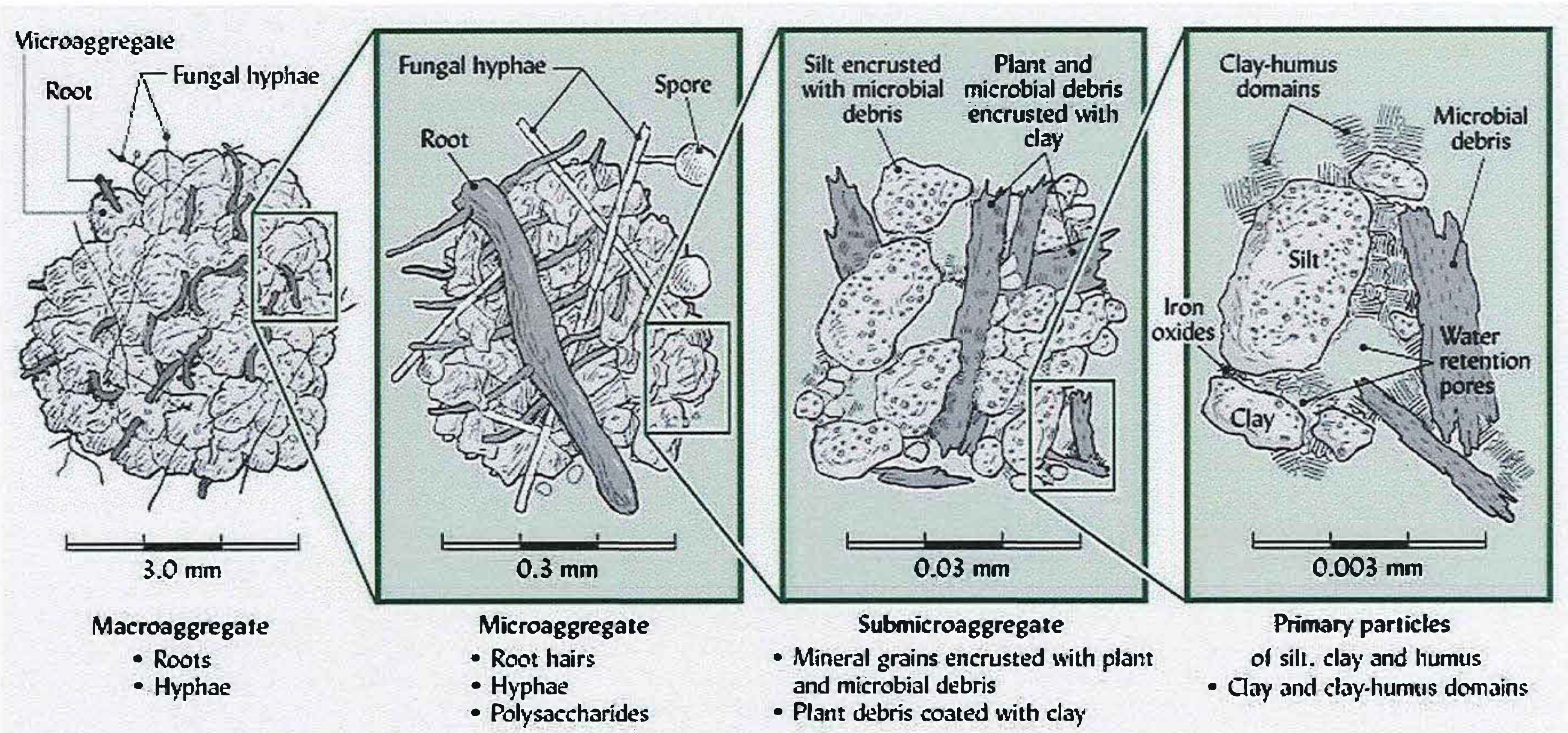
- Mechanical action (freezing/thawing) bring particles together and orient them for maximum interaction
- Flocculation by multivalent cations
- Binding by fungal mycelia during initial OM decomposition
- Binding by sticky organic exudates
- None of the preceding provide permanent stability

AGGREGATE FORMATION & STABILIZATION

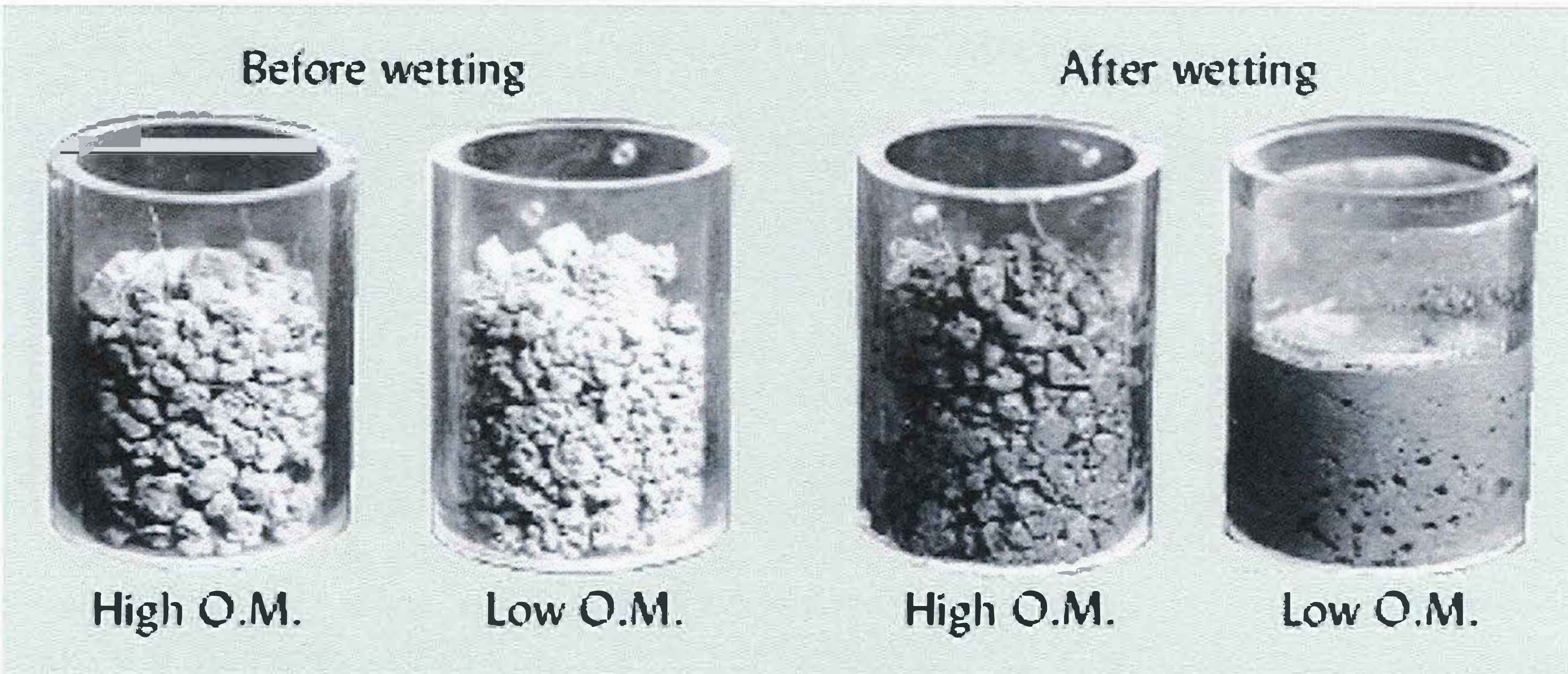
Stabilization

- Orientation of clay particles in OM
- Decomposition of OM into more permanent binding compounds
- Binding by Al and Fe oxides
- Formation of clay, oxide, and humic skins around existing aggregates

LEVEL OF HIERARCHY OF SOIL AGGREGATES



EFFECT OF ORGANIC MATTER ON SOIL AGGREGATE STABILITY



Organic matter imparts stability to aggregates

Soil Quality Indicators: Aggregate Stability

USDA Natural Resources Conservation Service **April 1996**

What are soil aggregates?

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

What is aggregate stability?

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

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

Why is aggregate stability important?

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

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

How is aggregate stability measured?

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

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

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

What influences aggregate stability?

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

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

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

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

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

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

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

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

Soil Quality Indicators

Aggregate Stability

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. Aggregate stability refers to the ability of soil aggregates to resist disintegration when disruptive forces associated with tillage and water or wind erosion are applied. Wet aggregate stability suggests how well a soil can resist raindrop impact and water erosion, while size distribution of dry aggregates can be used to predict resistance to abrasion and wind erosion.

Long-term use of a conservation tillage system (no-till) and cover crops resulted in increased soil organic matter and improved soil structure and aggregate stability of this north Georgia (Cecil) soil. Photo courtesy James E. Dean, USDA NRCS (retired).

Factors Affecting

Inherent - Aggregation and stability of soil aggregates are affected by predominant type and amount of clay, adsorbed cations, such as calcium and sodium, and iron oxide content. Expansion and contraction of clay particles as they become moist and then dry can shift and crack the soil mass and create aggregates or break them apart. Calcium, magnesium, iron, and aluminum stabilize aggregates via the formation of organic matter – clay bridges. In contrast, aggregate stability decreases with increasing amounts of exchangeable sodium. Dispersion is promoted when too many sodium ions accumulate between soil particles.

Dynamic - Aggregate stability is highly dependent on organic matter and biological activity in soil, and it generally increases as they increase. Fungal hyphae, thread-like structures used to gather resources, bind soil particles to form aggregates. Other soil organisms, like earthworms, secrete binding materials. Soil particles are also aggregated and stabilized by organic "glues" resulting from biological decomposition of organic matter. Physical disturbance, e.g. tillage, accelerates organic matter decomposition rates, and destroys fungal hyphae and soil aggregates. Soil biota help create aggregates and use them as habitat or refugia to escape predation.

Relationship to Soil Function

Changes in aggregate stability may serve as early indicators of recovery or degradation of soils. Aggregate stability is an indicator of organic matter content, biological activity, and nutrient cycling in soil. Generally, the particles in small aggregates (<0.25 mm) are bound by older and more stable forms of organic matter. Microbial decomposition of fresh organic matter releases products (that are less stable) that bind small aggregates into large aggregates (>2-5 mm). These large aggregates are more sensitive to management effects on organic matter, serving as a better indicator of changes in soil quality. Greater amounts of stable aggregates suggest better soil quality. When the proportion of large to small aggregates increases, soil quality generally increases.

Stable aggregates can also provide a large range in pore space, including small pores within and large pores between aggregates. Pore space is essential for air and water entry into soil, and for air, water, nutrient, and biota movement within soil. Large pores associated with large, stable aggregates favor high infiltration rates and appropriate aeration for plant growth. Pore space also provides zones of weakness for root growth and penetration.

Problems with Poor Function

Aggregate stability is critical for infiltration, root growth, and resistance to water and wind erosion. Unstable aggregates disintegrate during rainstorms. Dispersed soil particles fill surface pores and a hard physical crust can develop when the soil dries. Infiltration is reduced, which can result in increased runoff and water erosion, and reduced water available in the soil for plant growth. A physical crust can also restrict seedling emergence.

Wind normally detaches only loosely held particles on the soil surface, but as blowing soil particles are accelerated by the wind they hit bare soil with sufficient energy to break additional particles loose from weakly aggregated soil. This action increases the number of particles that can be picked up by the wind and abrade a physically-unprotected soil surface.

Practices that lead to poor aggregate stability include:

- Tillage methods and soil disturbance activities that breakdown plant organic matter, prevent accumulation of soil organic matter, and disrupt existing aggregates,
- Cropping, grazing, or other production systems that leave soil bare and expose it to the physical impact of raindrops or wind-blown soil particles,
- Removing sources of organic matter and surface roughness by burning, harvesting or otherwise removing crop residues,
- Using pesticides harmful to beneficial soil microorganisms.

