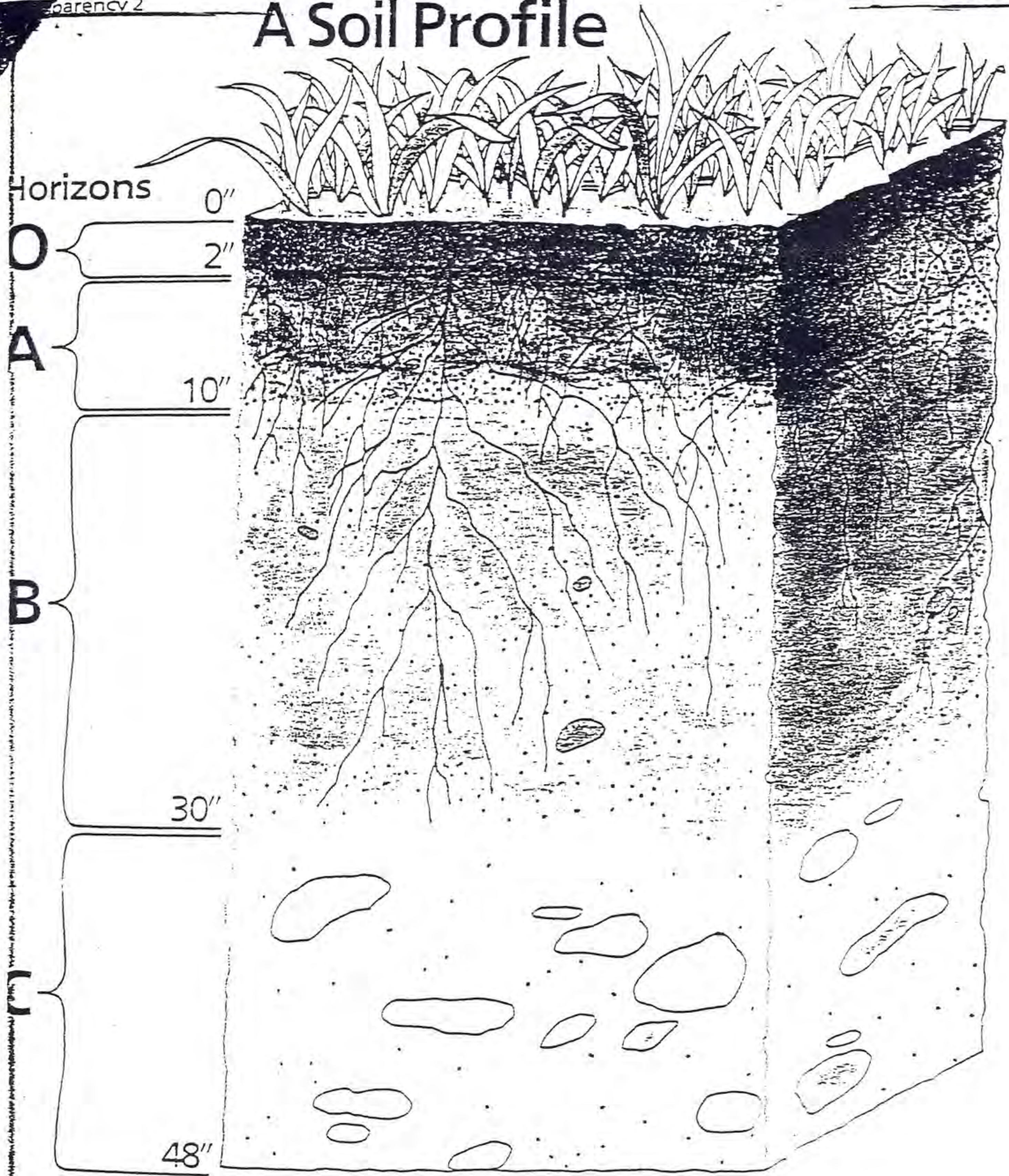
Soil Materials

List of Resource Soil Scientist's that are available to provide soils information, material, and come into the Schools and teach soils classes.

Resource Soil Scientist	Counties Covered
Rick Bandy 12 3rd Street NW Great Falls, MT 59404 453-9641	Broadwater, Meagher, Lewis & Clark, Cascade, Teton, Fergus, Petroleum, Judith Basin, Wheatland, Golden Valley, Musselshell, Phillips, Blaine, Hill, Chouteau, Liberty, Toole, Glacier, Pondera
Steve VanFossen 3120 Valley Drive East Miles City, MT 59301 232-2782	Valley, Daniels, Sheridan, Roosevelt Garfield, McCone, Richland, Dawson, Yellowstone, Big Horn, Treasure, Rosebud, Custer, Prairie, Wibaux, Fallon, Carter, Powder River
Tony Rolfes 3710 Fallon Street # B Bozeman, MT 59715 587-6988	Stillwater, Carbon, Sweetgrass, Park Gallatin, Jefferson, Madison, Silver Bow, Beaverhead
Neal Svendsen 5115 Highway 93 South Missoula, MT 59801 252-4826	Ravalli, Granite, Deerlodge, Powell, Missoula, Mineral, Sanders, Lake, Flathead, Lincoln

A Soil Profile



O_i	Organic horizon of undecomposed organic matter
O_e	Organic horizon of partially decomposed organic matter. (O_i and O_e usually absent on prairie soils)
A (A_p)	Surface mineral horizon which has an accumulation of well decomposed organic matter which coats the mineral particles and darkens the soil. A_p is used when surface layer is plowed. Granular structure common
E	Subsurface horizon which has lost organic matter, clay, iron, or aluminum through eluviation wi concentration of resistant sand and silt sized particles. Platy structure common.
B_W / B_T	Mineral horizon characterized by one or more of the following. 1. Illuvial concentration of clay, iron, aluminum, or organic matter. 2. Residual concentration of iron and aluminum oxides or silicate clays. 3. Coatings of iron and aluminum oxides which give darker, stronger, or redder colors. 4. Alteration of parent material through physical and chemical means with formation of silicate clay minerals, liberation of oxides and formation of granular, blocky, or prismatic structure.
B_K	Mineral horizon characterized by accumulations of calcium carbonate ($CaCO_3$).
B_Y	Mineral horizon characterized by accumulations of Gypsum ($CaSO_4$).
B_Z	Mineral horizon characterized by accumulations of soluble salts.
C	Mineral horizon that has been little affected by soil-forming processes but may be otherwise weathered.
C_R	Weakly consolidated bedrock. It can be dug through with some difficulty. Roots do not penetrat except along fracture planes.
R	Consolidated bedrock. Generally can not be dug through.

3) Soil Color

Soil color is influenced by the parent material and/or pedogenic processes. It is recorded using internationally standardized names and notations of the Munsell Color Chart. Munsell colors are based on the HUE, VALUE and CHROMA. There are 7 charts (pages) displaying 199 standard colors.

HUE - The dominate color based on the relation of red and yellow wavelengths reflected by the soil material. Each page represents a particular combination of these wavelengths. Most (90%) of the well-drained soils in Montana have color hues of 10YR or 7.5YR.

VALUE - The lightness or darkness of a soil. The bottom of the page, zero, is dark and as the numbers increase the color gets lighter. A dry soil commonly becomes darker (value decreases) as it is moistened.

CHROMA - The strength or purity of the color. The left side of the page is dull, zero and the right side of the page is bright, eight.

When determining soil color hold a small sample of moist soil under the color chips in the Munsell Color Book. Stand so that light is coming over your shoulder and in direct light find the best match between the soil and the color chips. Record the color notation in the appropriate place on the profile description sheet. Colors are also recorded for mottles, concretions, nodules and other special features which contrast the soil matrix.

General Guidelines For Soil Color

Black:

Parent Material - black shale, coal.

Organic Matter Accumulation (humus).

- Black normally indicates high vegetation production, especially from grasses.
- Exception: High Na (sodic) causes organic matter to dissolve and coat soil particles.

Slow Decomposition of Organic Matter

- From low temperatures - high latitude, high elevation, cold depression and possibly north slopes.
- Low oxygen (poor aeration) as caused by a high water table.

Gray and Blue:

"Gley" soil is found in swamps, marshes and sometimes along streams. The gray is reduced iron which forms under poor aeration.

White:

Salts - Calcium carbonate ($CaCO_3$), gypsum ($CaSO_4$) and other salts.

Silica - Highly leached quartz sand (SiO_2) that is often in eluviated E horizons.

Yellow and Brown:

This usually indicates a well-drained site in a moist environment.

4) Soil Texture

Soil texture refers to the distribution of 3 soil separates (sand, silt and clay) less than 2mm in diameter. This soil material is commonly called the fine earth fraction. Discrete soil materials greater than 2mm in diameter that can not be dispersed into fine fraction constituents are called coarse fragments. Coarse fragments range from gravels (2-76mm), to cobbles (76-250mm), to stones (250-610mm), to boulders (greater than 610mm in diameter).

Soil Separates - Determined by the size of the soil particle.

sand	.05 - 2 mm	50-2,000 microns
silt	.002-.05 mm	2-50 microns
clay	<.002 mm	<2 microns

Textural Analysis - The determination of the soil separate distribution. It is determined in the field by the hand texture method. A mechanical analysis can be performed in the lab to verify. The hydrometer method of mechanical analysis will be performed in the lab on soil physical properties.

Hand Texture Method - Soil scientists and people involved with the land use the hand texture method to describe soil texture. With sufficient practice one can become very adept at determining soil texture. One way to do the hand texture method is described below and in Figure 1.5.

1. Place 15 to 20 grams of soil in your hand and moisten slowly while manipulating the soil with your fingers. Stop adding water when the soil has the consistency of bread dough.

2. Firmly press part of the moist soil between your first two fingers and thumb. Try to identify the presence of each separate (clay feels sticky, silt feels greasy or sometimes like flour, and sand feels gritty).

3. It takes an estimate of only 2 soil separates to determine a point on the textural triangle (Figure 1.4), the third one automatically intersects. The two "easiest" separates to feel are clay and sand.

Estimating the % clay. Does it take a lot of water to wet up? Is it hard to work up? Does it form a ribbon that supports itself? Is it sticky? Positive answers indicate a high clay percentage, but remember, a soil rarely has more than 60% clay. Find the value of your percent clay estimation on the % CLAY axis. You can then draw a horizontal line across the triangle that will intersect all possible soil textures that have the % clay you have estimated.

