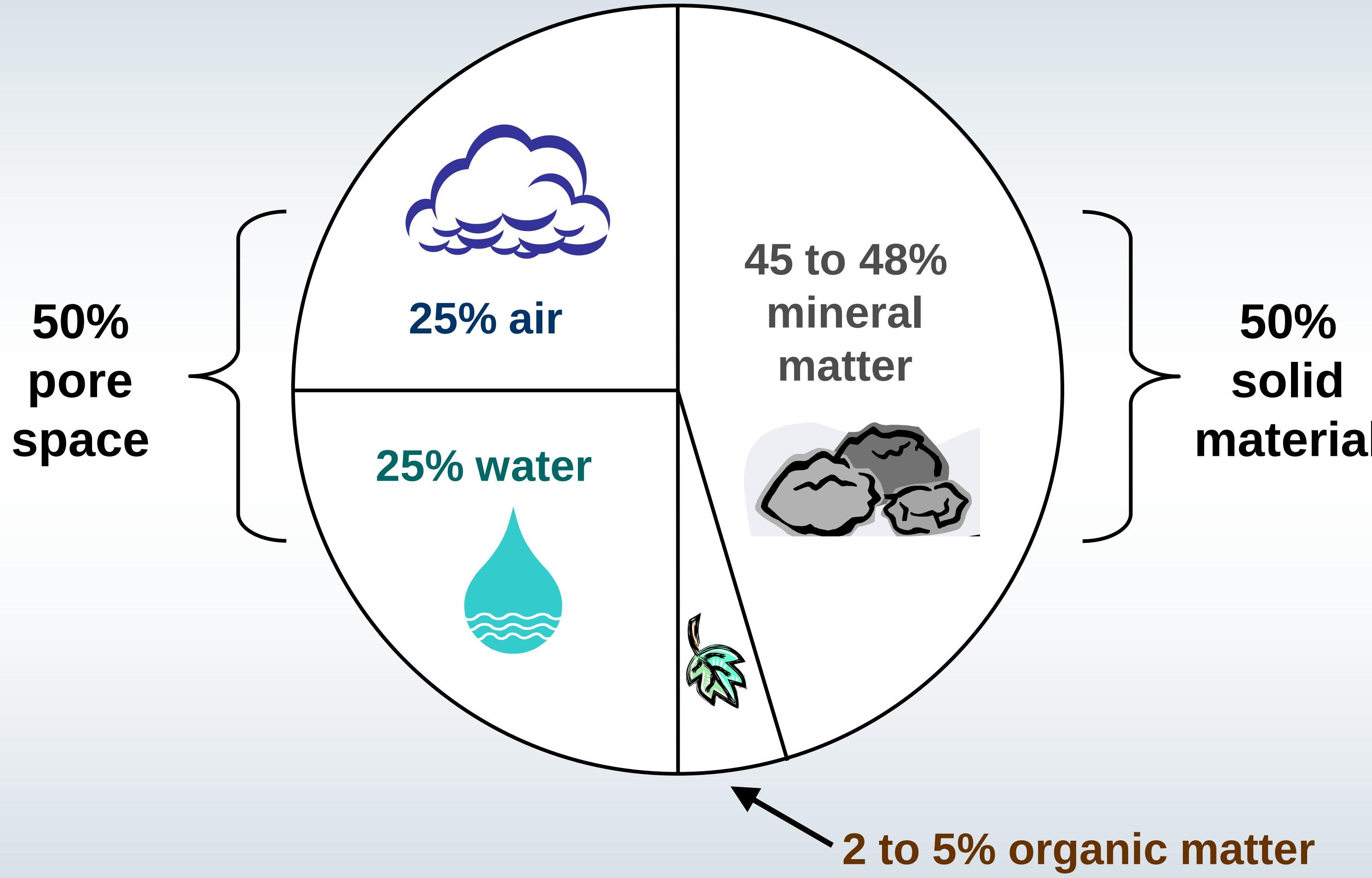
Concepts of Basic Soil Science

W. Lee Daniels and Kathryn C. Haering, Virginia Tech

PowerPoint presentation prepared by Kathryn Haering

Soil formation and soil horizons

Volume composition of a desirable surface soil



Soil parent material and weathering

❖The mineral material of a soil is the product of the weathering of underlying rock in place, or the weathering of transported sediments or rock fragments.

❖The material from which a soil has formed is called its ***parent material***.

❖The rate and extent of weathering depends on:

- the chemical composition of the minerals that comprise the rock or sediment
- the type, strength, and durability of the material that holds the mineral grains together
- the extent of rock flaws or fractures.
- the rate of leaching through the material
- the extent and type of vegetation at the surface

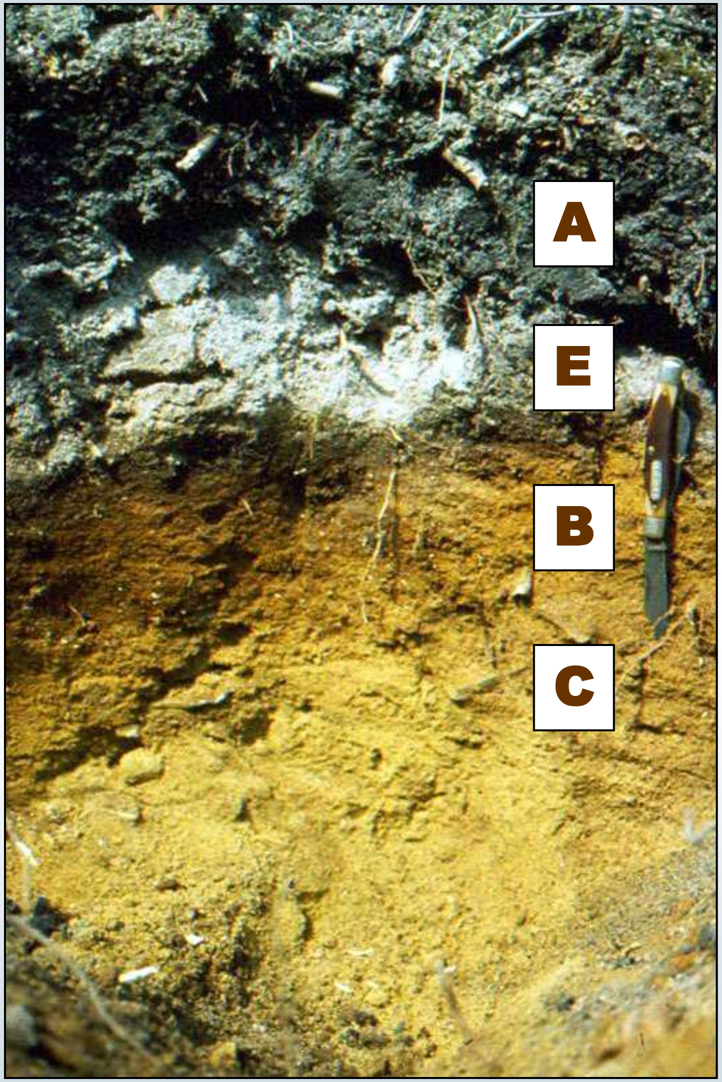
Soil horizons

❖Principal (master) soil horizons found in managed agricultural fields are:

- *A horizon* or mineral surface soil (if the soil has been plowed, this is called the *Ap horizon*).
- *B horizon* or subsoil.
- *C horizon* or partially weathered parent material.
- *rock (R) or unconsolidated parent materials* similar to that from which the soil developed.

❖Unmanaged forest soils also commonly contain:

- *O (organic) horizon* on the surface
- *E (eluviated) horizon*: a light-colored leached zone just below the A horizon.