Improving Aggregate Stability

Practices that keep soil covered physically protect it from erosive forces that disrupt aggregation, while also building organic matter. Any practice that increases soil organic matter, and consequently biological activity, improves aggregate stability. However, it can take several growing seasons or years for significant organic matter gains. In contrast, management activities that disturb soil and leave it bare can result in a rapid decline in soil organic matter, biological activity and aggregate stability.

Aggregates form readily in soil receiving organic amendments, such as manure. They also form readily where cover and green manure crops and pasture and forage crops are grown, and where residue management and/or reduced tillage methods are used.

Improving aggregate stability on cropland typically involves cover and green manure crops, residue management, sod-based rotations, and decreased tillage and soil disturbance. Aggregate stability declines rapidly in soil planted to a clean-tilled crop.

Pasture and forage plants have dense, fibrous root systems that contribute organic matter and encourage microbial activity. However, grazing and fertility must be managed to maintain stands and prevent development of bare areas or sparse vegetation.

Conservation tillage systems, such as no-till with cover crops, reduce soil disturbance, and provide and manage residue for increased soil organic matter and improved aggregate stability. Additionally, surface roughness provided by crop residues protects soil from wind erosion.

Conservation practices resulting in aggregate stability favorable to soil function include:

- Conservation Crop Rotation
- Cover Crop
- Pest Management
- Prescribed Grazing
- Residue and Tillage Management
- Salinity and Sodic Soil Management
- Surface Roughening

Measuring Aggregate Stability

Measuring Water Stable Aggregates is described in the Soil Quality Test Kit Guide, Section I, Chapter 8, pp. 18 - 19. See Section II, Chapter 7, pp. 69 - 71 for interpretation of results.

Arshad MA, Lowery B, and Grossman B. 1996. Physical Tests for Monitoring Soil Quality. In: Doran JW, Jones AJ, editors. Methods for assessing soil quality. Madison, WI. p 123-41.

Kemper WD, Rosenau RC. 1986. Aggregate Stability and Size Distribution. In: Klute A, editor. Methods of soil analysis. Part 1. Physical and mineralogical methods. Madison, WI. p 425-42.

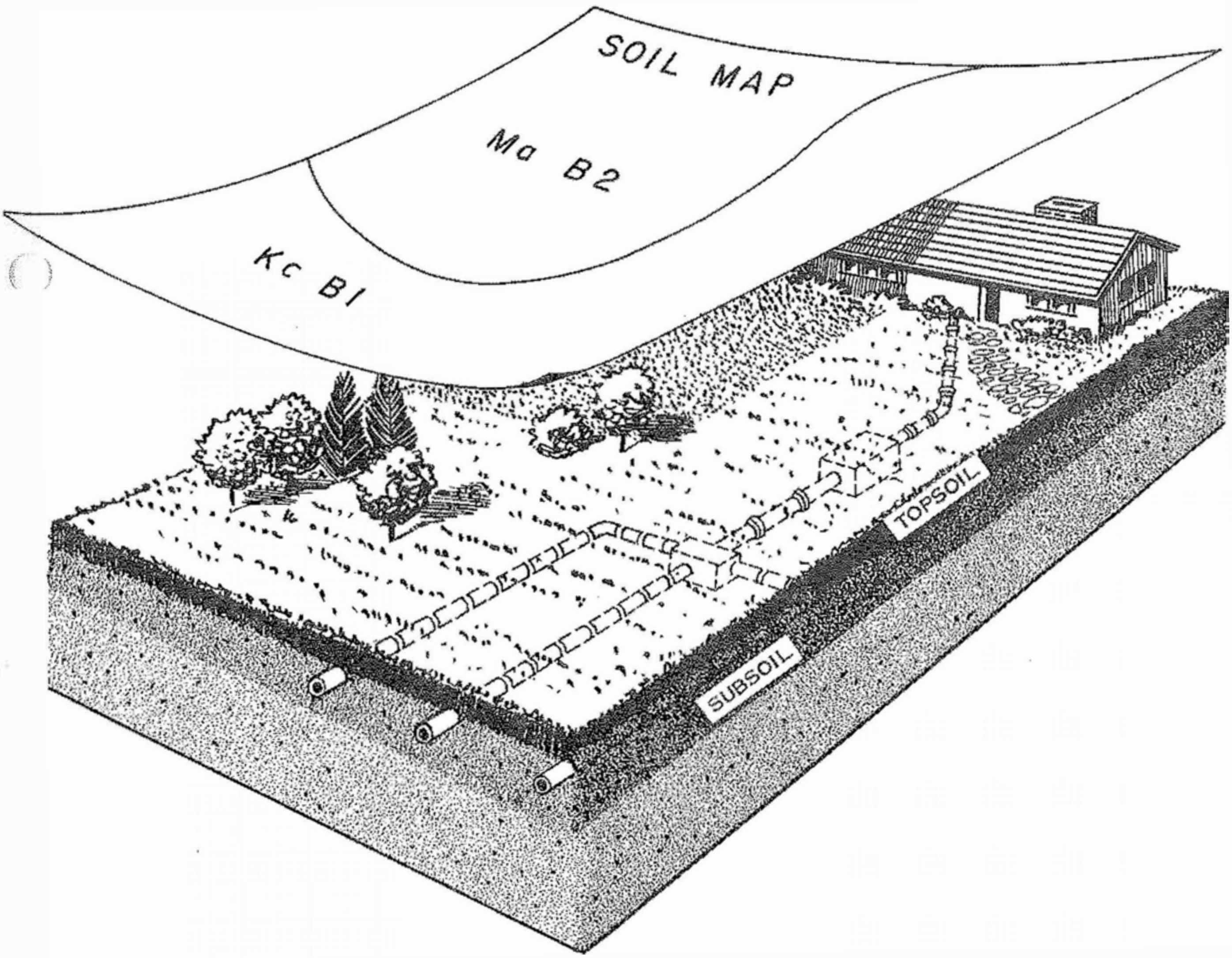
Specialized equipment, shortcuts, tips:

Determine for the top three inches of soil. However, in rangeland conditions determine for the top ¼ to ½ inch of soil as it is most likely to be removed by erosion. A 400-watt hairdryer and drying chamber are required to conduct the wet aggregate stability test.

Time needed: 2 hours

SOILS Suitable for SEPTIC TANK Filter Fields

A Soil Map Can Help You



U.S. DEPARTMENT OF AGRICULTURE Soil Conservation Service

Agriculture Information Bulletin No. 243

SOILS SUITABLE FOR SEPTIC-TANK FILTER FIELDS

A Soil Map Can Help You

By William H. Bender, ***soil scientist, Soil Conservation Service***

Septic tanks have been used for sewage disposal by some farmers and suburbanites for several decades. But the electrification of farms plus the rapid expansion of residential areas to rural communities within recent years have greatly accelerated the number of private sewage disposal systems now being installed.

If you are one of those who must have a private sewage disposal system, doubtless you would like to have one that will give many years of trouble-free service. The most satisfactory system probably will be one that has the sewer line leading to a septic tank in the yard with the overflow from the tank dispersed over a fairly large area through subsurface draintile or perforated pipe (*1*). The tile or pipe may be laid in trenches or in a seepage bed (*3*). In either case, the septic tank and tile or pipe will be covered with soil and planted to grass, leaving no visible evidence of their existence.

You should not assume, however, that you have necessarily buried all your sewage problems. You should have no serious trouble if the soil in the disposal area is satisfactory and the system properly installed. But if the soil is not satisfactory, you are likely to have trouble regardless of how well the sewage disposal system was constructed.

CONN-10255

The recent rapid expansion of residential areas to rural communities has led millions of people to build homes beyond existing sewer lines, and private sewage disposal systems have become necessary.

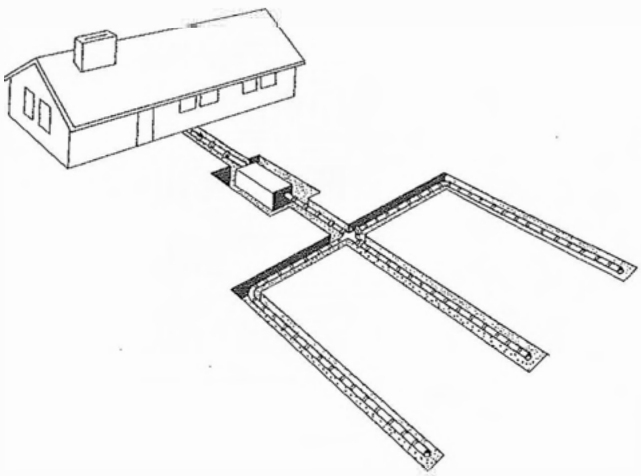
Soil Absorptive Ability Is Important

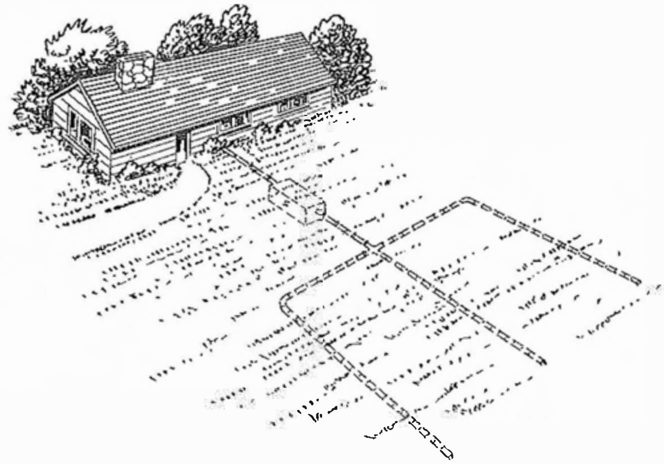
The first thing you should find out when planning a sewage disposal system is whether the soil is suitable for absorbing and filtering the liquid sewage (the effluent) that flows from the septic tank. Some soils absorb the effluent rapidly; other soils absorb it very slowly.

How long and how well a private sewage disposal system works depends largely on the absorptive ability of the soil. The septic-tank effluent must be absorbed and filtered by the soil. This is the filtering process that removes odors, prevents contamination of ground water, and prevents a concentration of unfiltered sewage that may reach the ground surface. Improperly filtered sewage that reaches the ground surface will result in offensive odors, fly-breeding areas, and the spread of diseases traceable to unfiltered sewage.

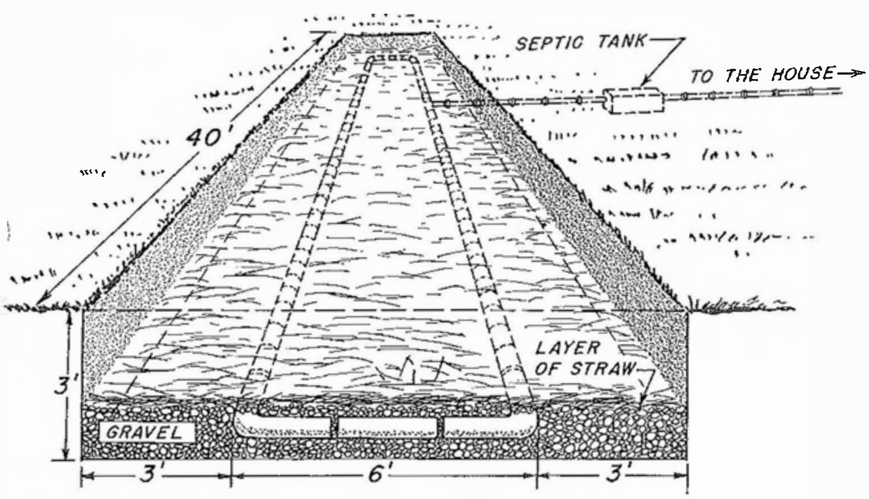
You also should know the absorptive ability of the soil in order to know the size of filter field you need. Soils with a slow rate of absorption require a larger field than those with a rapid rate. Hence, the size of building lot you need may depend on the kind of soil you have. If the filter field required is larger than your building lot will allow, local ordinances may prohibit you from installing a sewage system and thus prevent you from building your home. And some soils are not suited for septic-tank filter fields regardless of their size.