Estimate the % sand. How gritty does the material feel? If only a few sand grains are felt or observed there is probably 10-15% sand. When squeezed does a ribbon form? If it easily falls apart there is a high percentage of sand. Find the value of your percent sand estimation on the % SAND axis. You can then draw a line across the triangle that will intersect all possible soil textures that have the % sand you have estimated. Your soil textural class is indicated by the region of the triangle where your two lines intersect.

Definitions of Textural Classes - The following are definitions[1] of the basic soil textural classes. They are included here as an example of the kind of field criteria that can be used.

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

Sandy loam: A sandy loam is a soil containing much sand but which has enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart, but if squeezed when moist a cast can be formed that will bear careful handling without breaking.

Loam: A loam is a soil having a relatively even mixture of different grades of sand and of silt and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly plastic. Squeezed when dry, it will form a cast that will bear careful handling, while the cast formed by squeezing the moist soil can be handled quite freely without breaking.

Silt loam: A silt loam is a soil having a moderate amount of the fine grades of sand and only a small amount of clay, over half of the particles being of the size called "silt." When dry it may appear cloddy but the lumps can be readily broken, and when pulverized it feels soft and floury. When wet the soil readily runs together and puddles. Either dry or moist it will form casts that can be freely handled without breaking, but when moistened and squeezed between thumb and finger it will not "ribbon" but will give a broken appearance.

Clay loam: A clay loam is a fine textured soil which usually breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger it will form a thin "ribbon" which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy compact mass.

Clay: A clay is a fine textured soil that usually forms very hard lumps or clods when dry and is quite plastic and usually sticky when wet. When the moist soil is pinched out between the thumb and fingers it will form a long, flexible "ribbon."

1 Soil Survey Staff. 1951. Soil Survey Manual. Agric. Handb. No. 18. USDA. p. 212.

TEXTURE COMPONENTS

SAND

2.0 - 0.05 mm diameter

Individual particles visible to the eye

Rounded or irregular shape

Gives texture gritty feel

Influences drainage and air movement

SILT

0.05 - .002 mm diameter

Magnify 10 to 100 times to see particles

Irregular shape

Gives texture soft, slippery, floury feel

Largely influences water holding capacity

CLAY

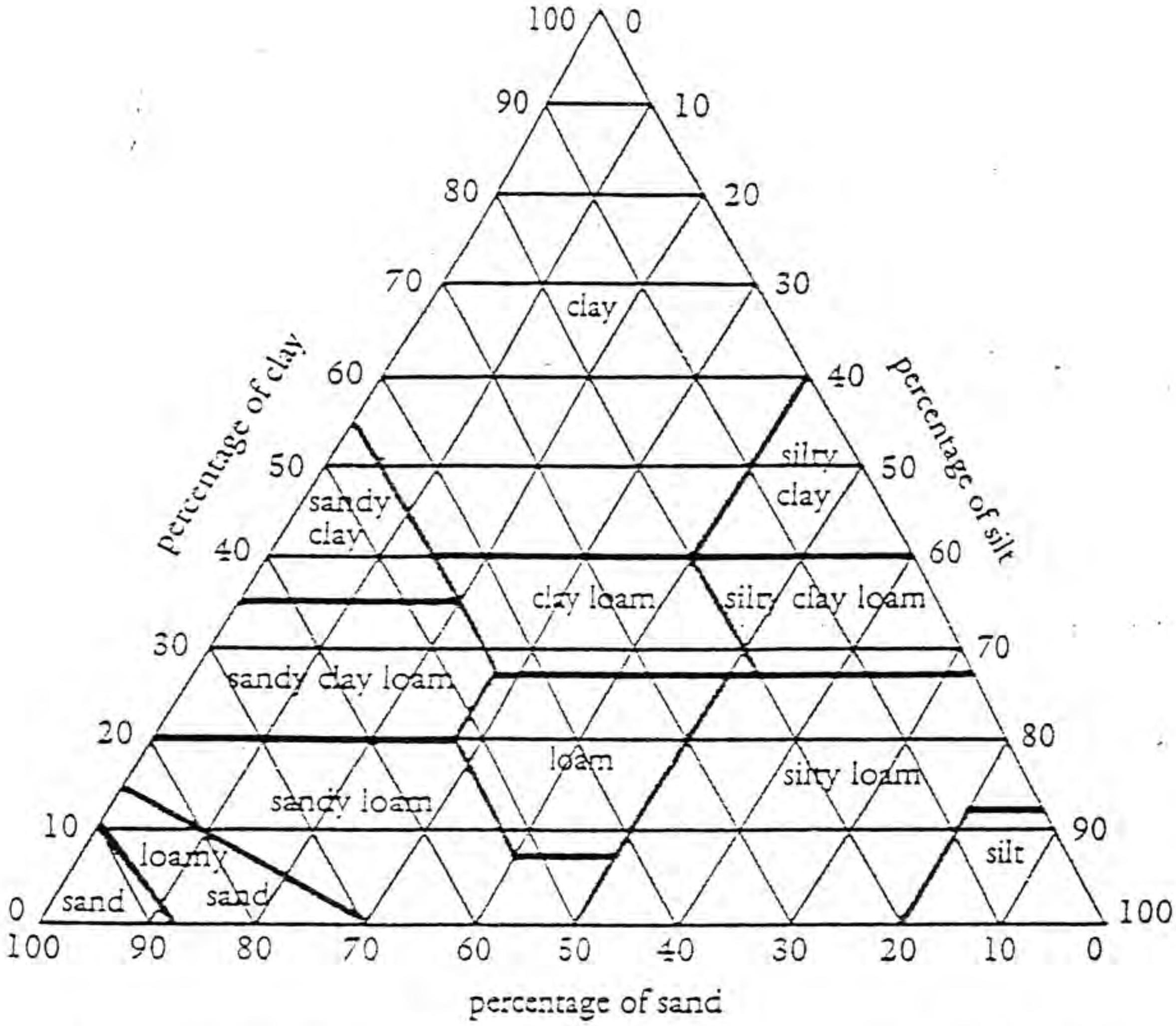
Less than .002 mm diameter

Magnify 2,000 times to see particles (electron microscope)

Gives texture sticky, greasy feel

Largely influences fertility, permeability, shrinking and swelling

Soil texture can range from clay, with mostly very fine particles, to sand, which is mostly the coarse particles. In between, soil scientists recognize ten more groupings (called textural classes).

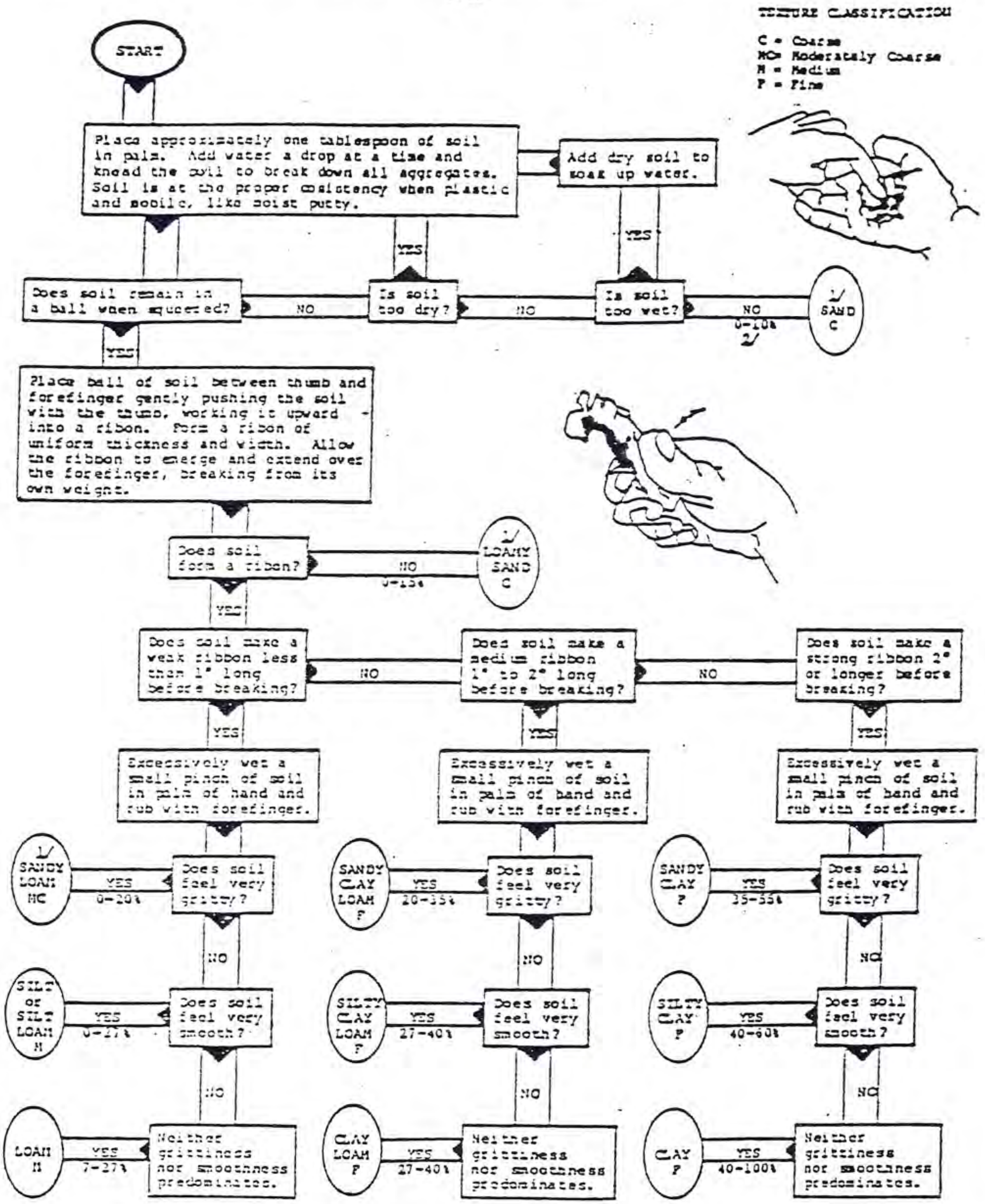


Use this textural triangle to look up the relative percentages of sand, silt, and clay. The area in which the three lines intersect will indicate the name of that soil's textural class.