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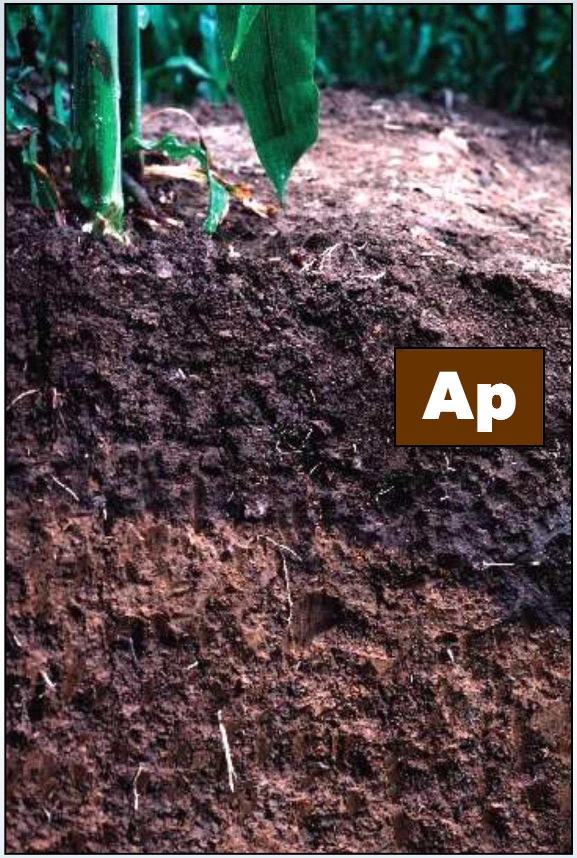
Surface soil horizons: Ap or A + E

❖ ***Ap or A+ E horizons:***

- **Contains more organic matter than the other soil layers.**
- **Often coarser than the subsoil layer.**
- **A or Ap horizon tends to be more fertile and have a greater concentration of plant roots than any other soil horizon.**
- **In unplowed soils, the *eluviated* (E) horizon below the A horizon is often light-colored, coarser-textured, and more acidic than either the A horizon or the horizons below it, because of leaching with time.**



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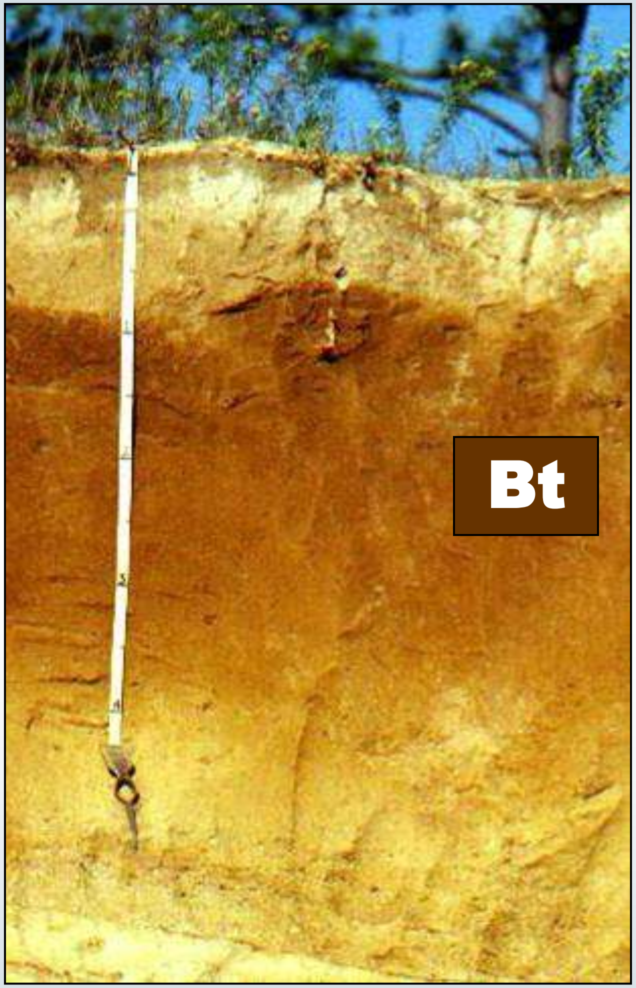
Subsurface soil horizons: B

- ***B horizon:***
  - **Typically finer in texture, denser, and firmer than the surface soil.**
  - **Organic matter content tends to be much lower than surface layer.**
  - **Subsoil colors are often stronger and brighter: shades of red, brown, and yellow predominating due to the accumulation of iron on clays and other particles.**
  - ***Bt horizon*: Subsoil layers with high clay accumulation relative to the A horizon.**



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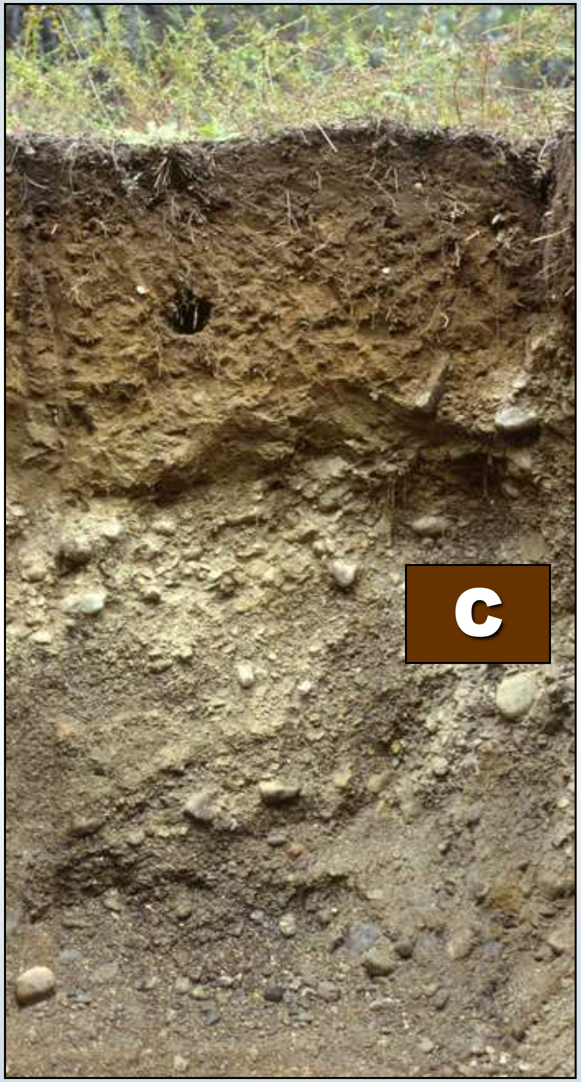
Subsurface soil horizons: C

❖ ***C horizon:***

- **Partially decomposed and weathered parent material that retains some characteristics of the parent material.**
- **More like the parent material from which it has weathered than the subsoil above it.**



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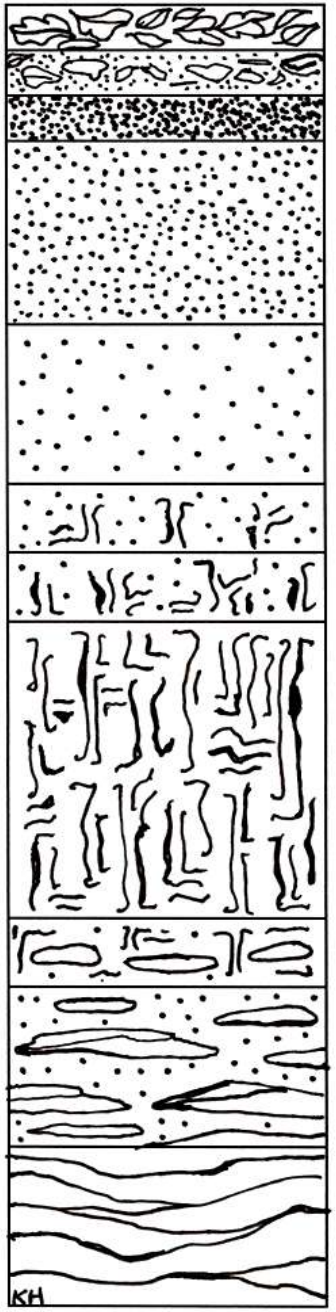
Idealized soil profile