Note.—Italic numbers in parentheses refer to References, p. 11.

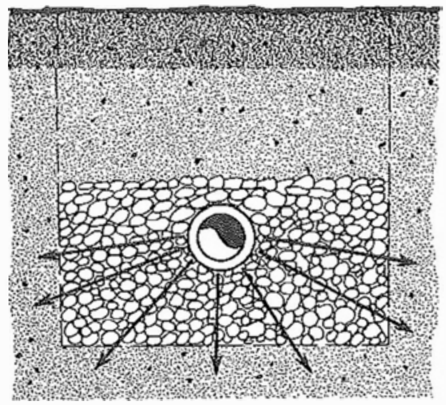




The conventional type septic-tank filter field has draintile laid in trenches (above, left). The tank and tile are covered with soil and the area planted to grass (above, right). The effluent from the tank is carried through the draintile to all points of the field where it is absorbed and filtered by the surrounding soil (right).



A seepage bed may be a satisfactory substitute for conventional trenches in some places. It operates on the same principles as a conventional filter field, except that it does not disperse the effluent over as large an area.



Why Filter Fields Fail

Numerous inspections by sanitary engineers show that most sewage filter fields that have failed to work properly were either on poorly drained soils or on soils so compact that the absorption rate was very slow.

Poorly drained soils are filled with water during wet weather and sometimes for long periods after heavy rains and there is no available space left for absorption of septic-tank effluent. Filter fields that function well during dry weather may fail to function during wet periods on such soils.

Where there is a layer of soil with a very slow absorption rate near the surface the septic-tank effluent often rises to the ground surface even during dry periods. And during wet weather the filter field usually becomes a boggy mess.

Other septic-tank filter fields have failed where the land was too steep, where there was a seasonal high water table, where there was only a shallow layer of soil over bedrock, where there was a cemented soil layer near the surface, or where the area was flooded from a nearby stream.

Seepage Pits

In some situations the septic-tank effluent may be disposed of by having it flow into a seepage pit instead of being dispersed through a subsurface-tile filter field. A seepage pit is a covered pit with a porous lining through which the effluent seeps into the surrounding soil.

Ordinarily, seepage pits will not be approved by local health inspectors except where subsurface-tile systems cannot be constructed. But if you should use a seepage pit, you should keep in mind that the effluent must be absorbed by the surrounding soil. Hence, the soil properties are fully as important in planning for a seepage pit as for subsurface-tile systems; the soil depth is even more important because of the greater depth of the seepage pit.

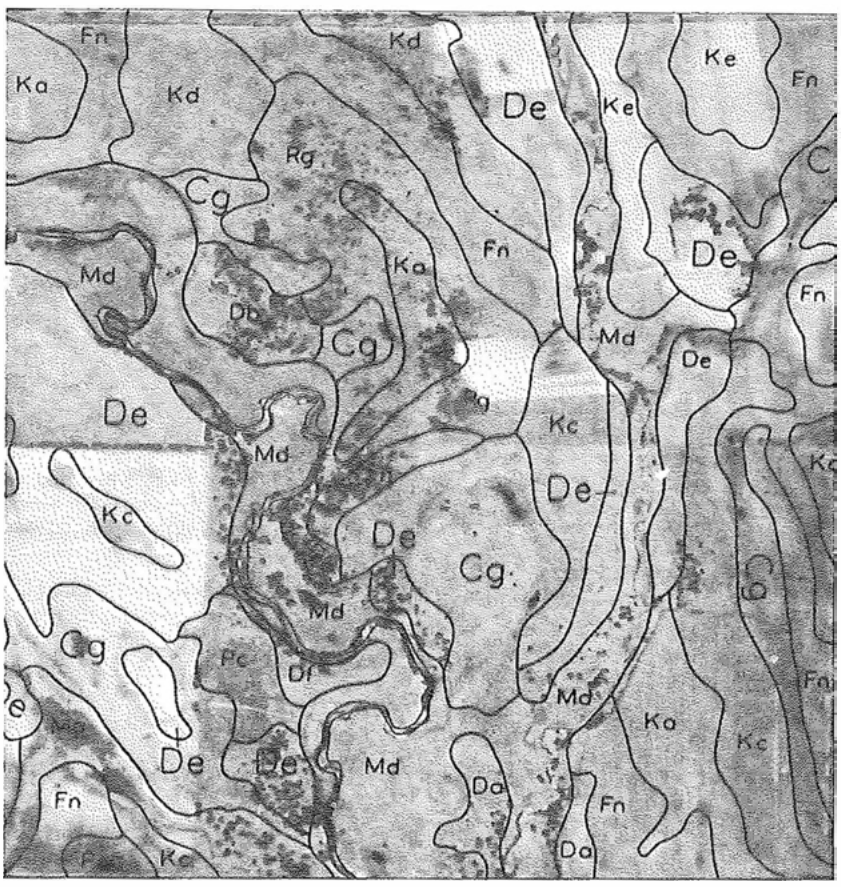
Soil Surveys Show Areas Suitable for Filter Fields

Soil-survey reports contain soil maps and soil descriptions and interpretations. The soil maps show the location of each kind of soil. The soil descriptions and interpretations in all reports indicate the suitability of each kind of soil for various agricultural purposes; the interpretations in most reports give information useful for many nonagricultural purposes. The newer reports contain interpretations useful for highway engineering, building-foundation construction, trenching operations for pipelines and power cables, subsurface sewage disposal, and so on.

Soil-survey reports have been published for more than 1,800 areas in the United States. Most areas include an entire county. Most of the older reports do not contain interpretations on soil suitability for septic-tank filter fields, but the soil descriptions contain the basic information necessary for making such interpretations. If you do not feel qualified to interpret the significance of the various soil properties described in a report, you should consult someone experienced in this line of work. Usually, you can get assistance from the person or agency from which you got the soil-survey report.

Soil-survey reports are published by the Soil Conservation Service of the U.S. Department of Agriculture in cooperation with State agricultural experiment stations. For information on whether a soil survey has been issued for your county and where a copy may be obtained or consulted, check with the local or county office of the Agricultural Extension Service, the Soil Conservation Service, or the soil conservation district or with your State agricultural experiment station.

Soil maps and reports can be used to predict the behavior of a sewage filter field with a reasonable degree of accuracy. The soil map is reliable for predicting the general suitability of an area of several acres, but it may not contain sufficient detail to predict the suitability for a specific site. Soil variations may occur within short distances, and most maps are not detailed enough to supply the precise information as to where on a building site you should locate your filter field. Therefore, onsite evaluation by a soil scientist or measurements of the water-movement rate may be needed. The rate of water movement is measured by a percolation test as described on page 11. A percolation test will not only indicate whether the soil is suitable but will also enable you to calculate the size of the filter field you need.



Soil map on aerial photograph of about 1 square mile in a North Central State.

Some Typical Soil Descriptions

The soil map at the lower left and the soil descriptions below for Dakota and Clyde soils were taken from a recent soil-survey report from a North Central State. The soils described may be located on the map by the symbols (De) and (Cg). In the descriptions below, the items that particularly apply to soil suitability for septic-tank filter fields are in italics.

Dakota Soils

The Dakota soils are dark-colored, level to undulating prairie soils on glacial outwash plains. Their slopes range from 0 to 17 percent. The soils have developed on sandy or gravelly material under prairie grasses.

The Dakota loams have finer textured surface soils and subsoils than the sandy loams. The loams are *well drained*, and the sandy loams are *somewhat excessively drained*.

Dakota loam, 0 to 1 percent slopes (De)—This soil lies on glacial terraces *above overflow*. The surface soil is very dark brown and *fairly high in organic matter*. *At depths of 30 to 42 inches are stratified layers of loose porous sand and gravel of varying thickness.*

Runoff is medium, and *internal drainage is medium to rapid*. The soil is *easy to work* and can be plowed throughout a wide range of moisture content.

Clyde Soils

The dark-colored Clyde soils occur in *very poorly drained depressional areas* on the glacial till plain. Clyde soils have formed from Iowan glacial till under a cover of swampgrass. The black color and organic matter content have resulted from the decay of sedges and rank sloughgrass.

Because of their low position the Clyde soils *are periodically flooded*, especially after heavy rains. Except during dry periods, *the water table is often very high and the soils are excessively moist. A few areas are saturated most of the time.* Artificial drainage is needed for successful crop production.

Clyde silty clay loam (Cg)—This soil, to depths of about 12 to 20 inches, is very dark gray *plastic* silty clay loam, high in organic matter. This layer is underlain by a dark grayish-brown *very plastic* silty clay. Sand and gravel occur in varying amounts in the lower layers. In some places *many boulders are on the surface.*

This soil is fertile, but because of its *heavy texture and wetness,* it is often difficult to work. It is generally *too moist to plow* early in spring.

By studying the soil descriptions given above it becomes obvious that *Dakota loam* is suitable for a septic-tank filter field. It is well drained, with medium to rapid permeability. It is generally well above the flood plains. It is usually on gentle slopes and easy to work so that construction is simple.

It becomes equally obvious, however, that the *Clyde silty clay loam* is not suitable. These soils are periodically flooded, have a high water table most of the time, and are very poorly drained. Furthermore, they have a considerable amount of plastic clay that will absorb septic-tank effluent very slowly when wet.

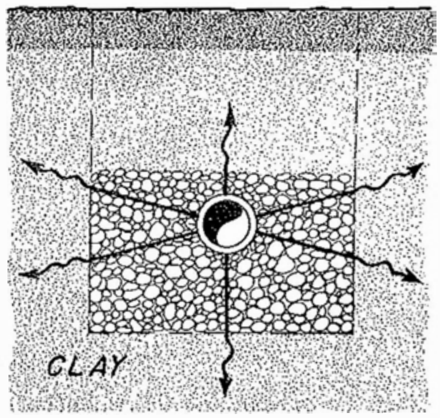
Soil Factors That Affect Filter Fields

How satisfactorily your sewage disposal system works depends largely on the rate at which the septic-tank effluent moves into and through the soil. But there are several other soil characteristics that may affect the soil suitability, such as ground-water level, depth of soil, types of underlying material, slope of the land surface, proximity to streams or lakes, and so on. You should consider all these characteristics in determining the location and size of your filter field.

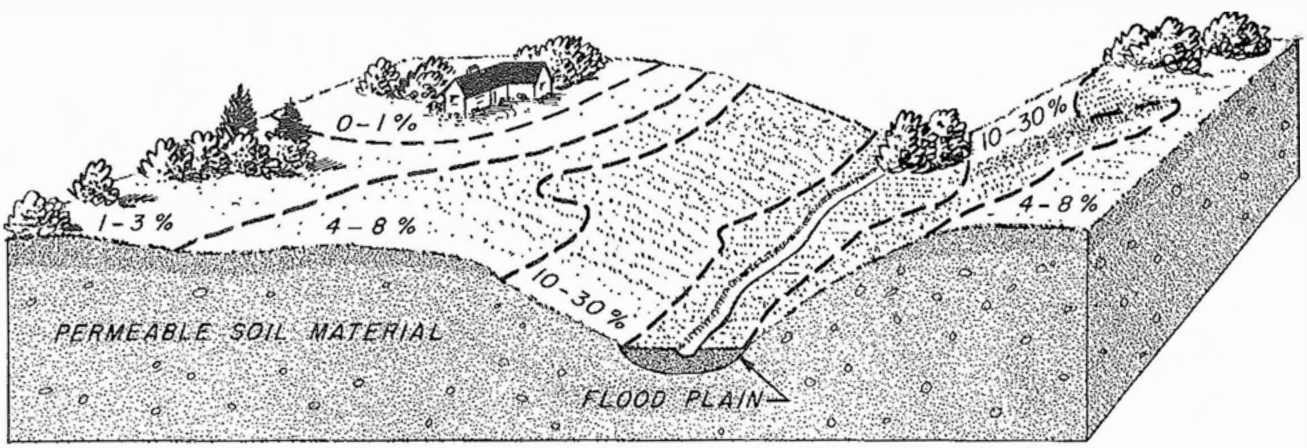
Soil Permeability

The rate of water movement through the soil is called its permeability. This is influenced by the amount of gravel, sand, silt, and clay in the soil, the kind of clay, and other factors. Water will move faster through sandy and gravelly soils than through soils with a large amount of clay.