Revised version

Figure 1.5 DETERMINING SOIL TEXTURE BY THE "FEEL METHOD" 1/

2/86



1/ Sand particle size should be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of very fine sand are not visible without magnification and there is a gritty feeling to a very small sample ground between teeth. Some fine sand particles may be just visible. Medium sand particles are easily visible. Examples of sand size descriptions where one size is predominant, are: very fine sand, fine sandy loam, loamy coarse sand.

2/ Clay percentage range.

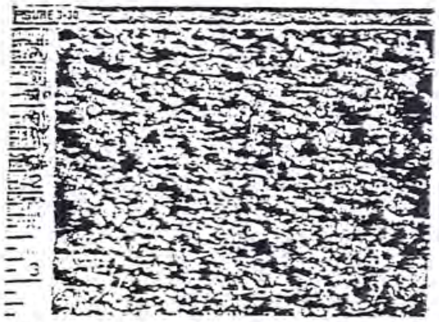
1/ Modified from: Thien, Steve J.; Kansas State University, 1979 Jour. Agronomy Education.

SOIL STRUCTURE

Soil structure is the way in which the individual particles, sand silt, and clay, are arranged into larger distinct aggregates. These aggregates are called peds and can usually be separated easily, particularly in dry soil. Aggregation is a result of the interaction between physical and biological forces. Structure is the major factor determining how fast air and water enter and move through the soil.

Structure can be described by the type, grade, and size class. The main types of soil structure are granular, platy, blocky, prismatic, and columnar. Some soils or horizons may lack structure and maybe labeled as single grained or massive.

TYPE - The shape of the ped.

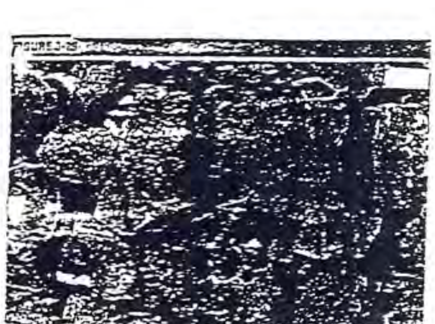


GRANULAR

Consists of small, porous aggregates which tend to be somewhat rounded in shape. Granular aggregates form very desirable seed beds for crops and allow rapid entry of water into the soil. Granular structure is commonly found in surface layers developed under grassland.

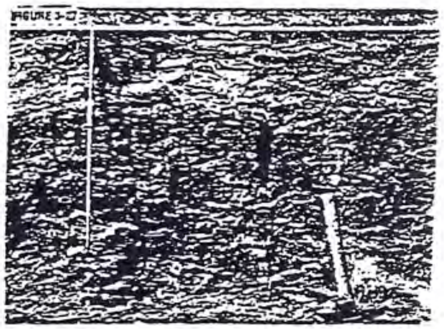
PLATY

Consists of aggregates that have longer horizontal faces than vertical faces. The fragments are flat and thin. Can be caused by compaction. It can occur in any horizon but is generally found in E horizons. Water and air movement in the soil maybe restricted. If found in surface horizon crusting and seedling emergency can be a problem.



BLOCKY

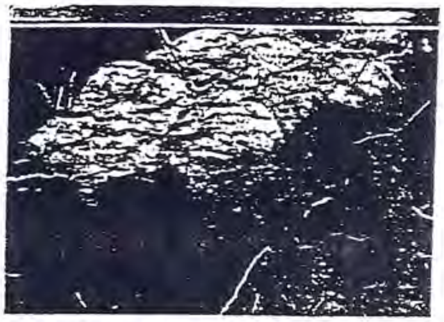
Consists of aggregates clinging together in nearly square or angular blocks. It is mainly found in the B horizon but can be found in the A & E horizon. Water, air, and root penetration occurs mainly along structural fracture planes.



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

PRISMATIC

Consists of aggregates in which the vertical faces are longer than the horizontal faces. The tops of the units are flat. It is found in the B horizon. Water and air movement in soil occurs along structural fracture planes. Most roots can also be found in the fracture planes.



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

COLUMNAR

This type of structure is similar to prismatic. The main difference is that it has rounded, white tops. This type of structure indicates slow or very slow permeability and poor root penetration into this horizon. This condition is caused by excess sodium within the soil. It is found in the B horizon.

STRUCTURELESS

Massive - Soil condition where there is no evidence of aggregation of soil particles

Single grain - Soil condition consisting primarily of sand sized particles which tend to remain separated. They do not form aggregates.

GRADE - How distinct and durable the natural peds are

- Weak - Peds are barely observed in place and break immediately upon handling.
- Moderate - Peds are easily observed in place and hold shape upon handling.
- Strong - Peds stand out distinctly and maintain their shape when handled roughly.

SIZE CLASS - The size of the ped

Size Class	Diameter of granules	Thickness of Plates	Diameter of Blocks	Diameter of Prisms
fine	<2 mm	<2 mm	<10 mm	<20 mm
medium	2-5 mm	2-5 mm	10-20 mm	20-50 mm
coarse	>5 mm	>5 mm	>20 mm	>50 mm

6) Soil Consistence

Consistence is a measure of a soil's resistance to deformation or rupture. Dry and moist consistence apply to undisturbed peds or group of peds. Wet consistence applies to a totally saturated soil. Soil consistence is related to the amount and kind of clay present (see Table 1.2). Refer to the terminology below to describe dry, moist and wet consistence.

DRY CONSISTENCE - Peds are air dried.

Loose - Falls apart without handling - cannot pick up a ped.

Soft - Can be picked up as a mass but falls apart with slight pressure and barely indents the fingers.

Slightly hard - A ped or clod can be picked up. Before breaking between thumb and forefinger it indents the finger deeply but breaks without strong pressure.

Hard - Must exert strong pressure to break. Can be broken between thumb and forefinger under strongest pressure one can exert.

Very hard - Cannot be broken between thumb and forefinger.

MOIST CONSISTENCE - Ped has approximately the amount of water held in the soil 24 yours after a rain.

Loose - Falls apart with handling - cannot pick up a ped.

Very friable - Crushes with only slight indentation of finger.

Friable - Indents finger when crushed but only gentle pressure is needed.

Firm - Crushes only when deliberate pressure is applied. Deeply indents the fingers.

Very firm - Can barely be crushed between thumb and forefinger.

Extremely firm - Cannot be crushed between thumb and forefinger.

WET CONSISTENCE - Wet consistency describes the stickiness and plasticity of your soil. It is determined at the same time as soil texture.

STICKINESS - The amount of adherence of soil material to another object. For field evaluation press moist soil between thumb and finger and describe as follows:

Nonsticky - Almost none adheres to either finger.

Slightly Sticky - Adheres to both fingers but finally pulls cleanly free of one without stretching.

Sticky - Stretches noticeably before breaking and leaves material on both fingers.

Very Sticky - Stretches as one exerts strong effort to pull fingers apart.

PLASTICITY - The ability of moist soil to change shape under pressure. For field evaluation roll the moist soil material between thumb and finger (or the palms of your hands) and express the degree of resistance as follows:

Non-plastic - Cannot form a "wire" by rolling in fingers.

Slightly plastic - Can form a "wire" by rolling. The "wire" will not support its own weight. Easily deformed under pressure.

Plastic - Can form a "wire" that will bear its own weight. Must press to deform.

Very plastic - Can form a strong wire that will "whip." Must exert strong pressure to deform.

CONSISTENCE AND CLAY

	Dry	Moist	Wet
Clay increases	Loose	Loose	Non-plastic, non-sticky
↓	Soft	Friable	Slightly plastic, slightly sticky
	Hard	Firm	Plastic, sticky

Table 1.2. Change in dry, moist and wet consistence with increases in amount of clay.

Water Displacement Method (coarse fraction)

a) Determine the volume of your soil sample by measuring the radius (r) of a beaker and the depth (height) of your sample in that beaker. Remember that for a cylinder: Volume = $\pi r^2 h$.

b) Grind your soil with a mortar and pestle to break up large aggregates. Pass your soil through a 2 mm sieve to separate the fine earth fraction from the coarse fraction.

c) Wrap the coarse fragments in a hair net and weigh in air.

d) Submerge netted coarse fragments in a bucket of water and weigh.

e) Determine the volume of coarse fragments by subtracting the weight in water from the weight in air. This illustrates the Buoyancy Principle first explained by Archimedes many centuries ago.

$$\frac{\text{weight of coarse fragments in air} - \text{weight of coarse fragments in water}}{\text{volume of coarse fragments}}$$

f) Calculate the % coarse fragments (CF) by volume by dividing the volume of coarse fragments by the volume of the entire soil.

$$\% \ CF = \frac{\text{Volume of coarse fragments}}{\text{Volume of entire soil}} \times 100\%$$

ARCHIMEDES PRINCIPLE (Buoyancy Principle)

This principle states that there is a buoyant force (the buoyant force acts in opposition to the force of gravity) exerted on a submerged, suspended object that is equal to the weight of the fluid it displaces. When an object is submerged in water, it displaces a volume of water exactly equal to its own volume. The difference between the weight of the object in air and its weight suspended in water will be equal to the weight of the water that it has displaced (the buoyant force). The volume of pure water in ml is equal to its weight in grams, and so a volume can be calculated from a weight measurement.

1 ml of H_2O = 1 gm of H_2O = 1 cubic cm of H_2O

2) Bulk Density

Density (D) is the weight (mass) per unit volume.

$$D = \frac{\text{Mass (in grams)}}{\text{Volume (in cubic cm)}}$$

Soil bulk density (BD) is the weight of a ped (or peds) per unit of total volume it occupies, including pore space. Soil bulk densities typically range from 1.00 to 2.00 g/cc. Water and root permeability are dependent on bulk density. Variabilities in bulk density can be attributed to texture, organic matter and porosity (see Table 3.4).

Particle density (PD) is the density of individual particles of sand, silt, clay, or coarse fragments. Consider PD to be 2.65 g/cc, which is the average density of rock.