Oi Loose, easily recognizable, organic debris

Oe Partially decomposed organic materials

Oa Fully decomposed organic materials

A Surface mineral horizon; darker and higher in organic matter. If plowed, will be designated Ap

E Eluviated horizon; light colored zone of maximum leaching of clay, iron, aluminum, and soluble organic matter. Often mixed into Ap

EB Transition from E to B; more like E than B

BE Transition from E to B; more like B than E

B Subsurface zone of maximum accumulation of clay, iron, etc. Common features include development of blocky and/or prismatic structure, clay coatings on larger particles, red and yellow colors from accumulation of iron oxides

BC Transition from B to C; more like B than C

C Weathered parent material such as saprolite, oxidized sediments, unconsolidated bedrock, etc.

R Hard bedrock; not always seen

Soil physical properties and organic matter

Soil particles

- ***Sand:***
  - **Particles range in size from *very fine (0.05 mm) to very coarse (2.0 mm)* in average diameter.**
  - **Most particles can be seen without a magnifying glass.**
  - **Feel coarse and gritty when rubbed between the thumb and fingers, except for mica flakes.**

Sand texture

(Photo by Jim Baker, Virginia Tech)

Soil particles

❖ ***Silt:***

- **Particles range in size from *0.05 mm to 0.002 mm.***
- **Cannot usually be seen by the unaided eye**
- **When moistened, silt feels smooth but is not slick or sticky. When dry, it is smooth and floury**

Silt loam texture

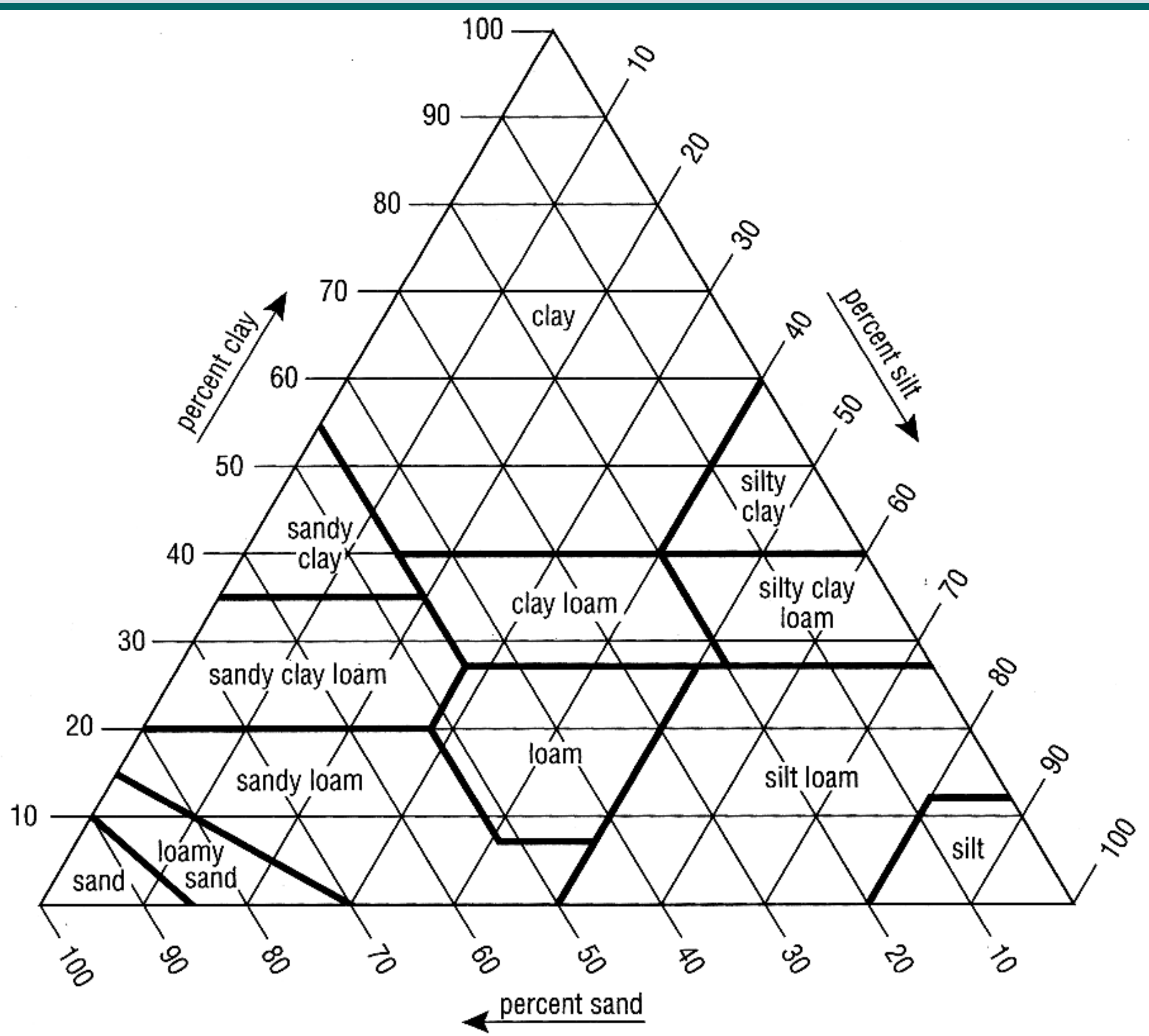
(photo by Jim Baker, Virginia Tech)

Soil particles

- ***Clay*:**
  - **Particles are *finer than 0.002 mm.***
  - **Can be seen only with the aid of an electron microscope.**
  - **Feels extremely smooth or powdery when dry, and becomes plastic and sticky when wet.**

Clay texture
(Photo by Jim Baker, Virginia Tech)

The USDA textural triangle



Soil structure

❖**Soil *aggregation* is the cementing of several soil particles into a secondary unit or aggregate.**

❖**Soil particles are grouped together during the aggregation process to form structural units (or *peds*).**

❖**These units vary in size, shape, and distinctness (also known as strength or grade).**

❖**The structure of the soil affects pore space size and distribution and, therefore, rates of air and water movement. Well-developed structure allows favorable movement of air and water, and root development.**

Types of structure: Granular and Blocky

❖ ***Granular:***

- **Soil particles are arranged in small, rounded units.**
- **Common in surface soils (A horizons).**
- **Most distinct in soils with relatively high organic matter content.**

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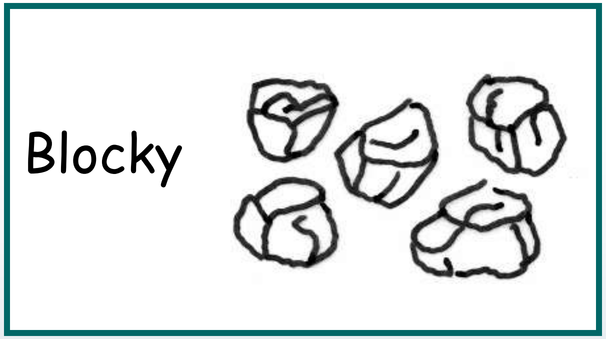
Types of structure: Granular and Blocky

- ***Blocky:***
  - Soil particles are arranged to form block-like units, which are about as wide as they are high or long.
  - Some blocky peds are rounded on the edges and corners; others are angular.
  - Blocky structure is commonly found in the subsoil, although some eroded fine-textured soils have blocky structure in the surface horizons.