Also important is the kind of clay in a soil. Some kinds of clay are very plastic and expand so much when wet that the pores of the soil swell shut. This slows water movement and reduces the capacity of the soil to absorb septic-tank effluent. Other kinds of clay expand very little when wet and therefore have little influence on the rate of water movement. Soil survey reports indicate the plasticity of a soil where it is important by giving the shrink-swell potential.



Septic-tank effluent moves into compact, plastic soil very slowly. Such soils should not be used for filter fields.



Septic-tank filter fields should operate very well in the deep, permeable soil above. Layout and construction problems may be encountered on slopes over 10 percent. Filter fields should not be constructed on the flood plain.

Soils can be rated on the basis of permeability into groups that are good, fair, poor, or unsuitable for septic-tank filter fields. Some soil-survey reports show the permeability or percolation rates in inches per hour for the different kinds of soil. Other reports give a rating of very rapid, rapid, moderate, slow, or very slow permeability. Some of the older reports do not give the permeability or percolation rating, but it can be estimated from the soil characteristics described in the report.

N-22550

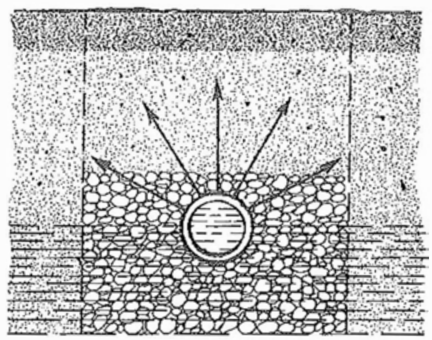
The septic tank and filter field for the suburban home (background) is located just beyond the wire fence (foreground). The soil is Iredell silt loam, which has a very plastic clay subsoil that is almost impermeable when wet. The roadside ditch in the immediate foreground is filled with septic-tank effluent that has seeped from the filter field, even though this picture was taken during a summer drought.

Ground-Water Levels

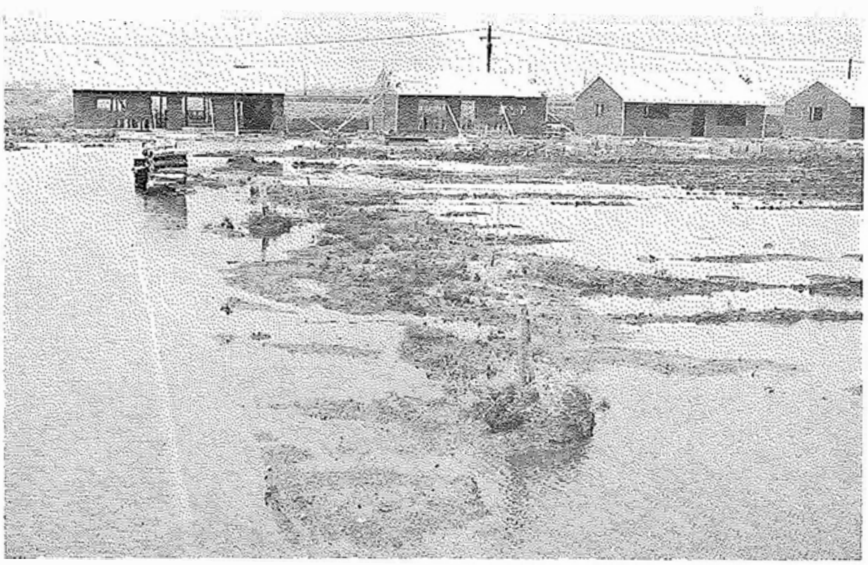
Some soils have a ground-water level within a foot or a few feet of the surface the year round. Other soils have a high ground-water level during certain seasons, usually during the winter and early spring. Still others may have a high water level during periods of prolonged rainfall. A sewage filter field will not operate properly under any of these conditions.

When the ground-water level rises to the height of the subsurface tile or pipe, the soil becomes saturated and there is no room in it for septic-tank effluent. Hence, the effluent must remain near or rise to the surface of the ground, and you have an ill-smelling, unhealthy bog in your filter field.

Soil-survey reports usually contain information about soil drainage and ground-water levels, especially where the water level is near the ground surface. Some reports give the depth in feet or inches to seasonally high water tables. Other reports use such terms as "well drained," "poorly drained," or "very poorly drained." Well-drained soils usually are suitable for septic-tank filter fields, while poorly drained soils are not.



The high water table at tile level (above) forces the sewage effluent upward to the soil surface. This creates an unsanitary condition and health hazard.



ILL-2035

The poorly drained soil on which these houses are being built will not be satisfactory for septic-tank filter fields.

Depth to Rock, Sand, or Gravel

Rock formations should be at least 4 feet below the bottoms of the trenches or seepage bed in order to provide adequate soil depth for the filtration and purification of septic-tank effluent.

In areas where water supplies come

from wells and the underlying rock formation is limestone, the soil depth may need to be greater to prevent unfiltered sewage effluent from traveling through the cracks and crevices that are commonly found in limestone.

Soil-survey reports describe the depth to rock formations or coarse gravel in areas where they are near the soil surface. The reports also describe the kind of rock and the type of soil material over the rock or gravel formations.

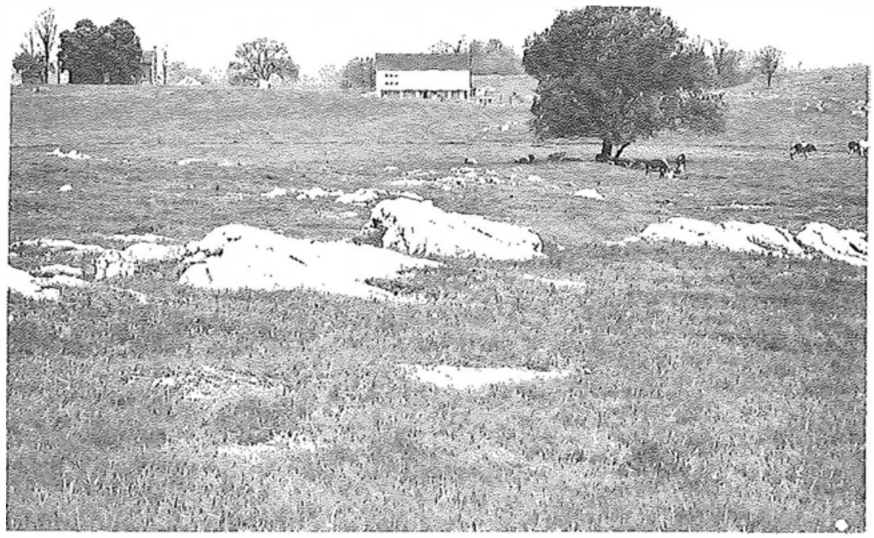
Slope of the Ground Surface

Slopes of less than 10 percent usually do not create serious problems in either the construction or maintenance of filter fields provided the soils are otherwise satisfactory. The trenches must be constructed approximately on the contour, however, so that the effluent will flow slowly through the tile or pipe and be dispersed properly over the filter field. And you will likely wish to use serial distribution if you use a trench system on sloping ground (*2*).

On steeper slopes, trench-filter fields are more difficult to lay out and construct and seepage beds become impractical. In addition, there may be a serious problem in controlling the lateral flow of the effluent to the downhill soil surface. This downhill flow may reach the soil surface before the effluent is properly filtered on steep slopes because of the short distance from the trenches to the soil surface down the slope. Wet, contaminated seepage spots may result.

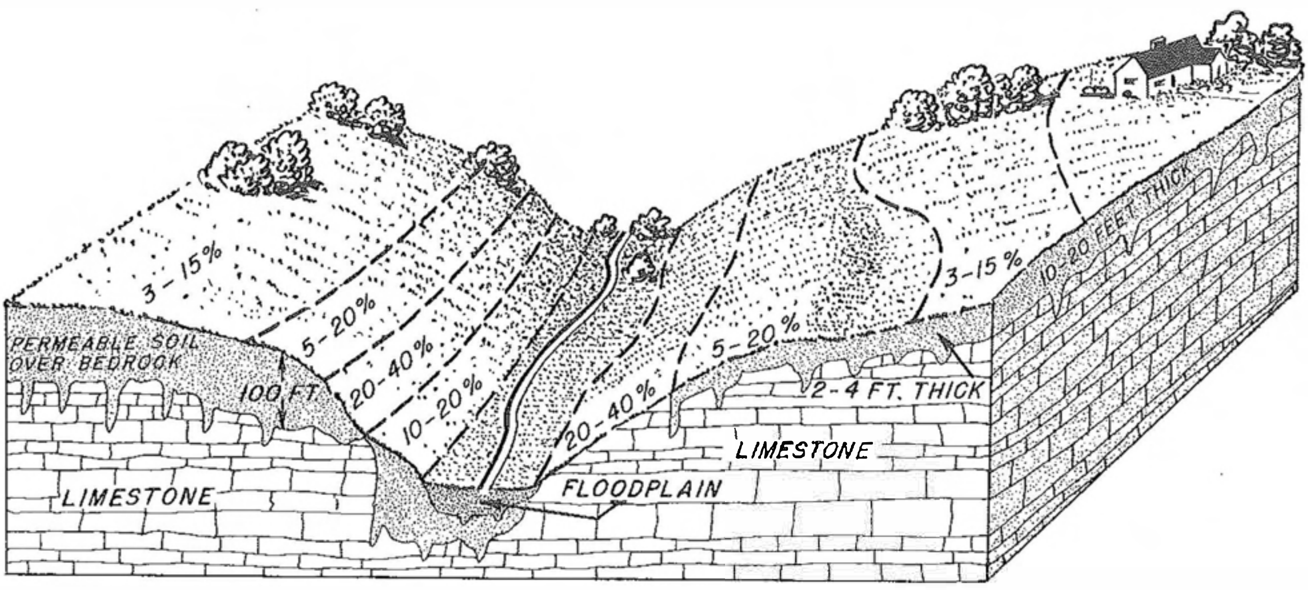
The lateral flow of effluent to the soil surface on steep slopes is often a serious problem if there is a layer of dense clay, rock, or other impervious material near the soil surface and especially so if the soil above the clay or rock layer is sandy.

Soil-survey reports describe these

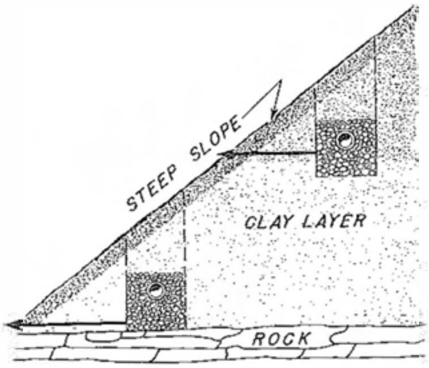


MD-49

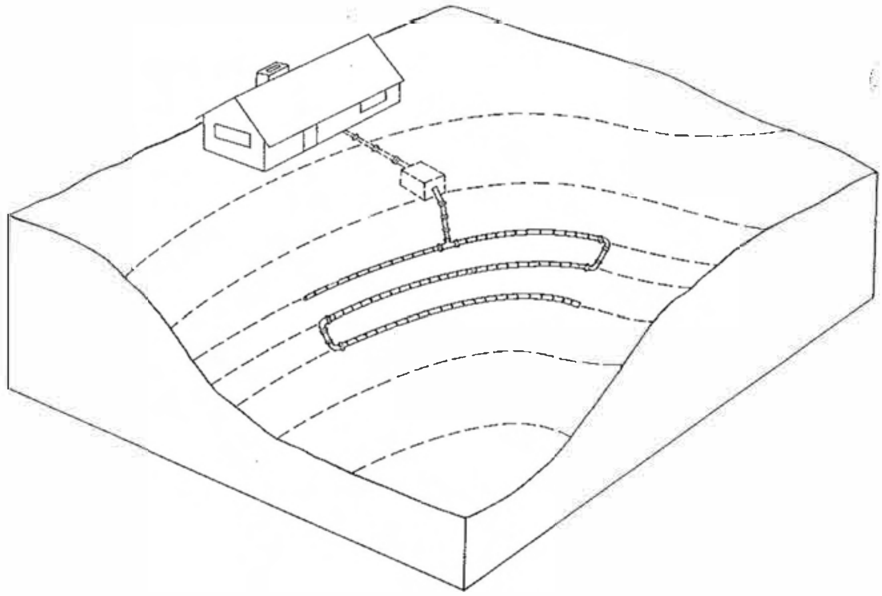
Shallow soil over massive rock may be scenic, but it presents many problems for septic-tank filter fields. Not only will construction be difficult; it is doubtful that you will find enough soil in any location to properly filter the sewage effluent.