BD

a. Weigh the saran coated ped in air.
b. Submerge the ped and weigh in water.
c. Determine the volume of the ped by subtracting the weight in water from the weight in air.
d. Calculate the BD by dividing the mass by the volume.

wt of ped in air
\- wt of ped in water
Volume of ped

Weight of ped in air ÷ volume of ped = BD

TEXTURE AND BULK DENSITY

fine texture (c, cl, sil)	1.00 to 1.60 g/cc
coarse texture (s, sl)	1.20 to 1.80 g/cc
compacted soils	>1.8 g/cc (but may be lower)
organic or volcanic ash soils	<1.00 g/cc

Table 3.4. Typical bulk densities for soils.

3) Porosity

Porosity is the percent of a soil not occupied by solid material and can be calculated from bulk density and particle density. It is reduced when soil is compacted impeding the movement of water, roots and air (permeability). Decreased permeability will decrease infiltration, increasing surface runoff and the risk of erosion. Platy structure is often associated with soil compaction.

% Pore Space Determination

a. Calculate the % solids by dividing BD by PD.

$$\% \text{ solids} = \frac{BD}{PD} \times 100$$

b. Calculate the % pore space by subtracting % solids from 100%.

$$\% \text{ pore space} = 100\% - \% \text{ solids}$$

SOIL CHEMISTRY

Soil chemistry involves positively charged cations, negatively charged anions, and charged exchange sites on clay size particles. The electrochemical reactions that occur are important in plant growth. To help understand these reactions we will determine electrical conductivity, pH, and other chemical data for your assigned soil.

Objective

To be able to understand soil chemical data.

Procedure

Working in teams, prepare your soil for a pH and EC (Electrical Conductivity) analysis.

a) Place a 50 g sample of dried, sieved soil into a 150 ml beaker.
b) Add 100 ml of distilled water.
c) Stir the solution thoroughly and let stand for at least 30 minutes.
d) While waiting, hand texture another sample of the same soil and estimate texture, % clay, % OM, CEC, and determine if $CaCO_3$ is present.

1) Soil Salts

Soil salts are cations (positive charge) and anions (negative charge) in soil solution (see Table 5.1). Too much salt in solution reduces the productivity of a soil by holding water so tightly (osmotic potential) that the plant cannot extract it.

Soluble salts in solution are measured with an EC (Electrical Conductivity) meter. This instrument measures the ease of electrical flow (conductivity) as it travels through a solution. An electrical current will not pass through pure water but will if salts are present. Therefore, high EC readings correspond with high amounts of soluble salt.

Cations		Anions		Soluble Salts		Insoluble Salts
Na^{++}	Mg^{++}	Cl^{-}	$CO_3^{=}$	K_2CO_3	$MgCl_2$	$CaCO_3$
Ca^{++}	K^{+}	HCO_3^{-}	$SO_4^{=}$	$CaCl_2$	$MgSO_4$	$MgCO_3$

Table 5.1. Common cations, anions, soluble salts and insoluble salts.

2) pH (Soil Reaction)

Soil pH or reaction measures the amount of H^+ cations in solution. Nutrient availability and microbial activity are dependent upon pH.

pH Rating*

- pH 6.0 or less - Soil solution has so many H^+ ions that they replace other cations on the exchange sites making them vulnerable to leaching.
- pH 6.0 to 7.5 - Favorable range for most Montana crops. Optimal for nitrogen fixing bacteria.
- pH 7.5 to 8.5 - Soils dominated by calcium cations. Calcareous soils often have reduced availability of Fe, Mn, and Zn cations and phosphate anions.
- pH 8.5 or above - Soils dominated by sodium cations. Excess Na can cause physical alteration of the soil system when wetted.

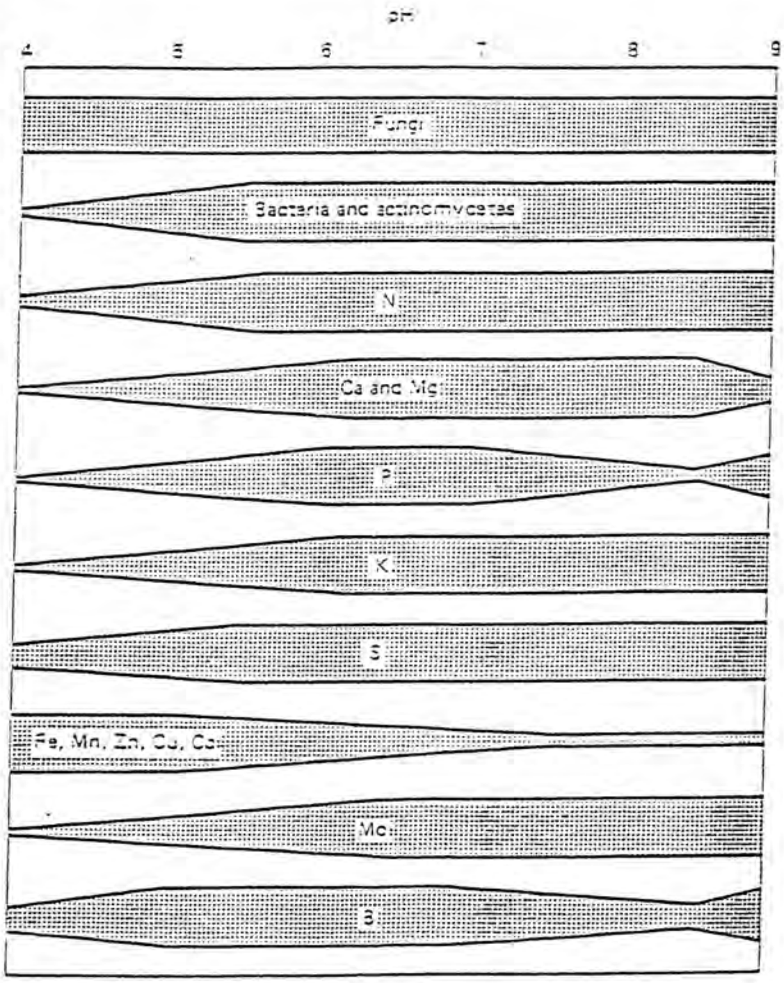


FIGURE 14:3. Relationships existing in mineral soils between pH on the one hand and the activity of microorganisms and the availability of plant nutrients on the other. The wide portions of the bands indicate the zones of greatest microbial activity and the most ready availability of nutrients. Considering the correlations as a whole, a pH range of approximately 6 to 7 seems to promote the most ready availability of plant nutrients. In short, if soil pH is suitably adjusted for phosphorus, other plant nutrients if present in adequate amounts, will be satisfactorily available in most cases.

3) Organic Matter

Organic matter dissociates $R\text{-}OH \longrightarrow R\text{-}O^- \ H^+$ leaving an exposed negative charge commonly known as an exchange site. The more organic matter present, the more exchange sites and the greater the ability of the system to hold cations essential for plant growth.

Soil organic matter is given in percent. It is sometimes useful to express it in parts per million (PPM) or pounds per acre furrow slice (AFS).

We know:

% = parts per 100
ppm = parts per 1,000,000
lbs/AFS = parts per 2,000,000

A sample of Bozeman silt loam (Mollisol) with 6 percent organic matter has:

$$\frac{6}{100} = \frac{60,000}{1,000,000} = \frac{120,000}{2,000,000}$$

or, 60,000 ppm organic matter and 120,000 lbs. of organic matter per acre furrow slice.

A sample of Scobey clay loam (Mollisol) with 2 percent organic matter has:

$$\frac{2}{100} = \frac{20,000}{1,000,000} = \frac{40,000}{2,000,000}$$

or, 20,000 ppm organic matter and 40,000 lbs. of organic matter per acre furrow slice.

OM Rating For Montana*

Less than 1% - Very low, organic matter should be incorporated. The addition of stubble or other organic matter is often recommended.

1 to 2.5% - Low, care should be taken that organic matter is not reduced. Burning stubble reduces the organic matter content and is therefore not recommended.

2.5 to 10% - High, organic matter is at productive levels.

Greater than 10% - Too much organic matter may complex with essential nutrients making them unavailable. This depends on the physical and chemical character of the OM and will differ from soil to soil.

* Source is Extension Soils, MSU

4) Cation Exchange Capacity(CEC)

Clay size particles and organic matter have negatively charged sites (exchange sites) that hold and exchange cations. Exchange sites act as a storehouse for cations that are essential to plant growth. If cation exchange sites did not exist cations would be leached from the root zone making them unavailable.

The CEC is often determined by the ammonium acetate extraction method. The soil is washed with ammonium acetate ($NH_4C_2H_3O_2$) solution. The ammonium (NH_4^+) cation replaces all the cations on the exchange sites and they go into solution. The solution is then analyzed for each cation. The sum of the cations replaced is the cation exchange capacity.

CEC = Sum of the cations

CEC Rating*

Low - 0 to 15 meq/100g
Medium - 15 to 30 meq/100g
High - over 30 meq/100g

The percent of clay and organic matter in a soil can be used to make an estimate of potential CEC. The equation used to estimate CEC this way is:

$$CEC = \frac{1}{2}(\%clay) + 2(\%OM).$$

For example, $CEC = \frac{1}{2}(30) + 2(2) = 19$ meq/100 g.

5) Anion exchange

Anion exchange sites are positively charged exchange sites which hold and exchange anions. Since anion exchange sites are not very common, free anions such as nitrate (NO_3^-) and sulfate (SO_4^-) are easily leached.

6) Base Cations*

Positively charged ions that dominate in high pH soils.

Ca^{++} (at. wt. = 40, valence = 2) Calcium is available to the plant as a free cation. It is involved in cementing cells together. Most Ca in the soil is readily available to the plant. Deficiencies may occur in soils where high precipitation and extensive leaching has removed the base cations, lowering the pH. In these areas lime is added to the soil.

Low - 0 to 100 ppm
Medium - 100 to 10,000 ppm
High - over 10,000 ppm

*Source is Extension Soils, MSU.

Mg^{++} (at. wt. = 24, valence = 2) Magnesium is available as a free cation. It is part of the chlorophyll molecule and activates many enzyme reactions. As with Ca, most Mg in the soil is plant available. Deficiencies are commonly found in high precipitation, low pH soils. Most lime added to soils contains both Ca and Mg.

Low - 0 to 100 ppm
Medium - 100 to 7500 ppm
High - over 7500 ppm

Na^{+} (at. wt. = 23, valence = 1) Sodium is not an essential plant nutrient but is common in dry soil environments. When sodium dominated soils (sodic) become wet soil aggregates disperse plugging up pore spaces. Upon drying these soils become very hard and lack the pore spaces necessary for the movement of gas, water, and nutrients needed in plant growth.