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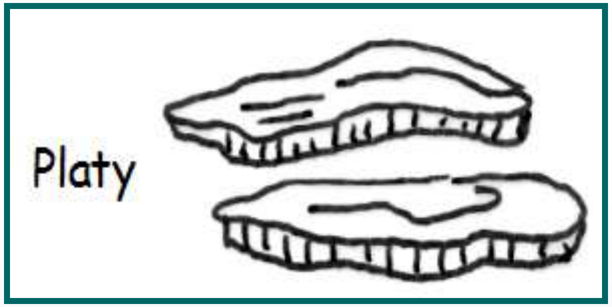
Types of structure: Platy

- ***Platy***:
  - Soil particles are arranged in **plate-like sheets**, which are approximately horizontal in the soil and may occur in either the surface or subsoil, although they are most common in the subsoil.
  - Platy structure strongly limits downward movement of water, air, roots and may result from compaction.



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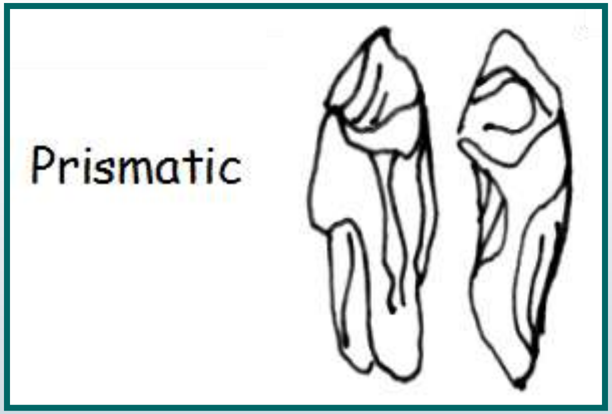
Types of structure: Prismatic

- ***Prismatic:***
  - Soil particles are arranged into **large peds with a long vertical axis.**
  - **Well developed subsoil prisms are associated with *fragipans* (dense subsoil layers), or soils that swell when wet and shrink when dry, reducing air and water movement.**
  - **Most clayey subsoils exhibit prismatic macro-structures to some extent.**



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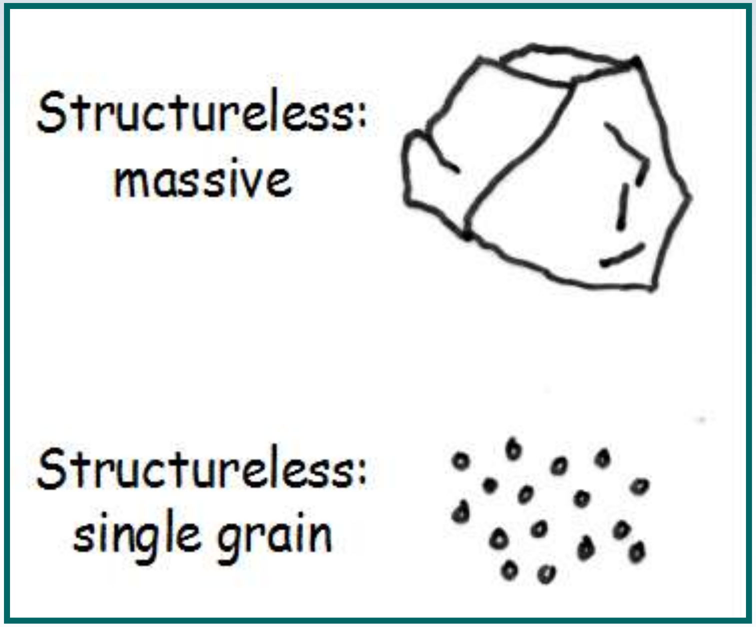
Types of structure: Structureless

- ***Structureless:***
  - **Two types:**
    - ***Massive*: no definite structure or shape, as in some C horizons or compacted material.**
    - ***Single grain*: typically individual sand grains in A or C horizons not held together by organic matter or clay.**



Soil porosity and bulk density

❖Soil *porosity*, or pore space, is the volume percentage of the total soil that is not occupied by solid particles. Pore space is commonly expressed as a percentage:

% pore space = 100 - [bulk density ÷ particle density x 100]

- ***Bulk density*** is the dry mass of soil solids per unit volume of soils.
- ***Particle density*** is the density of soil solids, which is assumed to be constant at 2.65 g/cm^3.

❖Bulk densities of mineral soils are usually in the range of 1.1 to 1.7 g/cm^3. A soil with a bulk density of about 1.32 g/cm^3 will generally possess the ideal soil condition of 50% solids and 50% pore space.

❖Under field conditions, pore space is filled with a variable mix of water and air:

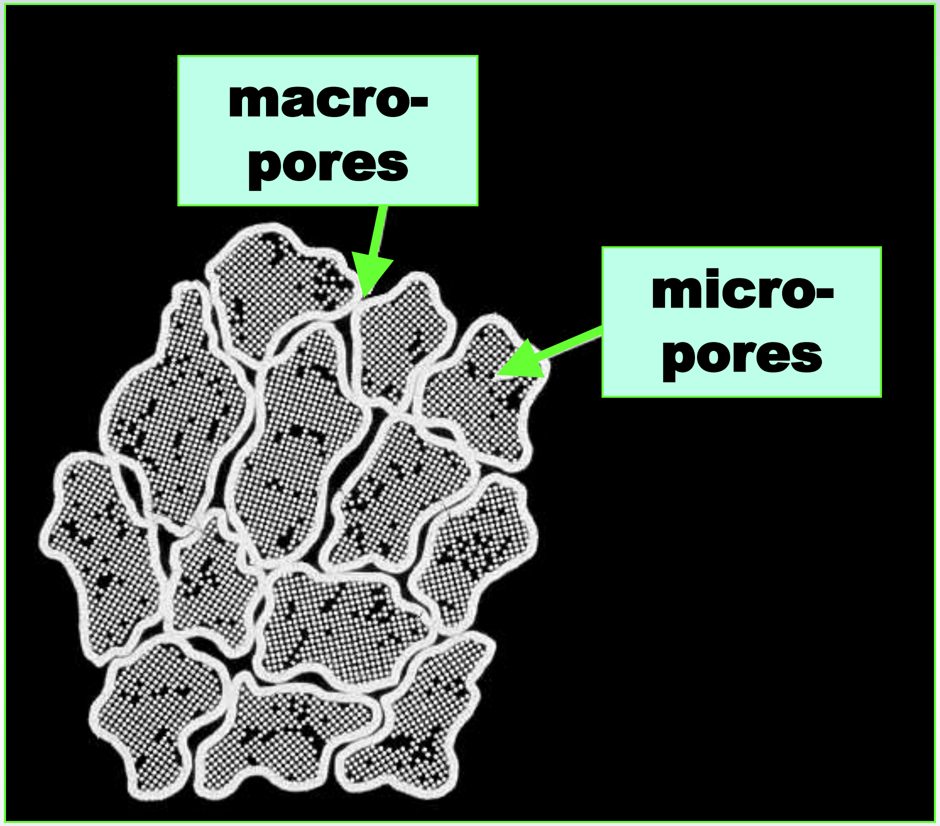
- If soil particles are packed closely together, total porosity will be low and bulk density will be high.
- If soil particles are arranged in porous aggregates, total porosity will be high and bulk density will be low.