The deep soil over limestone, at the left, makes this area suitable for septic-tank filter fields, except that layout and construction may be difficult on the steeper slopes. The soil area 10 to 20 feet thick, at extreme right, is questionable for filter fields if water supplies come from wells. The shallow soil, 2 to 4 feet thick, is unsuitable for filter fields and might result in stream pollution if fields are placed there.



A filter field on a steep slope where there is a layer of dense clay, rock, or other impervious material near the surface is unsatisfactory. The effluent will flow above the impervious layer to the hillside soil surface and run unfiltered down the slope.



In constructing a septic-tank filter field on sloping land, the tile lines should be laid on the contour. Serial distribution, as depicted above, should be used on most sloping fields or in fields where there is a change in soil type.

various conditions of slope, soil texture, clay or rock layers, and other conditions that may affect proper sewage filtering. By studying these descriptions you should be able to make correct interpretations as to the suitability of an area for a filter field.

Nearness to Streams or Other Water Bodies

Local regulations will probably require it, and certainly you will want to keep your filter field at least 50 feet from any stream, open ditch, lake, or other watercourse into which unfiltered and contaminated effluent can escape and spread.

Never place a filter field on the flood plain near a stream that is subject to flooding. An occasional flood over the filter field impairs its efficiency; frequent floods soon destroy its effectiveness.

Soil maps show the location of streams, open drainage ditches, lakes, ponds, and those alluvial soils subject to flooding. The reports usually indicate the probability of flooding for alluvial soils.

Changes in Soil Type

Soil types sometimes change within a distance of a few feet. A change in the kind of soil within a filter field is not important if the soils have about the same absorptive ability. It may be significant, however, if the soils differ greatly. You should use serial distribution of the effluent in fields where there is a considerable difference in the soils, so that each kind of soil may absorb and filter the effluent according to its capabilities (*2*).

The boundaries shown on soil maps that separate one kind of soil from another are approximate. At the scale normally used in published maps (1: 20,000) these lines may not be accurate enough to locate a suitable filter field. This is especially true if some soils not suitable for filter fields occur in the area. Hence, it is advisable to have a soil scientist examine the area or have a qualified person run percolation tests. In some cases it may be advisable to do both.

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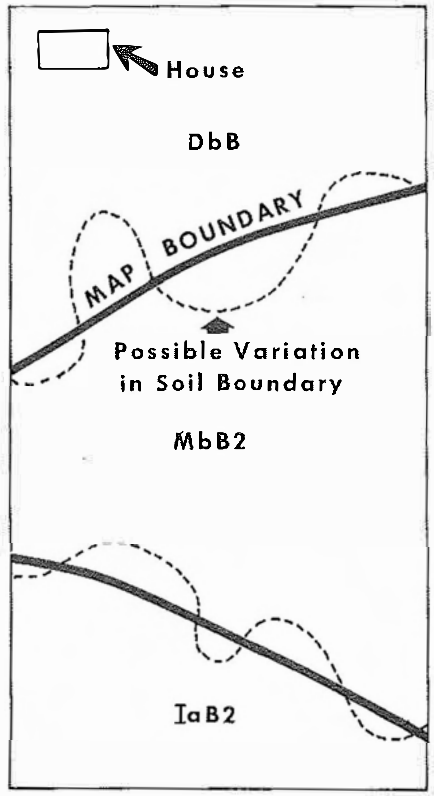
Sewage filter fields will not operate properly when flooded and for some time after the floodwater recedes. Filter fields should never be placed on land that floods frequently.

Using a Soil Map to Select a Site for a Filter Field



The soil map below is typical of the Piedmont region of the Southeast. The lines on the map show the general boundaries between the different kinds of soil. The symbols, such as (MbB2), show the kind of soil that predominates within each area outlined. The soils are fully described in the soil survey report from which this map was taken.

The hypothetical building lot of about 3 acres outlined in the upper right center of the map has three different kinds of soil, Davidson, Mecklenburg, and Iredell. These soils commonly occur close together in the Piedmont region.

The *Davidson clay loam, gently sloping phase* (DbB) is a deep (6 to 25 feet), well-drained soil with moderate permeability and a high water-holding capacity. It is rated as *good* for septic-tank filter fields.

The *Mecklenburg loam, eroded gently sloping phase* (MbB2) is moderately deep (4 to 15 feet) with good drainage and slow to moderate permeability. It is rated as *poor* for septic-tank filter fields.

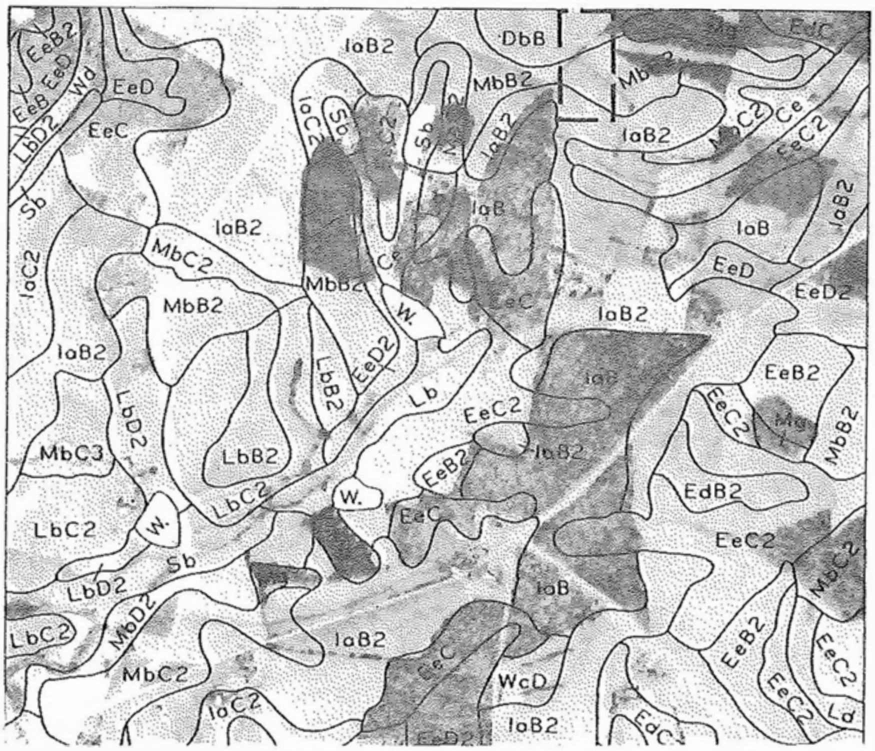
The *Iredell loam, eroded gently sloping phase* (IaB2) has a depth of 2 to 8 feet to bedrock. Its permeability is very slow. It has a very plastic subsoil that swells and closes soil pores when wet. This soil is *unsuitable* for filter fields.

The owner of this hypothetical lot can tell by looking at the soil map that the upper part of the lot has *Davidson* soil that is suitable for a filter field. The central part, with *Mecklenburg* soil, is questionable. The lower part, with *Iredell* soil, is unsuitable.

Assuming that he wishes to build a home on the high point of the lot (upper left corner), he would doubtless try to locate the septic-tank filter field on the Davidson soil. But if he plans to drill a well near the house, he should place the filter field at least 100 feet downslope from the well (*1*). This places it near the boundary line, as shown on the map, between the *Davidson* and *Mecklenburg* soils. And since this is a small scale map he cannot be sure that the soil change at any specific point is exactly on this boundary line.

The sketch at the right illustrates how actual soil changes might vary from the soil-change boundaries shown on a soil map. The heavy solid lines show the soil boundaries for this lot, as given on the map. The dotted lines indicate possible variations in these boundaries if the map was drawn in sufficient detail to pinpoint each small area the size of a filter field.

Hence, the owner of this lot should have an experienced soil scientist determine the soil boundaries more accurately or have percolation tests run to locate the site and size of his filter field. In many areas local regulations require percolation tests prior to installing septic-tanks.



Soil map from the Piedmont region, with a hypothetical building lot outlined at upper edge of the map.

Calculating the Size of Filter Field Needed

The size of filter field needed depends mainly on the amount of sewage to be filtered and the absorptive ability of the soil. The amount of sewage depends largely on the number of people living in a home. Most public health agencies set standards for size of filter fields on the basis of the number of bedrooms in a home, the best general guide to the probable number of occupants.

Standard Trenches. In calculating the size of filter field needed where subsurface tile or perforated pipe is laid in trenches, first determine the percolation rate of the soil. Then look at the chart below to determine the square feet of absorption area needed per bedroom. Multiply this figure by the number of bedrooms in your home. This gives you the total square feet of absorption area needed.

You count only the bottoms of the trenches as the effective absorption area. Thus, to find out the total length your trenches and draintile or perforated pipe should be, divide the square feet of absorption area needed by the width (in feet) of the trenches you plan to use.

Since the trenches should be spaced 6 to 8 feet apart, multiply the total trench length by the distance between the trench center lines to get the total area, in square feet, to be occupied by the filter field.

A Sample Calculation. For a 2-bedroom home where 24-inch wide trenches are used.

Percolation tests show 1-inch drop in 30 minutes. This is equivalent to a percolation rate of 2 inches per hour.

Chart at left shows the required absorption area as 250 square feet per bedroom.

Absorption area required for 2 bedrooms = 500 square feet.

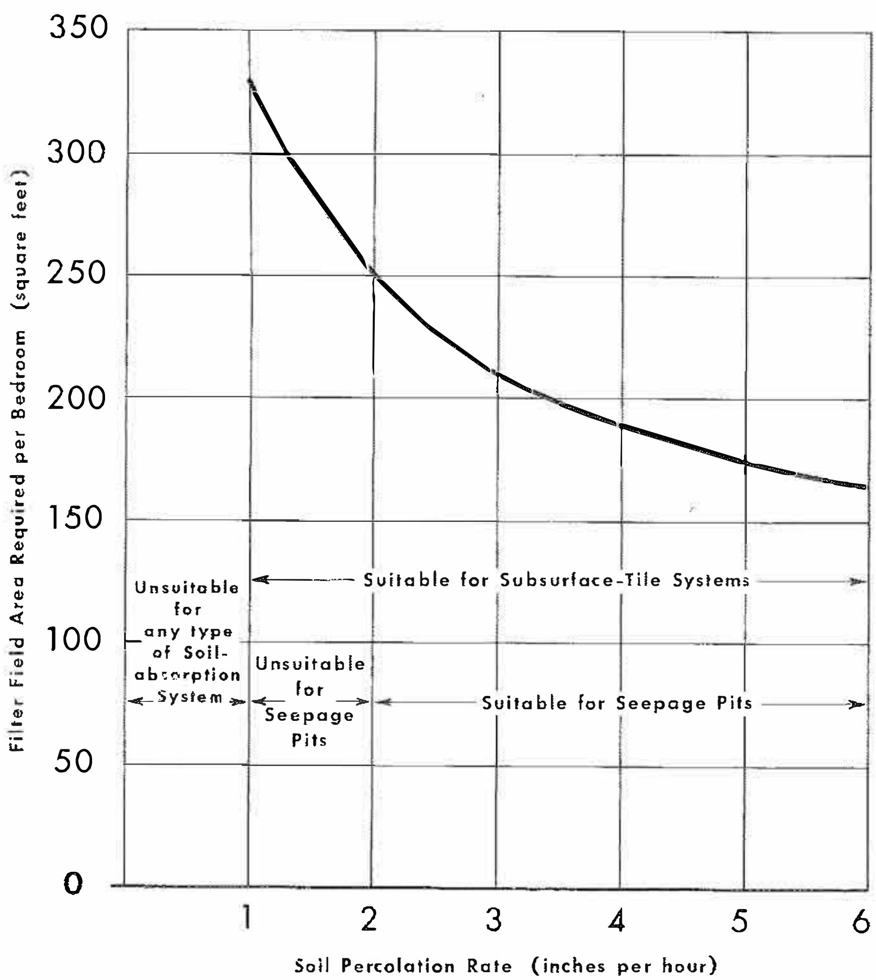
500 square feet ÷ by 2 feet (trench width) = 250 feet—total length of trench and tile or pipe required.