Low - 0 to 50 ppm
Medium - 50 to 450 ppm
High - (sodic) over 450 ppm

Sodic Soils - Soils with >15% E.S.P. and a pH >8.5. These soils are dominated by Na.

ESP - Exchangeable sodium percentage

$$ESP = \frac{\text{exchangeable Na}}{\text{Total CEC}} \times 100$$

SAR - Sodium adsorption ratio is related to ESP.

K^{+} (at. wt. = 39, valence = 1) Potassium is an essential nutrient in the plant. It is involved with translocation, stomatal movement, water retention and enzyme activities.

Very Low - 0 to 75 ppm
Low - 75 to 125 ppm
Medium - 125 to 250 ppm
High - over 250 ppm

* Low, medium, and high ratings are from Extension Soils, MSU.

7) Base Saturation (BS)

The percent of exchangeable base cations (Ca^{++}, Mg^{++}, K^{+}, Na^{+}) on the exchange sites.

$$\% \; BS = \frac{Ca^{++} + Mg^{++} + Na^{+} + K^{+}}{\text{Total CEC}} \times 100$$

8) Exchange Acidity

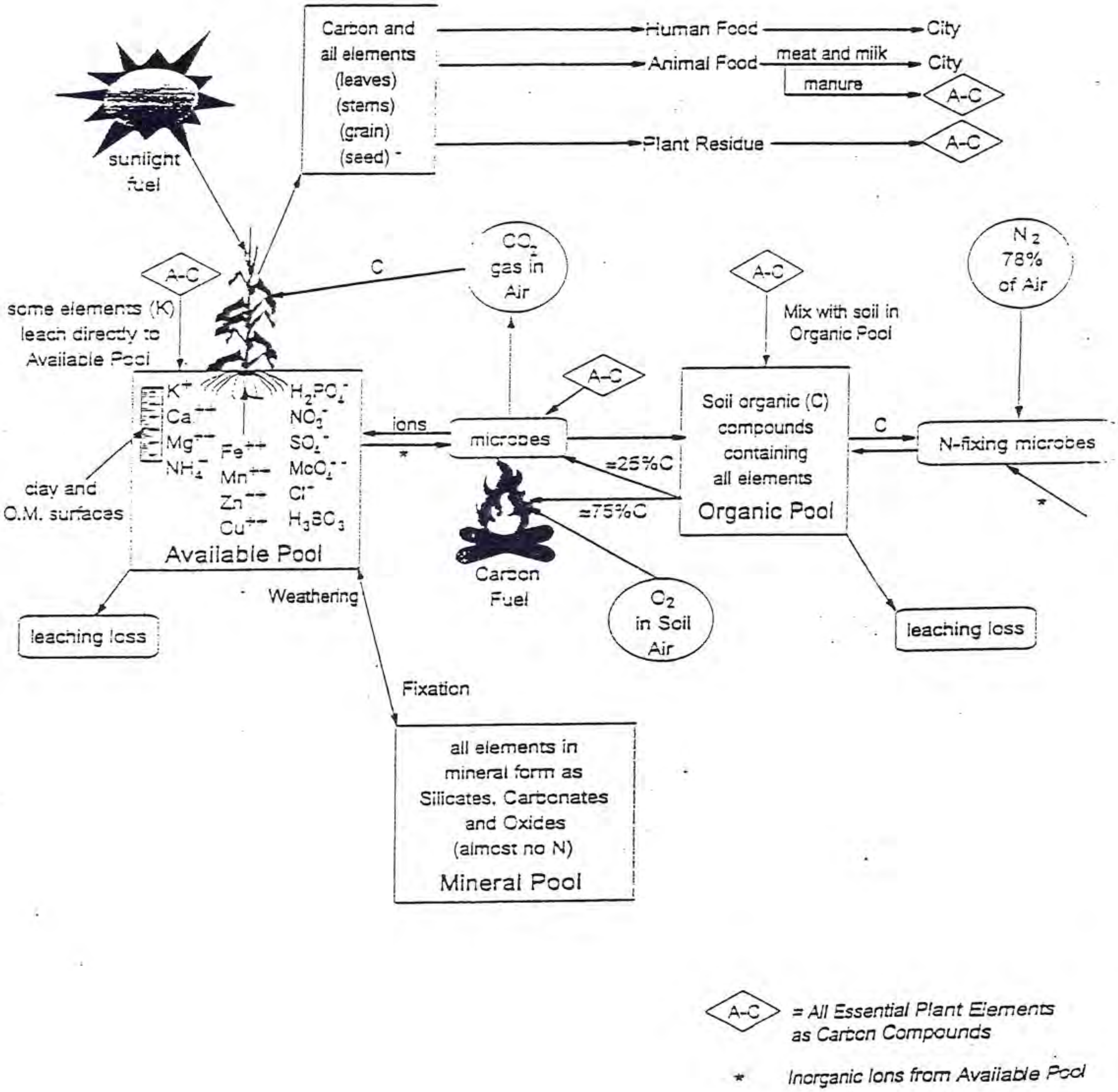
Hydrogen, H^+, and aluminum, Al^{+++}, cations held on the exchange sites.

H^+ at. wt. = 1, valence = 1 Al^{+++} at. wt. = 27, valence = 3

9) Soil Testing Lab

The Montana Soil Testing Laboratory, located on the 8th floor, Johnson Hall, has developed soil chemical tests especially for Montana soils. Sampling instructions, sample containers, price lists, and fertilizer guide sheets are available from the Soil Testing Lab or your County Extension Office. Feel free to visit or call the lab or Extension Office for more information.

Flow of Essential Elements From the Soil During Food Production



these changes may be controlled more or less by man while others are beyond his command. This interlocking succession of largely biochemical reactions constitutes what is known as the *nitrogen cycle* (see Fig. 16:1). It has attracted scientific study for years, and its practical significance is beyond question.

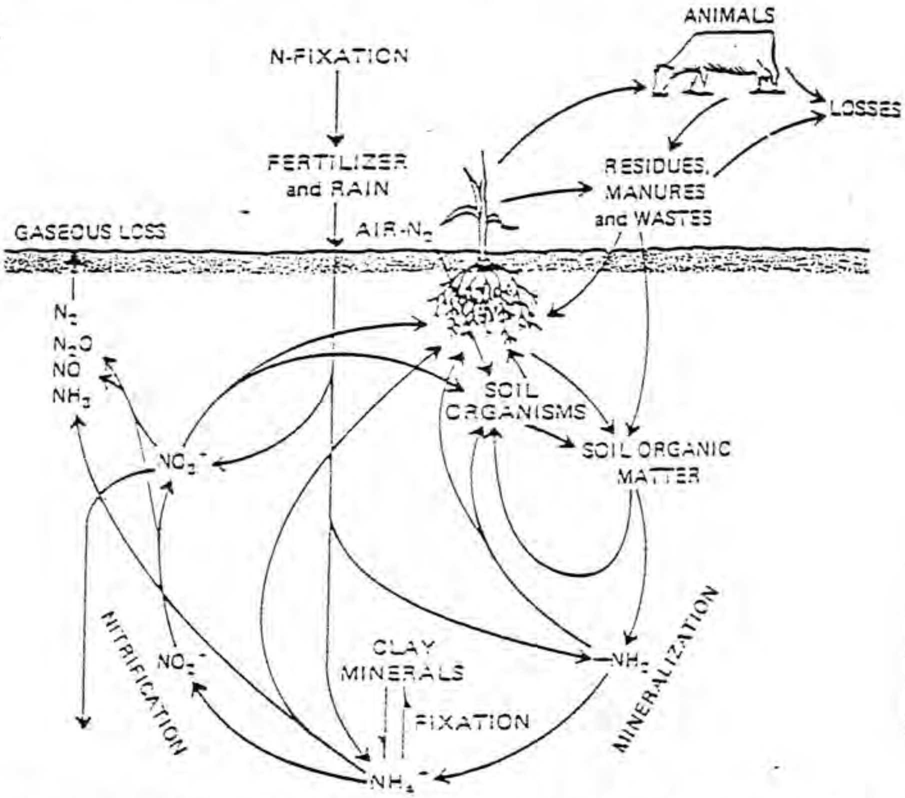


FIGURE 16:1. Main portions of the nitrogen cycle. Additions of chemical fertilizer make up an increasing important source of this element.

The nitrogen income of arable soils is derived from such materials as commercial fertilizers, crop residues, green and farm manures, and ammonium and nitrate salts brought down by precipitation. In addition, there is the fixation of atmospheric nitrogen accomplished by certain microorganisms. The depletion is due to crop removal, drainage, erosion, and to loss in a gaseous condition.