Soil porosity: Macropores and micropores

❖The size of the individual pore spaces, rather than their combined volume, will have the most effect on air and water movement in soil.

❖Pores smaller than about 0.05 mm (or finer than sand) in diameter are typically called *micropores*.

❖Pores larger than 0.05 mm are called *macropores*.



Soil porosity: Macropores and micropores

- *Macropores* allow the ready movement of air, roots, and percolating water.
  - Movement of air and water through a coarse-textured sandy soil is often rapid despite its low total porosity because of the dominance of *macropores.*

- *Micropores* in moist soils are typically filled with water, and this does not permit much air movement into or out of the soil.
  - Movement of air and water through a fine textured clay soil may be slow (see picture at right) despite high total porosity because of the dominance of *micropores.*

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Soil organic matter

❖ ***Soil organic matter:***

- **Plant and animal residues in various stages of decay.**
- **Sources: dead roots, root exudates, litter and leaf drop, and the bodies of soil animals such as insects and worms.**
- **Primary energy and nutrient source for insects, bacteria, fungi, and other soil organisms.**
- **After decomposition, nutrients released from the residues available for use by growing plants.**

❖ ***Soil humus*:**

- **Fully decomposed and stable organic matter.**
- **Most reactive and important component of soil organic matter.**
- **Form of soil organic material that is typically reported as "organic matter" on soil testing reports.**

Factors affecting organic matter content

❖ ***Type of vegetation*:**

- **Soils under grass generally have a relatively high percentage of organic matter in their surface.**

- **Soils that develop under trees often have a low organic matter percentage in the surface mineral soil, but do contain a surface litter layer (O horizon).**

- **Organic matter levels are typically higher in a topsoil supporting hay, pasture, or forest than in a topsoil used for cultivated crops.**

Factors affecting organic matter content

❖ ***Drainage*:**

- **Soil organic matter is usually higher in poorly-drained soils because of limited oxidation, which slows down the overall biological decomposition process.**

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Factors affecting organic matter content

- ***Tillage*:**
  - **Soils that are tilled frequently are often low in organic matter. Plowing and otherwise tilling the soil increases the amount of air in the soil, which increases the rate of organic matter decomposition.**

Lynn Betts, USDA-NRCS

Factors affecting organic matter content

- ***Soil texture*:**
  - **Soil organic matter is generally higher in fine-textured soils because soil humus forms stable complexes with clay particles.**
  - **Coarse-textured soils have faster gas exchange, thus more CO_2 loss.**

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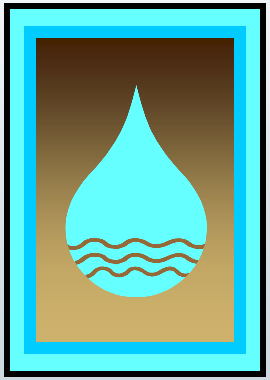
Soil-water relationships

Soil water-holding capacity

❖**Soil water-holding capacity is determined largely by the interaction of soil texture, bulk density/pore space, and aggregation:**

- **Sands hold little water because their large pore spaces allow water to drain freely from the soils.**
- **Clays adsorb a relatively large amount of water, and their small pore spaces retain it against gravitational forces.**
- **Clayey soils hold water much more tightly than sandy soils, so that not all the moisture retained in clayey soils is available to growing plants.**



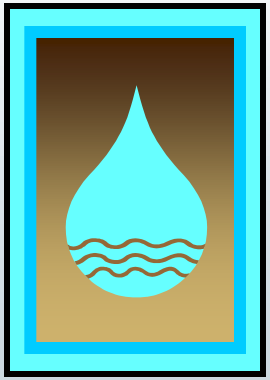
Water holding capacity: definitions

❖The term ***field capacity*** defines the amount of water remaining in a soil after downward gravitational drainage has stopped.

- This value represents ***the maximum amount of water that a soil can hold against gravity following saturation by rain or irrigation***.
- Field capacity is usually expressed as percentage by weight (for example, a soil holding 25% water at field capacity contains 25% of its dry weight as retained water).

❖The amount of water a soil contains after plants are wilted beyond recovery is called the ***permanent wilting percentage***.

❖The amount of water held by the soil between field capacity and the permanent wilting point is called ***plant-available water***.

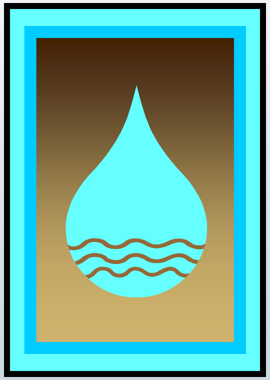


Soil drainage

❖ ***Soil drainage*** **is the rate and extent of vertical or horizontal water removal during the growing season.**

❖ **Important factors affecting soil drainage are:**

- **slope (or lack of slope).**
- **depth to the seasonal water table.**
- **texture of surface and subsoil layers, and of underlying materials.**
- **soil structure.**
- **problems caused by improper tillage, such as compacted subsoils or lack of surface soil structure.**



Soil drainage indicators

❖Soil drainage is usually indicated by soil color patterns (such as mottles) and color variations with depth.

❖Clear, bright red and yellow subsoil colors indicate well-drained conditions where iron and other compounds are present in their oxidized forms, as in the two soil profiles to the right.

Photos by Jim Baker, Virginia Tech

Soil drainage indicators

- ❖ **When soils become saturated for significant periods of time during the growing season, oxidized (red/yellow) forms of iron are biochemically reduced to soluble forms and can be moved with drainage waters. This creates a matrix of drab, dominantly gray colors.**

- ❖ **Subsoil zones with mixtures of bright red/yellow and gray mottling are indicative of seasonally fluctuating water tables, where the subsoil is wet during the winter/early spring and unsaturated in the summer/early fall.**

Photos by Jim Baker, Virginia Tech

Soil drainage indicators

- Poorly drained soils tend to accumulate large amounts of organic matter in their surface horizons because of limited oxidation, and may have very thick and dark A horizons.

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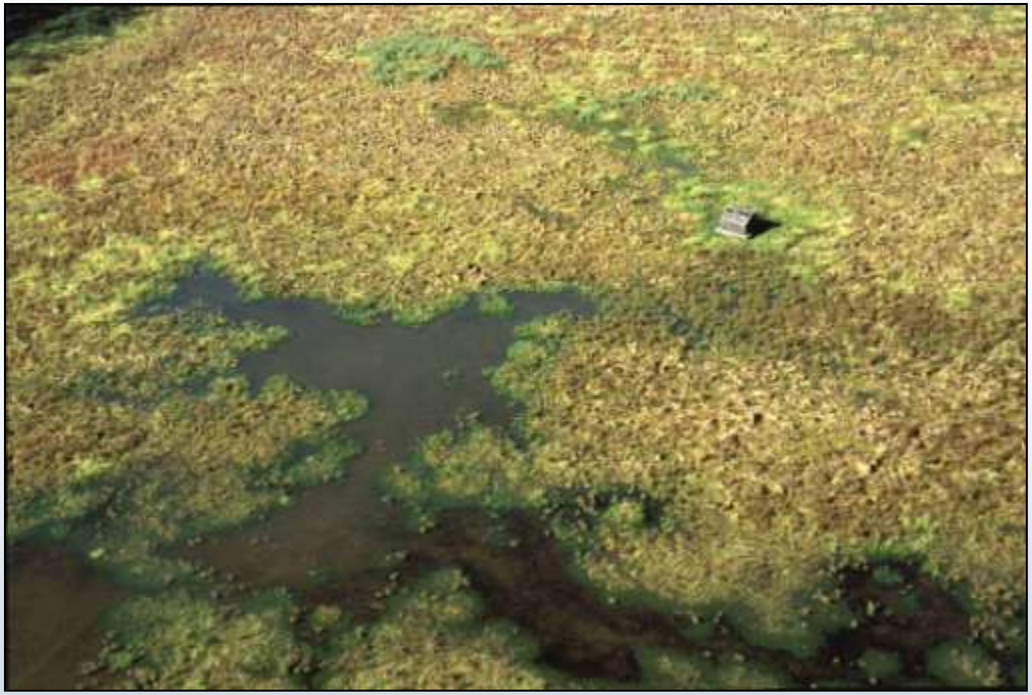
Redoximorphic features and hydric soils