For this system you should, preferably, use 4 trenches about 62 feet long. You may use 3 trenches about 84 feet long if such a layout best fits your space. You should not use trenches more than 100 feet long (*1*).

Seepage Beds. To calculate the size of seepage bed needed, determine the absorption area needed in th same way as for a trench system. Yo count the entire bottom of the bed as effective absorption area. Thus, for a 2-bedroom house where the percolation rate is 2 inches per hour, you need 500 square feet in the bottom of the seepage bed. A bed 10 feet wide and 50 feet long or a bed 12 feet wide and 42 feet long would meet the requirements.

Seepage Pits. To calculate the size of seepage pit or pits needed, determine the absorption area needed in the same way as for standard trenches.

You count only the vertical walls below the inlet as the effective absorption area of a seepage pit. Do not count the area on the bottom of the pit. Thus, to find out the size of pit or pits needed divide the total square feet of absorption area needed by the effective depth (in feet) you can safely dig your pit. This will give you the circumference required. Divide the required circumference by 3.14 to get the diameter of the pit needed.



Filter-field area needed for private residences. [Adapted from Manual of Septic Tank Practice, (*1*, p. 7)]

How To Make a Percolation Test

If there is any doubt about the absorptive ability of the soil where you plan to locate a filter field, you should have a percolation test made (*1*). Most local regulations require that trained personnel make the percolation test. From the test findings you can calculate the size of the filter field needed. The test is made as follows:

1. Dig six or more test holes 4 to 12 inches in diameter and about the depth that you plan to make the trenches or seepage bed. Space them uniformly over the proposed filter area. Roughen the sides of each hole to remove any smeared or slickened surface which might interfere with water entry into the soil. Remove loose dirt from the hole bottoms, and add 2 inches of sand or fine gravel to protect the bottoms from sealing.

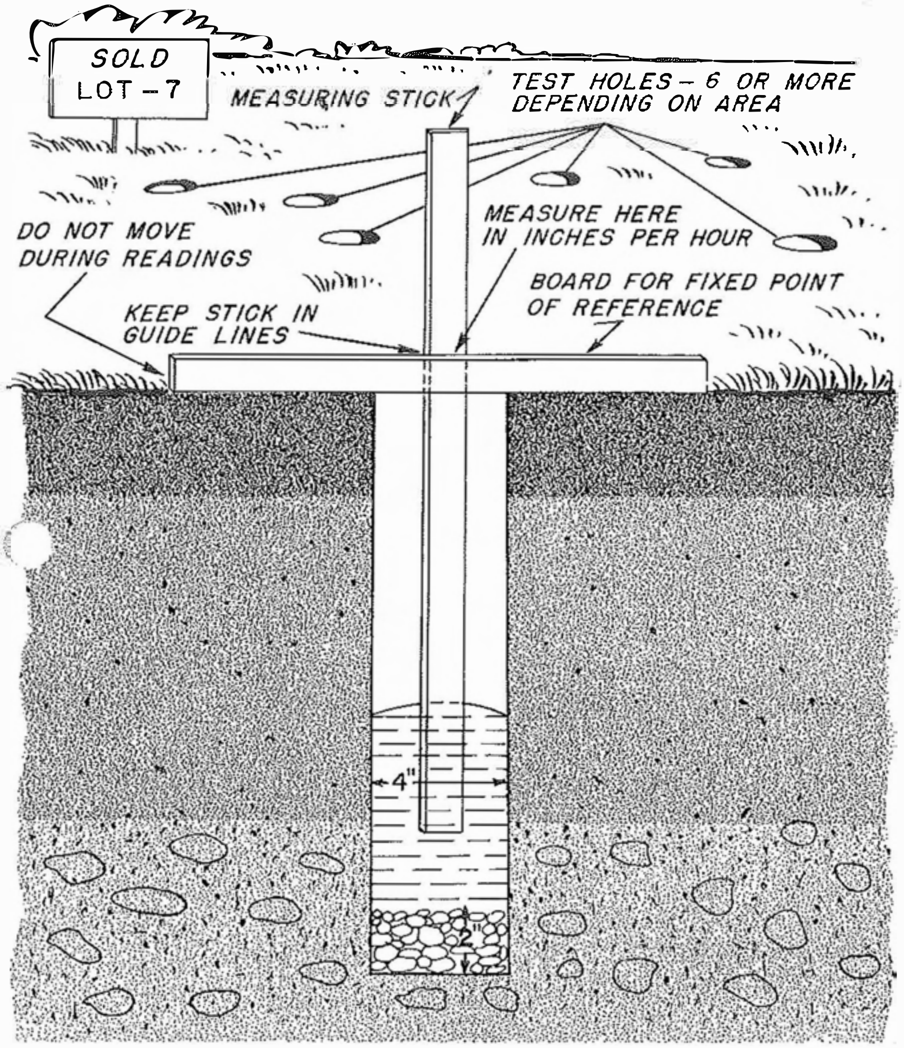
2. Pour at least 12 inches of water in each hole. Add water, as needed, to keep the water depth up to 12 inches for at least 4 hours and preferably overnight during dry periods. The soil must be thoroughly wetted so that it functions in the same manner as it will during the wettest season of the year. This allows for making the test during dry or wet seasons so that the results will be the same regardless of the season.

3. If water remains in the test holes overnight, adjust the water depth to about 6 inches. Measure the drop in water level over a 30-minute period. Multiply this measurement by 2 to convert to inches per hour. This is the percolation rate. The average rates for all the test holes is the percolation rate you should use in calculating the size of filter field you will need from the chart on page 10.

4. If no water remains in the test holes after the overnight period, add water to bring the depth to 6 inches. Measure the drop in water level every 30 minutes for 4 hours. Add water as often as needed to keep it near the 6-inch level. Use the drop in water level that occurs during the final 30 minutes to calculate the percolation rate.

5. In sandy soils where the water seeps away rapidly, the time interval between measurements may be reduced to 10 minutes and the test run for 1 hour. Use the drop that occurs during the final 10 minutes to calculate the percolation rate.

6. Percolation tests for seepage pits may be made in the same way except that each contrasting layer of soil should be tested. Use a weighted average of the results in figuring the size pit you need from the chart on page 10.



A percolation test hole with measuring stick is shown in the foreground with other test holes properly distributed over the field in the background.

REFERENCES

(1) *Manual of septic tank practice,* U.S. Dept. Health, Educ., and Welfare, Public Health Serv. Publ. 526, 1958. For sale by Supt. Docs., Govt. Printing Off., Wash. 25, D.C. Price 40 cents, including all addendums.
(2) *Addendum to part 1, manual of septic tank practice,* PHS Publ. 526. U.S. Dept. Public Health, Educ., and Welfare. 1959.
(3) *Addendum 2 to part 1, manaul of septic tank practice,* PHS Publ. 526. U.S. Dept. Public Health, Educ., and Welfare. In press.
(4) *Septic tank soil absorption systems for dwellings,* U.S. Housing and Home Finance Agency, Div. of Housing Res.. Construction Aid 5, 1954. For sale by Supt. Docs., Govt. Printing Off., Wash. 25, D.C. Price 25 cents.

Some Pointers in Selecting a Site for a Septic-Tank Filter Field

Soils vary so much from place to place that it is not possible to give specific recommendations the soils suitable for filter fields that would fit all localities. Furthermore, local regulations of health authorities vary greatly.

Before you design and construct a private sewage disposal system you should become familiar with the regulations, permit and inspection systems, and penalties of the local authority having jurisdiction over your area.

You probably can get advice and planning aid from your city or county planning commission, local health department, agricultural extension specialist, or engineering and agricultural departments of colleges and universities and State boards of health.

In addition to conforming with all local regulations, you should take certain precautions for your own protection and convenience in selecting the site for your sewage filter field. Some of the more important things to keep in mind are:

Soil permeability should be moderate to rapid, with a percolation rate of at least 1 inch per hour. If there is any doubt about the absorptive rate of the soil you should have a percolation test made.

Ground-water level, during the wettest season, should be at least 4 feet below the ground surface for a subsurface-tile filter field and 4 feet below the pit floor for a seepage pit.

Rock formations or other impervious layers should be more than 4 feet below the bottom of the trenches, seepage-bed floor, or pit floor.

Slope of the ground surface is not of great importance on slopes of less than 10 percent, but trench systems and seepage beds are difficult to lay out and construct on steeper slopes. If steep slopes are underlain at shallow depths by rock or other impervious material, you may have serious problems of seepage of septic-tank effluent to the soil surface.

Distance to streams or other water bodies should be at least 50 feet. You should never install a filter field on a flood plain that is subject to flooding.

Changes in kind of soil within a filter field are important only if the soils differ greatly in absorptive ability. In such cases you should run percolation tests for the entire field, and use serial distribution of the effluent.

Soil-survey reports and maps can help you select a site where soil conditions are suitable for a sewage filter field.

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Growth Through Agricultural Progress

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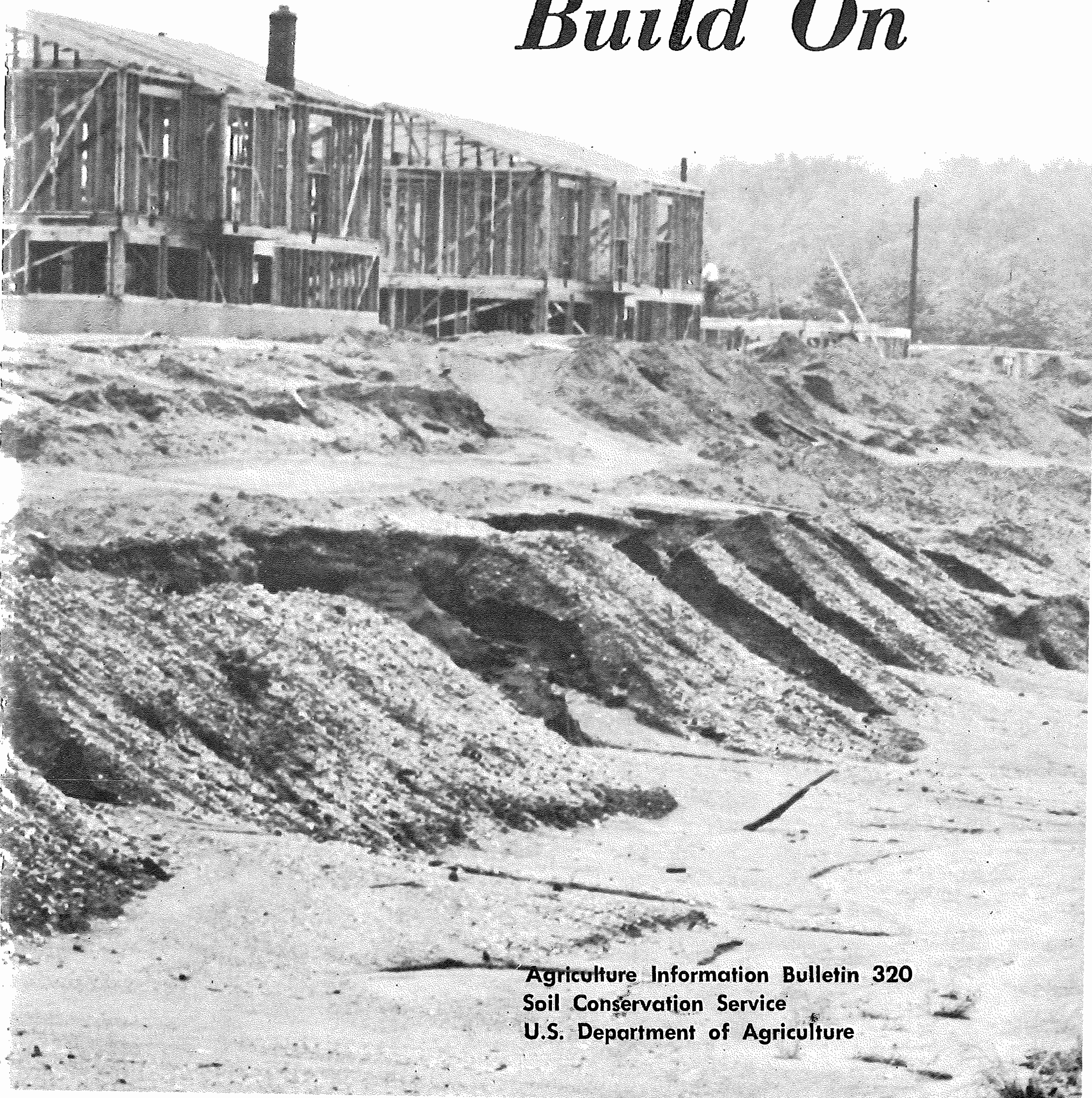
Know the Soil You Build On