Much of the nitrogen added to the soil undergoes many transformations before it is removed. The nitrogen in organic combination is subjected to especially complex changes. Proteins are converted into various decomposition products, and finally some of the nitrogen appears in the nitrate form.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn

Codes Used in Table (Examples)

Ten most abundant elements in the soil matrix

N Macronutrient Elements

Cl Micronutrient Elements

Co Potentially Toxic Elements

Li Less important elements

Mn Micronutrient, Potentially Toxic (combination code)

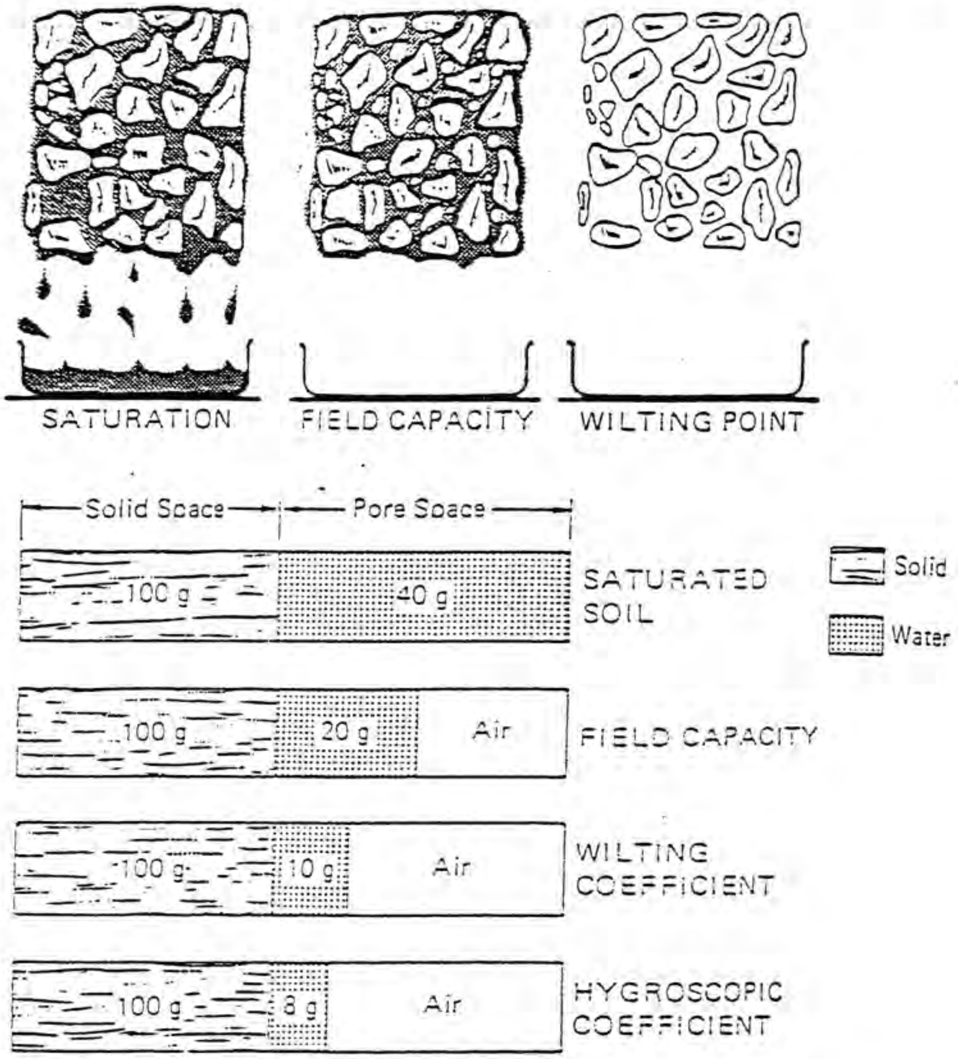


FIGURE 7:20. Volumes of solids, water, and air in a well-granulated silt loam at different moisture levels. The top bar shows the situation when a representative soil is completely saturated with moisture. This situation will usually occur for short periods of time during a rain or when the soil is being irrigated. Water will soon drain out of the larger or *macropores*. The soil is then said to be at the *field capacity*. Plants will remove moisture from the soil quite rapidly until the *wilting coefficient* is approached. Permanent wilting of the plants occurs at this point even though there is still considerable moisture in the soil (wilting coefficient). A further reduction in moisture content to the hygroscopic coefficient is illustrated in the bottom bar. At this point, the water is held very tightly, mostly by the soil colloids. [*Upper drawings modified from Irrigation on Western Farms published by the U.S. Departments of Agriculture and Interior.*]

SOIL WATER

Soil water movement is often very confusing. To help understand it, in your mind picture water moving through soil pores. We will observe how soil texture and pore size influence water movement. Remember that PORE SIZE controls the movement of water.

Objective

To understand how pore space controls soil water movement.

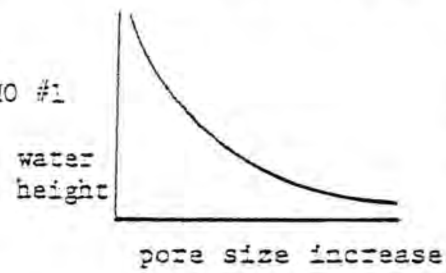
Procedure

Meet in lab for a movie and an exercise on soil water.

1) Soil Water Movie

The movie demonstrates the effect of pore size on water movement. After each demonstration we will stop the film to discuss the important concepts. Your lab manual should be used as a guide during the movie.

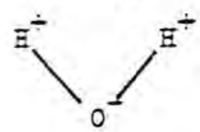
DEMO #1



The rise of water between the glass is due to tension.

TENSION - The pull exerted on soil water by soil particles. This pull is referred to as the matric potential and is measured in bars.

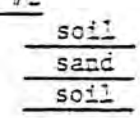
CAPILLARY RISE - The upward movement of water due to adhesion and cohesion. Pore spaces must be small enough for capillary rise to occur.



COHESION - The molecular attraction of water molecules to one another.

ADHESION - The molecular attraction of water to another surface, such as a pore wall.

DEMO #2



Water remains above the sand until saturation occurs because the smaller pore spaces have tension strong enough to prevent the water from entering the larger pore spaces of the sand. The upper soil can hold twice as much water with the sand layer present.

UNSATURATED FLOW - Pore spaces in the unsaturated zone are not completely filled with water. Instead the water occurs as films coating the pores. The films are thickest near the saturated zone and thinnest near the wetting front. Matric potential, the pull of thin water films through soil pores by adhesion and cohesion, dominates in unsaturated flow.

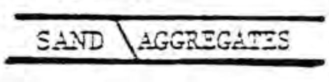
SATURATED FLOW - Pore spaces in the saturated zone are completely filled with water. Gravitational potential, the force of gravity pulling the water down, dominates in saturated flow. In field soils unsaturated flow is more common than saturated flow.

DEMO #3

soil
clay
soil

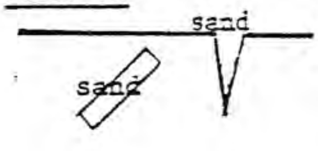
The clay layer adsorbs water readily, pulling it from the soil above as soon as the wetting front touches it. Water is transmitted very slowly through the clay often creating a perched water table. It may take weeks to months before gravitational potential takes over because of the high tension created by the small pore spaces of the clay. This situation is quite common in Montana.

DEMO #4



The wetting front enters the aggregates first because of the size of the pore spaces. Macropores are present between the sand and aggregates, but micropores, created by silt and clay particles, occur throughout the aggregated soil.

DEMO #5



Water does not enter the buried sand until saturation occurs because of the high tension (matric potential) of the surrounding soil.

KEY POINTS TO REMEMBER

SMALL PORE SPACES HOLD WATER WITH ENOUGH TENSION TO PREVENT IT FROM ENTERING LARGE PORE SPACES UNTIL SATURATION OCCURS.

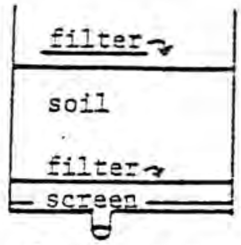
FINE TEXTURE = HIGH TENSION = HIGH MATRIC POTENTIAL = LOW WATER POTENTIAL

COARSE TEXTURE = LOW TENSION = LOW MATRIC POTENTIAL = HIGH WATER POTENTIAL

2) Permeameter Exercise

In this exercise you will compare water movement and water content in 2 different soil samples. Work in teams. Be sure to observe both permeameters to see the differences in water movement rates. Remember to record your data along with the texture of your soil sample.

a) Place a screen and then a filter at the bottom of the permeameter.



Permeameter

b) Using the plastic beakers provided, weigh approximately 200 ml of soil. Pour the soil into the permeameter. DO NOT COMPACT IT, but gently level the surface so that measurements can be made from the top of the soil.

c) Measure the depth of the soil.

d) Measure the diameter of the cylinder and calculate the radius.

e) Calculate the volume of soil.
(Remember: vol. of a cylinder = $\pi r^2 h$)

f) Calculate the bulk density of the soil.
(bulk density = mass/volume)

g) Place a piece of filter paper on top of the soil. Measure 100 ml of tap water in a graduated cylinder. Slowly pour the water onto the surface of the soil column, a little at a time, watching the advance of the wetting front in the soil. Picture how the water is moving (films of water in the soil pores).

h) At saturation, water will drip out of the bottom of the permeameter. Collect this water and stop adding water to the soil. At this time, all the pores in the soil will be <u>full</u> of water. Calculate how much water your soil holds at saturation - (ml water added) - (ml collected).

*Picture what your soil looked like at field capacity. This was when all soil particles were wet, but soil pores were not yet full of water (before water began dripping out of the permeameter.

i) Calculate the % water by weight at saturation. (See key formulas, page 52, lab manual.)

j) Using BD calculated in step f, calculate the % water by volume at saturation. (Key formulas, page 52, lab manual.)

k) Repeat i and j for your sample at field capacity (remember the doubling rule).

l) Again, using the doubling rule, estimate the % water by volume at wilting point.

% water by vol. at saturation = 2 (% water by vol. at field cap.)
% water by vol. at field cap. = 2 (% water by vol. at wilt point)

m) Estimate plant available water. (Key formulas, page 52, lab manual.)

KEY FORMULAS TO REMEMBER

1 ml H_2O = 1 gm H_2O = 1 cubic cm H_2O

$$\% \ H_2O, \text{ by weight} = \frac{\text{Weight of wet soil-weight of dry soil}}{\text{Weight of dry soil}} \times 100$$

% H_2O, by volume = % H_2O, by weight x bulk density

Available water = *Field Capacity (1/3 BAR) - Wilting Point (15 BAR)

* The amount of water at time of sampling may be substituted for field capacity water.

3) Plant Available Water

Water available for plant growth is that water held between field capacity and wilting point. This portion of water can be readily absorbed by plant roots.

Tables 7.1 summarizes differences in saturation, FC and WP, and should be used as a guide to help you understand the relationship of the terms used when discussing soil water. They are only ball park figures, all values will vary depending on texture, organic matter, salts and structure.

	Tension	Amount of water in pores	% Moisture
Saturation	0 BAR ($0 \ lbs/in^2$)	all pores filled	50
Field capacity	1/3 BAR ($5 \ lbs/in^2$)	half of pores filled	25
Wilting point	15 BAR ($225 \ lbs/in^2$)	quarter of pores filled	12

Table 7.1. The relationship of tension, pore space and percent water for saturation, field capacity and wilting point.