❖**Soils that are wet in their upper part for considerable amounts of time during the growing season and that support hydrophytic vegetation typical of wetlands are designated as *hydric soils*.**

❖**Drainage mottles in these soils are referred to as *redoximorphic features.***



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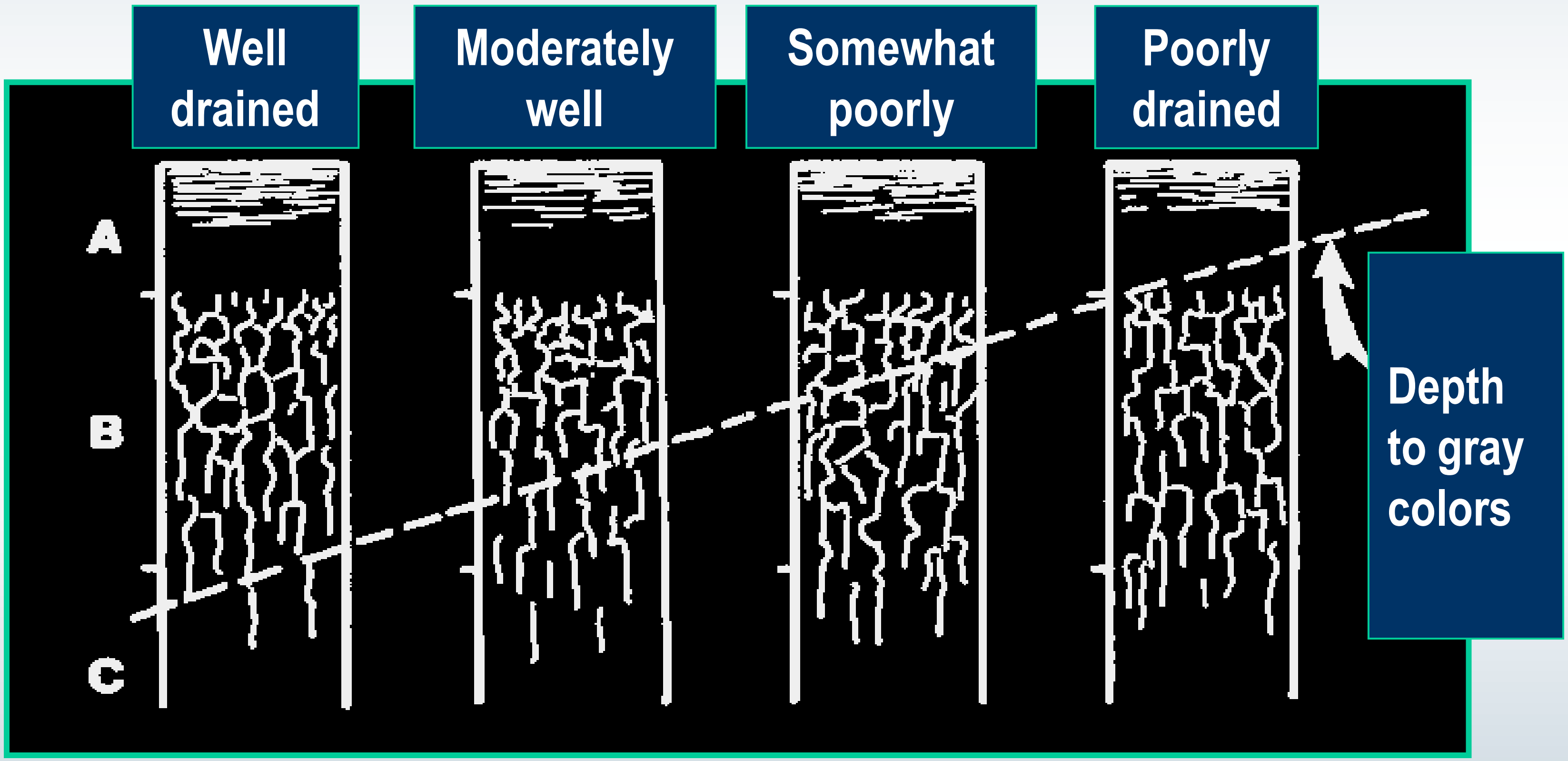
Soil drainage class

❖The *drainage class* of a soil defines the frequency of soil wetness as it limits agricultural practices, and is usually determined by the depth in soil to gray mottles or other redoximorphic features.



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Soil drainage classes as defined by USDA-NRCS

*Drainage Class**	*Soil Characteristics*	*Effect on Cropping*
Excessively drained	Water is removed rapidly from soil.	Will probably require supplemental irrigation.
Somewhat excessively drained		
Well drained	Water is removed readily, but not rapidly.	No drainage required.
Moderately well drained	Water is removed somewhat slowly at some periods of the year.	May require supplemental drainage if crops that require good drainage are grown.
Somewhat poorly drained	Water is removed so slowly that soil is wet at shallow depths periodically during the growing season.	Will probably require supplemental drainage for satisfactory use in production of most crops.
Poorly drained		
Very poorly drained	Free water is present at or near the surface during the growing season.	

*Refers to the natural drainage condition of the soil without artificial drainage.

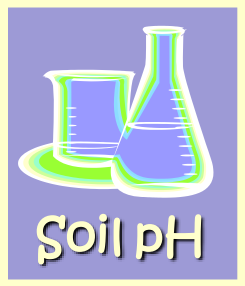
Soil chemical properties

Soil pH

❖Soil pH defines the relative acidity or alkalinity of the soil solution.

❖The pH scale in natural systems ranges from 0 to 14:

- A pH value of 7.0 is neutral.
- pH values below 7.0 are acid.
- pH values above 7.0 are alkaline, or basic.
- Many agricultural soils in the Mid-Atlantic region have a soil pH between 5.5 and 6.5.



Soil pH

❖Soil pH is a measurement of hydrogen ion (H^+) activity, or effective concentration, in a soil and water solution.

❖Soil pH is expressed in logarithmic terms, which means that each unit change in soil pH amounts to a tenfold change in acidity or alkalinity.

- For example, a soil with a pH of 6.0 has 10 times as much active H^+ as one with a pH of 7.0.

❖Soils become acidic when basic cations (such as calcium, or Ca^{2+}) held by soil colloids are leached from the soil, and are replaced by aluminum ions (Al^{3+}), which then hydrolyze to form aluminum hydroxide ($Al(OH)_3$) solids and H^+ ions in solution.

Cation exchange capacity: Definition

❖**All soils contain clay minerals and organic matter that typically possess negative electrical surface charges. These negative charges are present in excess of any positive charges that may exist, which gives soil a net negative charge.**

❖***Cation exchange capacity,* or *CEC* is the net ability of a soil to hold, retain, and exchange *cations* (positively charged ions) such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), ammonium (NH_4^{+}), aluminum (Al^{3+}), and hydrogen (H^{+}).**

CEC
Cation
Exchange
Capacity

Cation exchange capacity: Mode of action

❖Negative surface charges attract positively charged cations and prevent their leaching. These ions are held against leaching by electrostatic negative charges, but are not permanently bound to the surface of soil particles. Positively charged ions are held in a “diffuse cloud” within the water films that are also strongly attracted to the charged soil surfaces.