Agriculture Information Bulletin 320
Soil Conservation Service
U.S. Department of Agriculture

Figure 2.—These houses were built on a flood plain similar to that shown in figure 1, area 1. It is subject to periodic flooding. More than 10 percent of the land in the United States is subject to flooding, and millions of dollars worth of damage is done by floods every year. Much of this is along our thousands of small streams, not just near the large ones. Protective measures are costly and usually require community action.

Figure 3.—These flood-plain soils are always adjacent to a stream, ditch, or drainageway and are nearly level. Water may or may not be present in the waterway. You can judge the size of the flood plain by standing on a streambank and noting the width of the level area adjacent to the stream. If you dig in the soil, you usually find a dark surface layer but no naturally developed subsoil layers. Flood-plain soil is often uniform in texture (sand, silt, and clay content) down to 4 feet or so. In some places there are layers of coarse and fine materials.

Figure 4.—Soil with a high clay content often swells when wet and shrinks when dry, thus cracking foundations unless special provisions are made during construction. This soil can expand up to 50 percent between wet and dry conditions. In addition, it may have some of the other undesirable features described elsewhere.

Figure 5.—Unstable soil like this, which shrinks when dry and swells when wet, has a high clay content in the upper 3 to 4 feet. To check, press a small sample of the moist soil between the thumb and index finger. If it is clay, a ribbon forms. Such soil is fine textured, sticky when wet, commonly dark, and feels like putty. When dry, clay soil may have many cracks 2 to 4 inches wide and 10 to 20 inches deep. The surface may be sandy, silty, or clayey, underlain by dense plastic clay.

Figure 6.—Not all slopes are subject to slippage, but it is wise to doublecheck. Neither the builder nor the purchasers of these homes knew the soil would slip when it became saturated with water. To correct this problem costs a great deal and even then the results may be unsatisfactory.

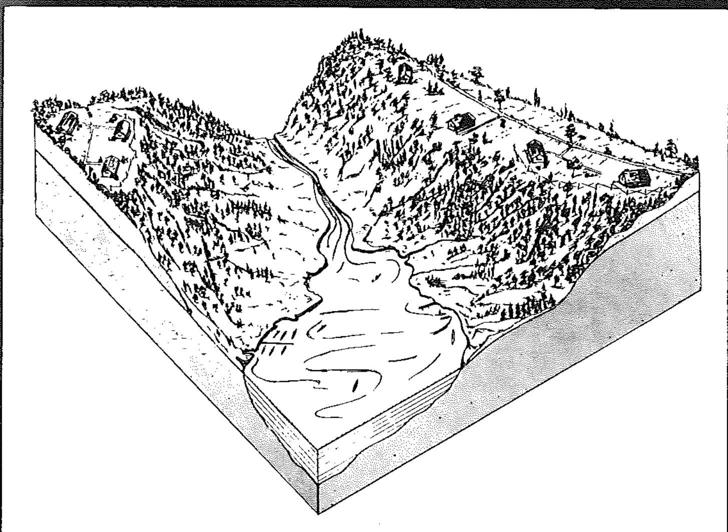


Figure 7.—Hillside slips occur on soils with a permeable surface 4 or more feet thick over a tight layer, usually clay or rock. Troublesome areas generally have a slope of 10 percent or more. You can be forewarned by studying adjacent undisturbed areas and noting any evidence of slips or steps from soil slipping down the slopes. Even in wooded areas you can see the natural slips if you look carefully. Road cuts or excavations may expose tight layers below. Soil and geology maps show potential slide areas.

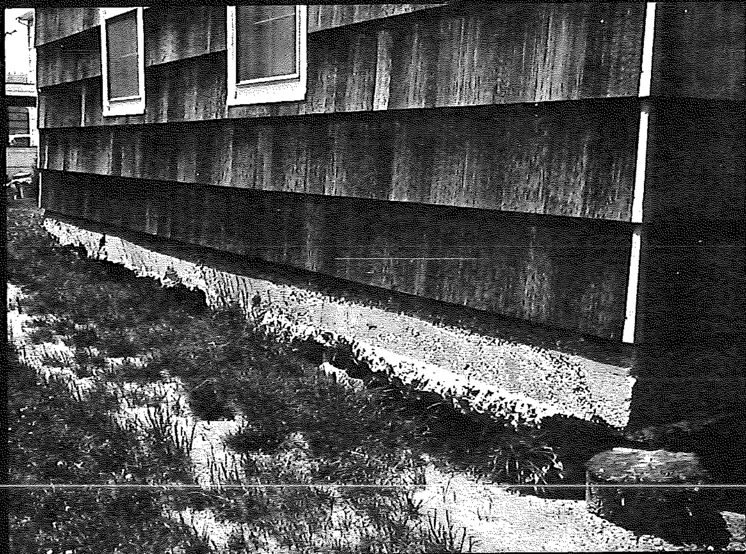


Figure 8.—More than 20 houses costing about $20,000 each were built in a former swamp area with highly organic soil. The swamp had been drained, fill added, and a cement slab placed on deep piling. In 2 years, the soil around these houses had settled about 2 feet. The soil will continue to settle at about this rate for years to come. This problem is difficult and costly to correct.

Figure 9.—Deep organic soil can be detected by i
It usually lies in low, swampy areas. Sedges and
or wet areas filled before construction should be co
before purchase.

Figure 10.—Underground utilities, septic tanks, and basements all require excavation of the soil. Excavation costs for shallow soil over rock are 10 to 20 times greater than for deep mineral soil. Trees, shrubs, and grasses grow poorly on most soil shallow to rock because of too little room for roots and for storage of water and nutrients.

Figure 11.—Shallow soil over rock is rather easy to detect. Study nearby road cuts or excavations for rock or dig a hole in the soil and look.

fibrous appearance, light weight, dark color, and spongy feel. ther water-loving grasses and trees grow on them. Soil like this efully examined by qualified specialists (soil scientists or engineers)

Figure 12.—Thousands of new houses are being built annually beyond existing municipal sewer lines. These areas must have on-site sewage disposal (see figure 13). Yet many soils do not absorb the effluent from a septic tank, and raw sewage is discharged as shown here. *This is a severe health hazard to the community.*

Figure 13.—Soil must absorb the effluent from the septic tank at a reasonable rate if a sanitary system is to be satisfactory. Deep, permeable, well-drained soils do this. On-site determinations of a soil's suitability can be made by digging pits when the soil is moist (at field capacity) and pouring water in to determine the absorption rate. Details of this method can be learned from your health department or from the publication "Soils Suitable for Septic-Tank Filter Fields," USDA Agriculture Information Bulletin No. 243. Tight layers, hard rock, or seasonal high water tables in the upper 4 feet of a soil make it unsuitable for on-site sewage disposal. Wet seepy areas, deep green lush grass, or water-loving plants over the prospective sewage filter field are indications that the soil is not likely to be suitable for sewage disposal.

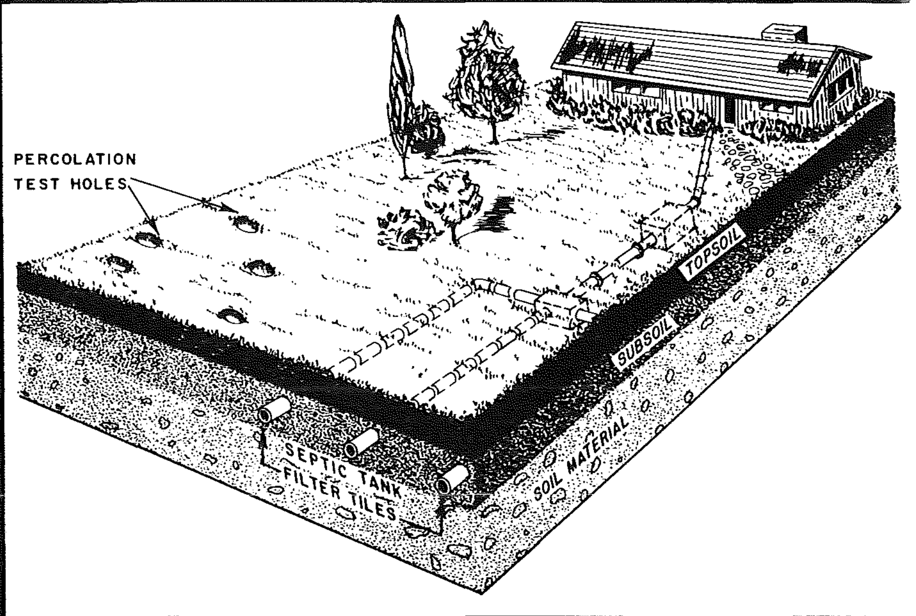
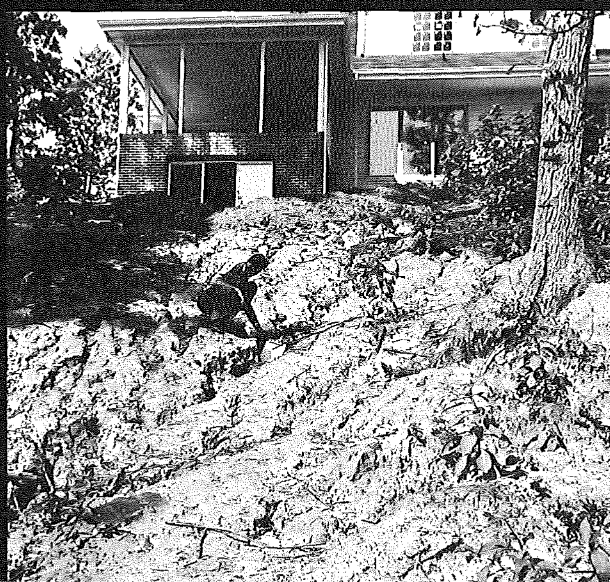


Figure 14.—Soil with a permanent or seasonal high water table causes problems for on-site sewage disposal, for underground utilities, and for basements. A high water table usually means special building foundations for stability.

Figure 15.—Soil that is wet part of the time can be easily identified during wet periods by water standing on or near the surface. Most wet soil has a dark surface layer followed by layers of medium to light gray. The gray may be splotched with orange, yellow, and rust. During dry periods, you can check by digging a hole 3 to 4 feet deep to see the color and to see if water seeps in from the bottom and sides.