PLANT AVAILABLE WATER CAPACITIES FOR SOIL TEXTURAL CLASSES IN MONTANA[1]

		SOIL TEXTURAL CLASS	ESTIMATED AVERAGE PLANT AWC (in/ft)[2]	RANGE IN ESTIMATED PLANT AWC (in/in) (For use on Soil Interpretations Records)[3]
Sandy Soils	Coarse texture	Sands	0.5	0.02 - 0.06
		Loamy sands	1.0	0.06 - 0.10
		Loamy fine sands		
		Loamy v. fine sands	1.25	0.08 - 0.12
		Fine sands		
		V. fine sands		
Loamy soils	Moderate coarse texture	Sandy Loam	1.5	0.11 - 0.15
		Fine sandy loam		
	Medium texture	V. fine sandy loam		
		Loam	2.0	0.15 - 0.19
		Silt loam		
		Silt		
	Moderately fine texture	Clay loam		
		Sandy clay loam	2.2	0.16 - 0.20
		Silty clay loam		
Clayey soils	Fine texture	Sandy clay		
		Silty clay	2.0	0.15 - 0.19
		Clay		

1 Soluble salts and gravel will decrease plant available water capacity; whereas, organic matter, good soil structures will increase it. The capacity increases about 0.1 in/ft for each 1% organic matter. Soils with water restricting layers like compact subsoils, shallow bedrock or stratification can increase PAWC of the overlying layers. Soils that are deep, medium textured and uniform can have decreased PAW but allow for deeper rooting.

2 Soil depth measured to depth of crop rooting or depth to a root-limiting layer.

3 For the loamy and clayey soils, the range in plant AWC is 10 to 15 percent on each side of the median AWC figure. For sandy soils, (other than "sands") the range is 20 to 25 percent. For "sands" the plant AWC is extremely variable, and depends upon the size of the individual sand grains. i.e.: Medium sands hold more water than do coarse sands.

Approved by Soils Committee, MSU, Plant and Soil Science Planning Conference, January 31, 1984.

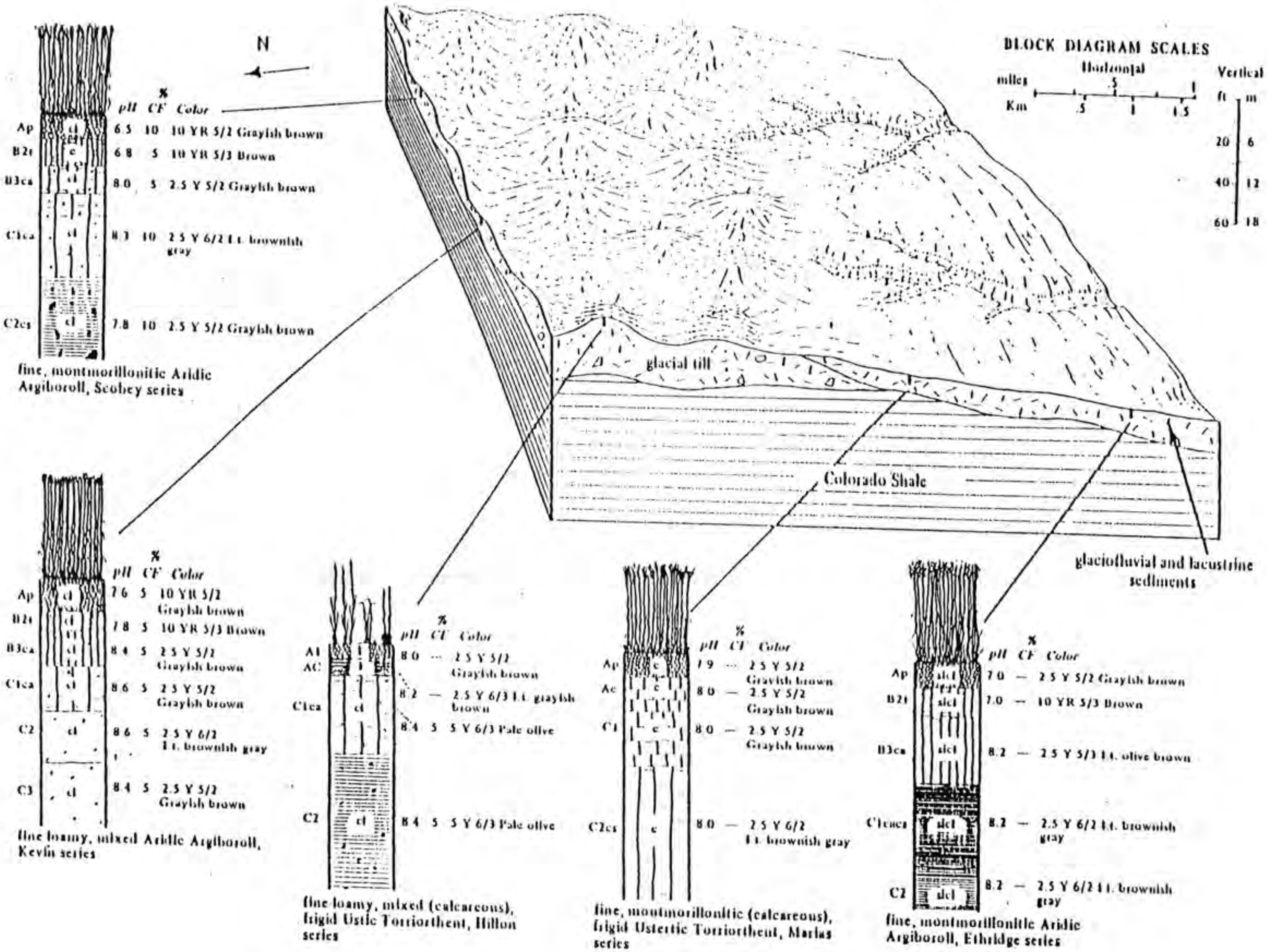


FIG. 16. SOILS OF GLACIATED COLORADO SHALE

STANDARD TERMINOLOGY
TO BE USED IN
MONTANA SOIL SURVEYS

GUIDE FOR DESCRIBING LANDSCAPES		
Major Physiography	Modifiers for Major Physiographic Positions	
Mountains	Hills	Flood plains
	Ridges	Bottoms
Uplands	Foot slopes	Depressions
	Fans & Fan Terrace	Swales
Valleys	Terraces--Lake	Sand dunes
	Outwash	
	Stream	
	River	
	Sedimentary	

SLOPES			
	%	Single	Complex
A	0-2	Nearly level	Nearly level
B	2-4	Gently sloping	Undulating
C	4-8	Moderately sloping	Gently rolling
D	8-15	Strongly sloping	Strongly rolling
E	15-25	Moderately steep	Hilly
F	25-45	Steep	Steep
G	45+	Very steep	Very steep

SOIL DEPTH *	
Inches	Term
Less than 10	Very shallow
10 to 20	Shallow
20 to 40	Moderately deep
40 to 60	Deep
Over 60	Very deep

*Depth to lithic or paralithic contact.

SOIL REACTION	
Term	pH
Extremely acid	Less than 4.5
Very strongly acid	4.5 to 5.0
Strongly acid	5.1 to 5.5
Medium acid	5.6 to 6.0
Slightly acid	6.1 to 6.5
Neutral	6.6 to 7.3
Mildly alkaline	7.4 to 7.8
Moderately alkaline	7.9 to 8.4
Strongly alkaline	8.5 to 9.0
Very strongly alkaline	Over 9.0

PERMEABILITY	
Inches/Hour	Class
Less than 0.06	Very slow
0.06 to 0.20	Slow
0.20 to 0.60	Moderately slow
0.60 to 2.00	Moderate
2.00 to 6.00	Moderately rapid
6.00 to 20.00	Rapid
Over 20.00	Very rapid

DEPTH TO WATER TABLE		
	Feet	Drainage
+2 - 1.0	~~0-1.5~~ and ponded	Very poorly
1.0 - 2.0	~~1.5 to 3~~	Poorly
2.0 - 3.5	~~3 to 5~~	Somewhat poorly
3.5 - 5.0	~~5 to 6~~	Moderately well
	Over 6	Well, Somewhat excessively, Excessively

AVAILABLE WATER CAPACITY	
Inches/60-inch Profile or to Limiting Layer	Class
<3.75	Very low
3.75 - 5	Low
5 - 7.5	Moderate
>7.5	High

PROCEDURE FOR MAKING 1 NORMAL HCL

1. Determine concentration of HCL purchased.
2. Divide 30.78 ml by % concentration HCL (30.78 / .28 = 110 ml of HCL per liter)
3. Put 110 ml of your HCL in bottle and add distilled water up to 1 liter mark. This solution will be 1 Normal HCL.

1 Normal HCl is used to determine the effervescent class in soils. Effervescent classes are used to estimate the amount of Calcium Carbonate (lime) in the soils.

Class	Indicator	CaCO3 equivalent
none	no bubbling	0%
slight	some bubbling	<5%
strong	low foam	>5%
violent	high foam	>5%

Procedure

Drop several drops of 1 N HCl on soil. Observe effervescence.

Reasons for interest in Calcium Carbonate.

Calcium Carbonate is an indicator of soil development in most of Montana. The deeper to CaCO3 the better developed the soil generally is.

CaCO3 can be used as an indicator of the average annual wetting depth of soils on stable landscapes with little erosion occuring.

CaCO3 in the surface layer makes the soil more susceptible to wind erosion and tends to tie up phosphorus.

LAND-CAPABILITY CLASSIFICATION

Agriculture Handbook No. 210

SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE

FOREWORD

Since soil surveys are based on all of the characteristics of soils that influence their use and management, interpretations are needed for each of the many uses. Among these interpretations the grouping of soils into capability units, subclasses, and classes is one of the most important. This grouping serves as an introduction of the soil map to farmers and other land users developing conservation plans.

As we have gained experience in this grouping, the definitions of the categories have improved. It is the purpose of this publication to set forth these definitions. In using the capability classification, the reader must continually recall that it is an interpretation. Like other interpretations, it depends on the probable interactions between the kind of soil and the alternative systems of management. Our management systems are continually changing. Economic conditions change. Our knowledge grows. Land users are continually being offered new things, such as new machines, chemicals, and plant varieties.

The new technology applies unevenly to the various kinds of soil. Thus the grouping of any one kind of soil does not stay the same with changes in technology. That is, new combinations of practices increase the productivity of some soils more than others, so some are going up in the scale whereas others are going down, relatively. Some of our most productive soils of today were considered poorly suited to crops a few years ago. On the other hand, some other soils that were once regarded as good for cropping are now being used more productively for growing pulpwood. These facts in no way suggest that we should not make interpretations. In fact, they become increasingly important as technology grows. But these facts do mean that soils need to be reinterpreted and regrouped after significant changes in economic conditions and technology.