❖Cations that are retained by soils can be replaced, or *exchanged*, by other cations in the soil solution. For example, Ca^{2+} can be exchanged for Al^{3+} and/or K, or vice versa The higher a soil’s CEC, the more cations it can retain.

CEC
Cation
Exchange
Capacity

Cation exchange capacity: Mode of action

❖ **There is a direct and positive relationship between the relative abundance of a given cation in solution and the amount of this cation that is retained by the soil CEC:**

- **If the predominant cation in the soil solution of a soil is Al $^{3+}$, Al^{3+} will also be the predominant exchangeable cation.**
- **When large amounts of Ca^{2+} are added to the soil solution by lime dissolving over time, Ca^{2+} will displace Al^{3+} from the exchange complex and allow it to be neutralized in solution by the alkalinity added with the lime.**

CEC
Cation
Exchange
Capacity

Cation exchange capacity: How it is calculated

❖**The CEC of a soil is expressed in terms of moles of charge per mass of soil.**

❖**The units used are *cmol+/kg* (centimoles of positive charge per kilogram) or *meq/100g* (milliequivalents per 100 grams; 1.0 cmol^{+}/kg = 1.0 meq/100g).**

❖**Soil CEC is calculated by adding the charge equivalents of K^{+}, NH_4^{+}, Ca^{2+}, Mg^{2+}, Al^{3+}, Na^{+}, and H^{+} that are extracted from a soil's exchangeable fraction.**

CEC
Cation
Exchange
Capacity

Cation exchange capacity: Sources of negative charge

- **Negative charge sources related to *mineralogy of the clay fraction*:**
  - ***Isomorphous substitution:*** **the replacement of a Si^{4+} or Al^{3+} cation in the mineral structure with a cation with a lower charge.**
  - **Clay minerals with a repeating layer structure of two silica sheets sandwiched around an aluminum sheet (2:1 clays, such as vermiculite or smectite), typically have a higher total negative charge than clay minerals with one silica sheet and one aluminum sheet (1:1 clays, such as kaolinite).**

- **Negative charge sources related to *soil pH*:**
  - **Direct relationship to the quantity of negative charges contributed by organic matter and, to a lesser extent, from mineral surfaces such as iron oxides.**
  - **As soil pH increases, the quantity of negative charges increases and vice versa.**
  - **Particularly important in highly weathered topsoils where organic matter dominates overall soil charge.**

CEC
Cation
Exchange
Capacity

Cation exchange capacity: Cation mobility in soils

❖**The retention and release of cations, which affects their mobility in soil, is dependent on several factors:**

- **Relative retention strength of each cation:**
  - **Determined by the charge of the ion and the size, or diameter, of the ion.**
  - **The greater the positive charge and the smaller the ionic diameter of a cation, the more tightly the ion is held (higher retention strength) and the more difficult it is to force the cation to move through the soil profile. For example, K^+ (charge of one and a larger ionic radius), leaches much readily than Al^{3+} (positive charge of three and a very small ionic diameter).**
- **Relative amount or mass of each cation present.**
  - **If cations are present in equal amounts, the general strength of adsorption that holds cations in the soil is in the following order:**

$$Al^{3+} >> Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+$$

CEC
Cation
Exchange
Capacity

Effect of CEC on soil properties

❖A soil with ***a low CEC value*** **(1-10 meq/100 g) may have some, or all, of the following characteristics:**

- **high sand and low clay content**
- **low organic matter content**
- **low water-holding capacity**
- **low soil pH**
- **will not easily resist changes in pH or other chemical changes**
- **enhanced leaching potential of plant nutrients such as Ca^{2+}, NH_4^+, K^+**
- **low productivity**

❖A soil with ***a higher CEC value*** **(11-50 meq/100g) may have some or all of the following characteristics:**

- **low sand and higher silt + clay content**
- **moderate to high organic matter content**
- **high water-holding capacity**
- **ability to resist changes in pH or other properties**
- **less nutrient losses to leaching than low CEC soils**

CEC
Cation
Exchange
Capacity

Base saturation

❖Of the common soil-bound cations, Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} are considered to be *basic cations*.

❖The *base saturation* of the soil is defined as the percentage of the soil's CEC (on a charge equivalent basis) that is occupied by these cations.

❖High base saturation (>50%) enhances Ca, Mg, and K availability and prevents soil pH decline.

❖Low base saturation (<25%) is indicative of a strongly acid soil that may maintain Al^{3+} activity high enough to cause phytotoxicity.

CEC
Cation Exchange Capacity

Buffering capacity

❖The resistance of soils to changes in pH of the soil solution is termed ***buffering capacity*****.**

❖***Buffering capacity*** **increases with the amount of clay and organic matter:**

- **Soils with high clay and organic matter content (high buffer capacity) require more lime to increase pH than sandy soils with low amounts of organic matter (low, or weak, buffer capacity).**

Soil survey

Soil survey reports

❖**The soils of most counties have been mapped by the USDA-NRCS Cooperative Soil Survey Program, and these maps are available in *soil survey reports*.**

❖**Each soil survey report contains information about soil morphology, soil genesis, soil conservation, and soil productivity.**

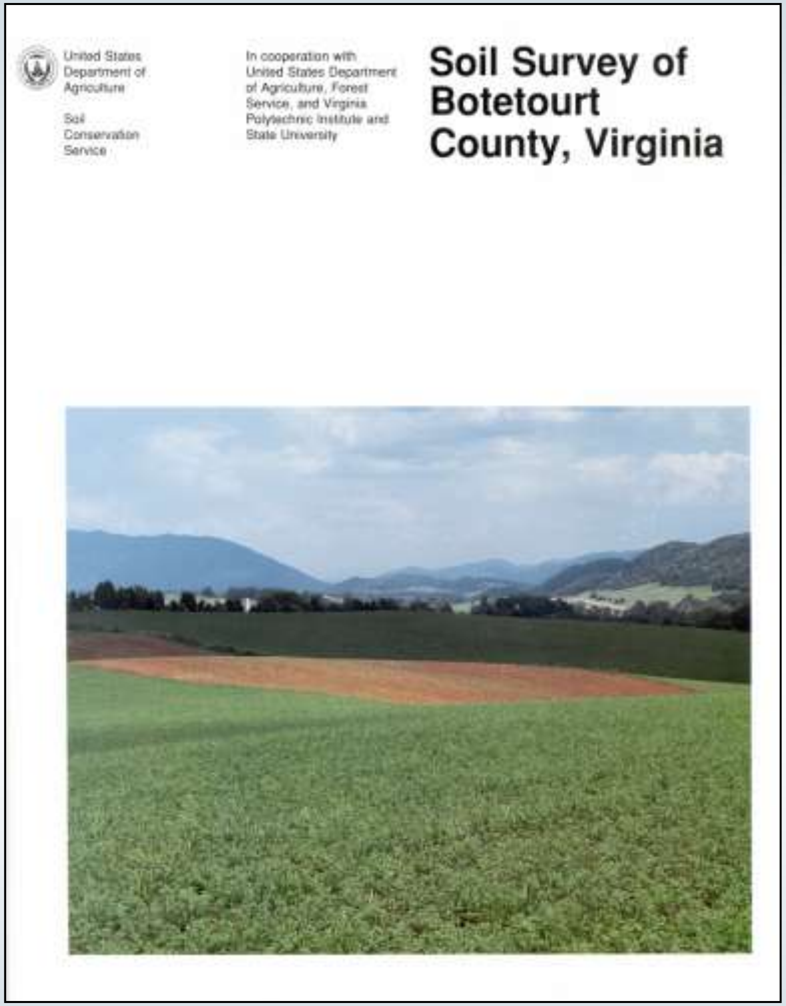
NRCS soil scientist
(photo by Jeff Vanuga, USDA-NRCS)

Soil survey reports

❖A soil survey report reveals the kinds of soils that exist in the county (or other area) covered by the report at a level of detail that is usually sufficient for agricultural interpretations.