Figure 16.—To build on hillsides requires additional excavation for a solid foundation. Except for extremely steep slopes, however, runoff and erosion can be controlled with proper soil and water conservation practices. On most slopes that have clayey soil it is difficult to establish a good cover of grass and trees.

Figure 17.—Soil with a high erosion *hazard is easy to detect.* Generally, the steeper the slope, the greater the erosion hazard. Yet there are many exceptions. Even on gentle slopes, soil with shallow open surface layers over tight layers is susceptible to severe erosion. Shallow droughty soil that supports poor vegetation is likely to erode and is generally undesirable for homesites.



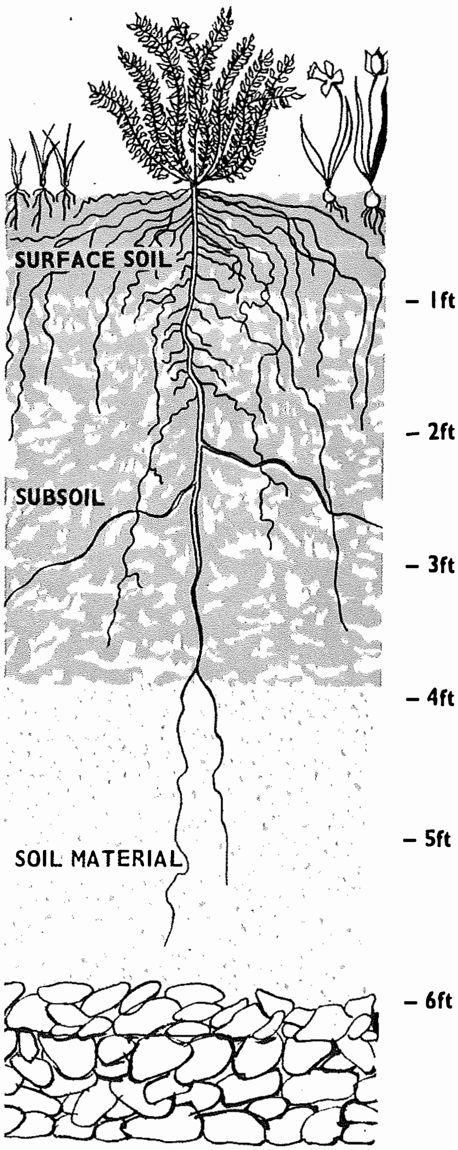


Figure 18.—Most soils are made up of contrasting layers soil scientists call horizons.

From the illustrations, it is clear that this country has numerous kinds of soil—more than 70,000—varying widely in their uses and characteristics (fig. 18). It is a major function of soil scientists in the Soil Conservation Service, U.S. Department of Agriculture, and cooperating agencies to classify, to map, and to describe soils so that they may be used for their best purposes.

USDA soil scientists, in cooperation with State agricultural experiment stations and other agencies, have been at this work since 1899. Their soil surveys contain valuable information intended in the beginning mainly for farmers. Now they are widely used by developers, contractors, government planners, highway engineers, and individual homeowners as well. The same soil properties concern most soil users.

About 45 percent of all privately owned land in the United States has been surveyed. Many of the soil surveys are modern and up to date; many of those more than 25 years old are still useful for general land use planning but do not have all the detailed information needed for current interpretations.

It is entirely possible that the land you are considering buying has a soil survey. If so, it may be seen in the office of the local soil conservation district or the county extension service.

Soil scientists (fig. 19) are experts with years of experience in studying soils and interpreting soil properties for many uses. They walk over the land and, using various tools, stop frequently to dig into the soil and study its properties. They describe, name, and classify the soils according to a national classification system. Their field work is supported by laboratory examinations of samples of the soil layers. Soil boundaries and symbols are plotted on high-quality aerial photos (fig. 20). These lines and symbols show the location and extent of different soils. Soil descriptions and their interpretations are prepared to accompany the soil map. Soil scientists and other specialists use this information to advise on safe uses of the soil.

Traditionally, soil surveys have been used to identify farmland and to match suitable

Figure 19.— A soil scientist examines the soil, identifies it, and draws its boundaries on an aerial photograph.

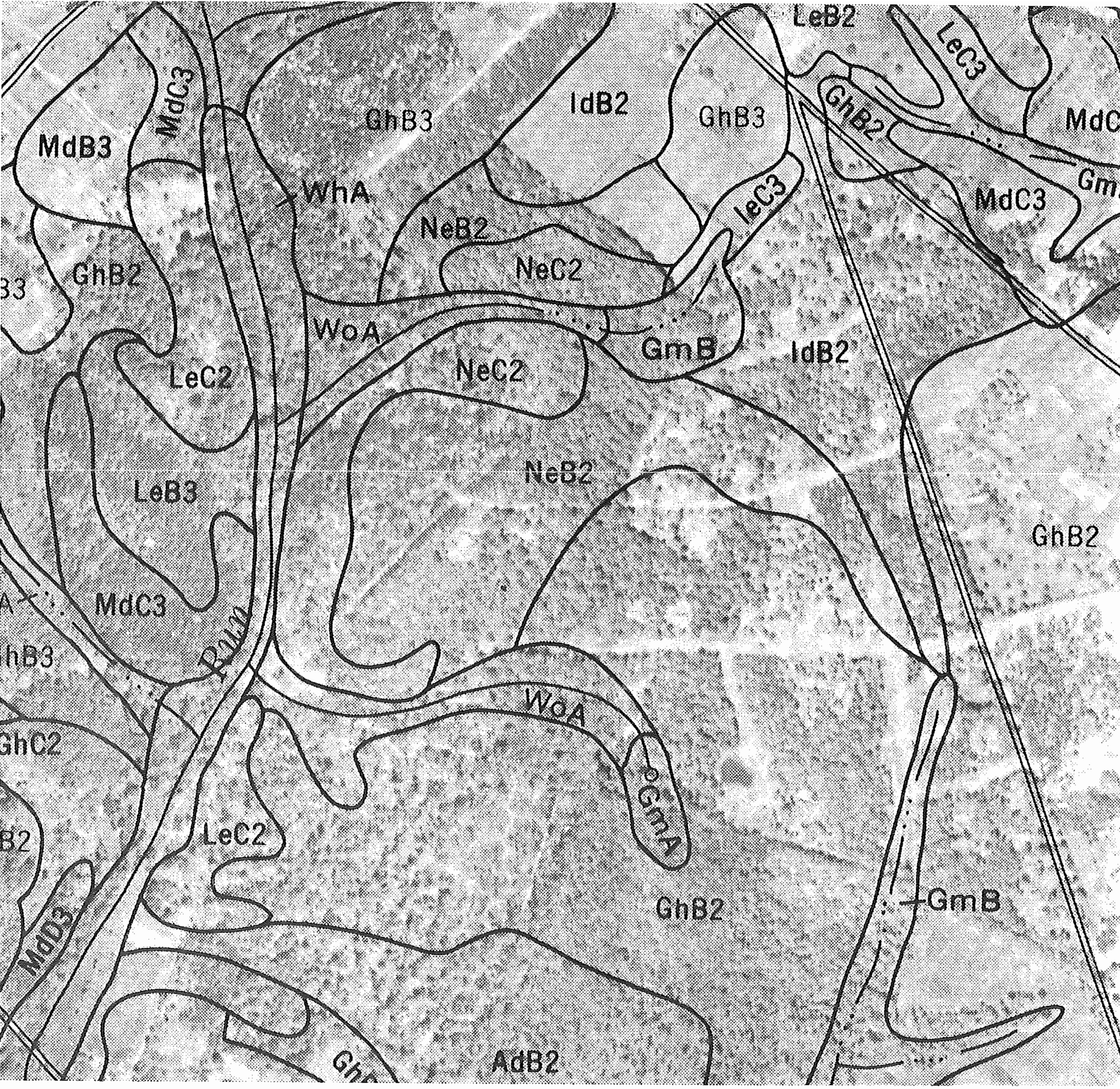


Figure 20.—Part of the soil map of Montgomery County, Md. The symbols indicate the different soils and the solid lines show the extent of each. WhA is a flood-plain soil (see figure 1, area 1) and presents the kind of problem shown in figures 2 and 3. WoA, a wet soil in upland drainageways, is similar to those shown in figure 1, areas 2 and 3; water from higher surrounding areas runs off and concentrates in the natural drainage courses, resulting in frequent flooding. IdB2, because of a dense layer of clay that is very slowly permeable to water and has a high shrink-swell potential, has problems similar to those shown in figures 4, 5, 12, and 13. LeB2, LeB3, LeC2, and LeC3 are shallow to rock and some have lost all original surface soil. The problems are similar to those shown in figures 10 and 11. Soil and water conservation practices to control erosion and reduce runoff are needed on all the steeper slopes, shown by C and D in the map symbol. They also require more excavation for construction and great care in installing filter fields for the effluent from septic tanks. The severely eroded areas, shown by a 3 in the map symbol, may need topsoil for good lawns and gardens.

land areas with suitable crops, vegetation, and soil and water conservation practices. But it was soon learned that the basic principles of soil behavior the farmer needs to know are also useful to many others. Now soil surveys are extensively used by both rural and urban people.

In fact, soil maps are especially important for urban users. If a farmer uses a soil in the wrong way he may suffer losses that year but he can adjust the next year. But an urban user can hardly do that if his "crop" on the land is a cracking superhighway or a sinking schoolhouse. These kinds of "crop failures" are followed by years of unusable or damaged roads and buildings and high taxes for maintenance.

Soil surveys show soil wetness, overflow hazards, depth to rock, hardpans, tight layers, erodibility, clay layers that crack when dry and swell when wet, and the hazard of slippage on slopes. They show the location and extent of different soils and provide information about their properties to a depth of about 6 feet.

For good living without excessive costs and taxes, advanced community planning is becoming more and more necessary. Such planning requires accurate knowledge of the available soils and their alternative potentials.

Estimates by community planners of the value of soil surveys for site selections run as high as $2 million per year per county for counties with rapid increases in population. Some communities report savings of one-quarter of a million dollars by choosing the right site for a school building. Specifically:

1. A developer in southeastern Wisconsin bought 80 acres which he divided into 60 lots. Each lot was to have an $18,000 house. The local board of health, using a soil survey, inspected the site and rejected 58 of the 60 lots because of poor soil conditions. The estimated savings to the community was about $1 million.

2. The planning board of Millis, Mass., estimates that soil-survey information will save the community around half a million dollars in its school building program. Soil surveys provide an inventory of suitable sites prior to purchase. This can save costs for land preparation and building foundations. Substantial savings are anticipated for other uses of the soil survey.

3. San Antonio, Tex., has many soils that are poor for building purposes. It costs between $1,000 and $1,500 more to put down a minimum house foundation in some San Antonio soils than it does in soils with good bearing strength. They shrink when dry and swell when wet and this makes it difficult to build and maintain good roads and underground utilities. Using a soil map, contractors and builders can either avoid these high shrink-swell areas or design their structures with the extra strength needed. This has saved them many thousands of dollars annually.

4. The Southeastern Wisconsin Regional Planning Commission estimates savings to local citizens of more than $300 million on housing alone in southeastern Wisconsin during the next 25 years through the use of soil surveys. Additional savings in other land uses are also expected.

The more that soil surveys and soil interpretations are used by builders and construction companies, the less will be the chance that any future house of yours will go off in floods or down in cracks.

As an individual home buyer or builder, you may spend months checking and considering the design, materials, and construction of your new home. You should be equally concerned about the soil underneath. The soil you build on can seriously affect the stability of your home, your repair bills, your comfort, and the resale value of your property.

If you buy or build a house, or do extensive landscaping on your present one, it will pay you to check on whether your area has a soil map and to have that map interpreted for you.

Soil maps made by soil scientists do not eliminate the need for on-site sampling and testing of soils for design or construction of specific engineering works.

The right soil can go a long way toward insuring you the house of your dreams. The wrong soil can wreck your house and your bank account.

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