❖The soils are described in terms of their location on the landscape, their profile characteristics, their relationships to one another, their suitability for various uses, and their needs for particular types of management.

❖Soil survey reports are available from county and state USDA-NRCS Cooperative Extension offices and on-line (for certain counties).

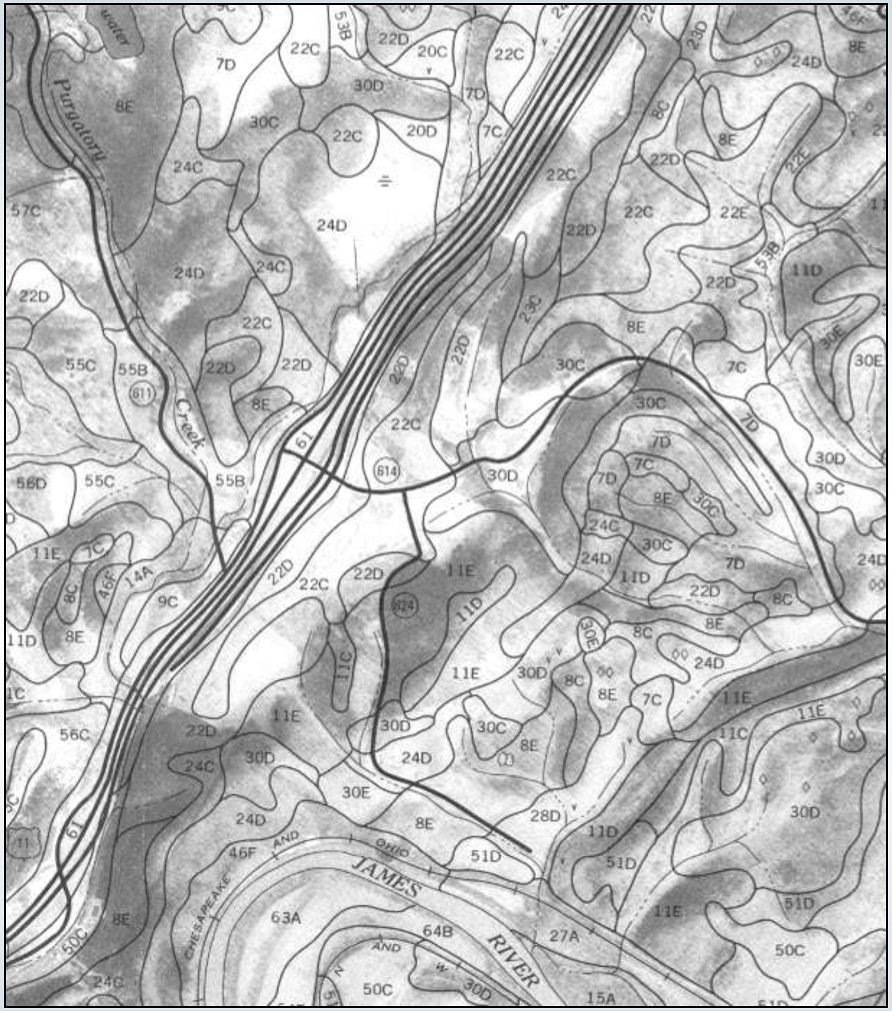


Soil Survey of Botetourt County, VA (USDA-NRCS, 1994).

Parts of a soil survey

1. Soil maps:

- Usually printed over an aerial photographic base image.
- Current USDA-NRCS mapping is published at 1:24,000 to match United States Geologic Survey (USGS) topographic quadrangle maps.
- Each soil area is delineated by an enclosing line on the map. Soil delineation boundaries are drawn wherever there is a significant change in the type of soil. The boundaries may follow contour lines but they also cross contour lines.



Portion of soil map from Soil Survey of Botetourt County, VA . (USDA-NRCS, 1994).

Parts of a soil survey

2. Narrative:

- **Symbols on each map are keyed to a list of soil mapping units.**
- **The nature, properties, and classification and use potentials of all mapping units are described in detail.**

Contents

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Table of contents from the Soil Survey of Botetourt County, Virginia (USDA-NRCS, 1994).

Terminology used in soil surveys

❖ ***Soil series:***

- **A basic unit of soil classification, consisting of soils that are essentially alike in all main profile characteristics.**

❖ ***Soil phase:***

- **Subdivision of a soil series or other unit of classification having characteristics that affect the use and management of the soil but which do not vary enough to merit a separate series. These include variations in slope, erosion, gravel content, and other properties.**

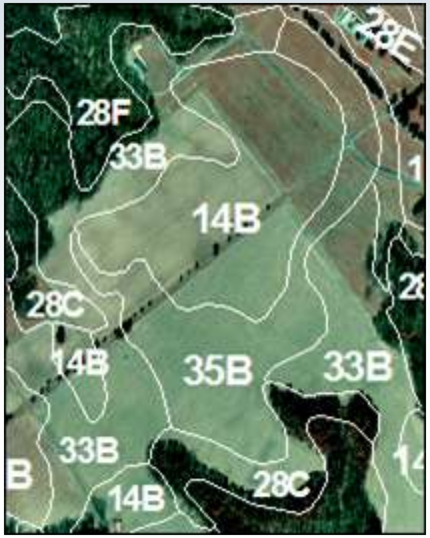
❖ ***Soil complexes* and *soil associations:***

- **Naturally occurring groupings of two or more soil series with different use and management requirements which occur in a regular pattern across the landscape, but that cannot be separated at the scale of mapping that is used. *Soil complexes* are used to map two or more series that are commonly intermixed on similar landforms in detailed county soil maps. *Soil associations* are utilized in more general and less detailed regional soil maps.**

Terminology used in soil surveys

❖ ***Map units*** **are the actual units which are delineated on the soil map and are usually named for the dominant soil series and slope phase.**

- **Map units generally contain more than one soil series:**
  - **Units are given the name of the dominant soil series if >85% of the area is correlated as a single soil series (or similar soils in terms of use and management).**
  - **Soil complexes are used to name the map unit if the dissimilar inclusions exceed 15%.**
- **Each map unit is given a symbol (numbers or letters) on the soil map, which designates the name of the soil series or complex being mapped and the slope of the soil.**
- **More details on how soil mapping units are developed and named can be found at http://soils.usda.gov/technical/manual/.**



Jim Baker, Virginia Tech

Using a soil survey

- ***To Find:***
  - ***Overall picture of the soils in a county:***
    - **See soil association section of the soil survey report. The general soil pattern of the county is discussed in this section.**
  - ***Soils of a particular farm:***
    - **Locate farm on the soil map by using index sheets included with soil maps**
    - **Determine what soils are present using map and map legend.**
  - ***Nature and properties of the soils mapped:***
    - **See narrative portion of the soil survey report.**
  - ***Use and management of the soils:***
    - **See soil interpretations. These give management needs, estimated yields, engineering properties, etc.**

Applying knowledge to improve water quality

Mid-Atlantic

Regional Water Program

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The Mid-Atlantic Nutrient Management Handbook is available on the Mid-Atlantic Regional Water Program's website at: www.mawaterquality.org/