Besides the capability classification explained in this publication, other important interpretations are made of soil surveys. Examples include groupings of soils according to crop-yield predictions, woodland suitability, range potentiality, wildlife habitat, suitability for special crops, and engineering behavior. Many other kinds of special groupings are used to help meet local needs.

CHARLES E. KELLOGG
Assistant Administrator for Soil Survey
Soil Conservation Service

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LAND-CAPABILITY CLASSIFICATION

By A. A. Klingebiel and P. H. Montgomery, *soil scientists, Soil Conservation Service*

The standard soil-survey map shows the different kinds of soil that are significant and their location in relation to other features of the landscape. These maps are intended to meet the needs of users with widely different problems and, therefore, contain considerable detail to show important basic soil differences.

The information on the soil map must be explained in a way that has meaning to the user. These explanations are called interpretations. Soil maps can be interpreted by (1) the individual kinds of soil on the map, and (2) the grouping of soils that behave similarly in responses to management and treatment. Because there are many kinds of soil, there are many individual soil interpretations. Such interpretations, however, provide the user with all the information that can be obtained from a soil map. Many users of soil maps want more general information than that of the individual soil-mapping unit. Soils are grouped in different ways according to the specific needs of the map user. The kinds of soil grouped and the variation permitted within each group differ according to the use to be made of the grouping.

The capability classification is one of a number of interpretive groupings made primarily for agricultural purposes. As with all interpretive groupings the capability classification begins with the individual soil-mapping units, which are building stones of the system (table 1). In this classification the arable soils are grouped according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specialized site conditioning or site treatment. Nonarable soils (soils unsuitable for longtime sustained use for cultivated crops) are grouped according to their potentialities and limitations for the production of permanent vegetation and according to their risks of soil damage if mismanaged.

The individual mapping units on soil maps show the location and extent of the different kinds of soil. One can make the greatest number of precise statements and predictions about the use and management of the individual mapping units shown on the soil map. The capability grouping of soils is designed (1) to help landowners and others use and interpret the soil maps, (2) to introduce users to the detail of the soil map itself, and (3) to make possible broad generalizations based on soil potentialities, limitations in use, and management problems.

The capability classification provides three major categories of soil groupings: (1) Capability unit, (2) capability subclass, and (3) capability class.

TABLE 1.—Relationship of soil-mapping unit to capability classification

Soil-mapping unit	Capability unit	Capability subclass	Capability class
A soil mapping unit is a portion of the landscape that has similar characteristics and qualities and whose limits are fixed by precise definitions. Within the cartographic limitations and considering the purpose for which the map is made, the soil mapping unit is the unit about which the greatest number of precise statements and predictions can be made.	A capability unit is a grouping of one or more individual soil mapping units having similar potentials and continuing limitations or hazards. The soils in a capability unit are sufficiently uniform to (a) produce similar kinds of cultivated crops and pasture plants with similar management practices, (b) require similar conservation treatment and management under the same kind and condition of vegetative cover, (c) have comparable potential productivity.	Subclasses are groups of capability units which have the same major conservation problem, such as— e—Erosion and runoff. w—Excess water. s—Root-zone limitations. c—Climatic limitations.	Capability classes are groups of capability subclasses or capability units that have the same relative degree of hazard or limitation. The risks of soil damage or limitation in use become progressively greater from class I to class VIII.
The soil mapping units provide the most detailed soils information. The basic mapping units are the basis for all interpretive groupings of soils. They furnish the information needed for developing capability units, forest site groupings, crop suitability groupings, range site groupings, engineering groupings, and other interpretive groupings. The most specific management practices and estimated yields are related to the individual mapping unit.	The capability unit condenses and simplifies soils information for planning individual tracts of land, field by field. Capability units with the class and subclass furnish information about the degree of limitation, kind of conservation problems and the management practices needed.	The capability subclass provides information as to the kind of conservation problem or limitations involved. The class and subclass together provide the map user information about both the degree of limitation and kind of problem involved for broad program planning, conservation need studies, and similar purposes.	The capability classes are useful as a means of introducing the map user to the more detailed information on the soil map. The classes show the location, amount, and general suitability of the soils for agricultural use. Only information concerning general agricultural limitations in soil use are obtained at the capability class level.

The first category, capability unit, is a grouping of soils that have about the same responses to systems of management of common cultivated crops and pasture plants. Soils in any one capability unit are adapted to the same kinds of common cultivated and pasture plants and require similar alternative systems of management for these crops. Longtime estimated yields of adapted crops for individual soils within the unit under comparable management do not vary more than about 25 percent.[1]

The second category, the subclass, is a grouping of capability units having similar kinds of limitations and hazards. Four general kinds of limitations or hazards are recognized: (1) Erosion hazard, (2) wetness, (3) rooting-zone limitations, and (4) climate.

The third and broadest category in the capability classification places all the soils in eight capability classes. The risks of soil damage or limitations in use become progressively greater from class I to class VIII. Soils in the first four classes under good management are capable of producing adapted plants, such as forest trees or range plants, and the common cultivated field crops[2] and pasture plants. Soils in classes V, VI, and VII are suited to the use of adapted native plants. Some soils in classes V and VI are also capable of producing specialized crops, such as certain fruits and ornamentals, and even field and vegetable crops under highly intensive management involving elaborate practices for soil and water conservation.[3] Soils in class VIII do not return on-site benefits for inputs of management for crops, grasses, or trees without major reclamation.

The grouping of soils into capability units, subclasses, and classes is done primarily on the basis of their capability to produce common cultivated crops and pasture plants without deterioration over a long period of time. To express suitability of the soils for range and woodland use, the soil-mapping units are grouped into range sites and woodland-suitability groups.

ASSUMPTIONS

In assigning soils to the various capability groupings a number of assumptions are made. Some understanding of these assumptions is necessary if

[1] Yields are significant at the capability-unit level and are one of the criteria used in establishing capability units within a capability class. Normally, yields are estimated under the common management that maintains the soil resource. The main periods for such yield estimates are 10 or more years in humid areas or under irrigation and 20 or more years in subhumid or semiarid areas. The 25 percent allowable range is for economically feasible yields of adapted cultivated and pasture crops.

[2] As used here the common crops include: Corn, cotton, tobacco, wheat, tame hay and pasture, oats, barley, grain sorghum, sugarcane, sugar beets, peanuts, soybeans, field-grown vegetables, potatoes, sweet potatoes, field peas and beans, flax, and most clean-cultivated fruit, nut, and ornamental plants. They do not include: Rice, cranberries, blueberries, and those fruit, nut, and ornamental plants that require little or no cultivation.

[3] Soil and water conservation practices is a general expression for all practices including but not limited to those for erosion control.

the soils are to be grouped consistently in the capability classification and if the groupings are to be used properly. They are:

1. A taxonomic (or natural) soil classification is based directly on soil characteristics. The capability classification (unit, subclass, and class) is an interpretive classification based on the effects of combinations of climate and permanent soil characteristics on risks of soil damage, limitations in use, productive capacity, and soil management requirements. Slope, soil texture, soil depth, effects of past erosion, permeability, water-holding capacity, type of clay minerals, and the many other similar features are considered permanent soil qualities and characteristics. Shrubs, trees, or stumps are not considered permanent characteristics.
2. The soils within a capability class are similar only with respect to degree of limitations in soil use for agricultural purposes or hazard to the soil when it is so used. Each class includes many different kinds of soil, and many of the soils within any one class require unlike management and treatment. Valid generalizations about suitable kinds of crops or other management needs cannot be made at the class level.
3. A favorable ratio of output to input [4] is one of several criteria used for placing any soil in a class suitable for cultivated crop, grazing, or woodland use, but no further relation is assumed or implied between classes and output-input ratios. The capability classification is not a productivity rating for specific crops. Yield estimates are developed for specific kinds of soils and are included in soil handbooks and soil-survey reports.
4. A moderately high level of management is assumed—one that is practical and within the ability of a majority of the farmers and ranchers. The level of management is that commonly used by the "reasonable" men of the community. The capability classification is not, however, a grouping of soils according to the most profitable use to be made of the land. For example, many soils in class III or IV, defined as suitable for several uses including cultivation, may be more profitably used for grasses or trees than for cultivated crops.
5. Capability classes I through IV are distinguished from each other by a summation of the degree of limitations or risks of soil damage that affect their management requirements for longtime sustained use for cultivated crops. Nevertheless, differences in kinds of management or yields of perennial vegetation may be greater between some pairs of soils within one class than between some pairs of soils from different classes. The capability class is not determined by the kind of practices recommended. For example, class II, III, or IV may or may not require the same kind of practices when used for cultivated crops, and classes I through VII may or may not require the same kind of pasture, range, or woodland practices.
6. Presence of water on the surface or excess water in the soil; lack of water for adequate crop production; presence of stones; presence of soluble salts or exchangeable sodium, or both; or hazard of overflow are not considered permanent limitations to use where the removal of these limitations is feasible.[5]
7. Soils considered feasible for improvement by draining, by irrigating, by removing stones, by removing salts or exchangeable sodium, or by protecting from overflow are classified according to their continuing limitations in use, or the risks of soil damage, or both, after the improvements have been installed. Differences in initial costs of the systems installed on individual tracts of land do not influence the classification. The fact that certain wet soils are in classes II, III, and IV does not imply that they should be drained. But it does indicate the degree of their continuing limitation in use or risk of soil damage, or both, if adequately drained. Where it is considered not feasible to improve soils by drainage, irrigation, stone removal, removal of excess salts or exchangeable sodium, or both, or to protect them from overflow, they are classified according to present limitations in use.
8. Soils already drained or irrigated are grouped according to the continuing soil and climatic limitations and risks that affect their use under the present systems or feasible improvements in them.
9. The capability classification of the soils in an area may be changed when major reclamation projects are installed that permanently change the limitations in use or reduce the hazards or risks of soil or crop damage for long periods of time. Examples include establishing major drainage facilities, building levees or flood-retarding structures, providing water for irrigation, removing stones, or large-scale grading of gullied land. (Minor dams, terraces, or field conservation measures subject to change in their effectiveness in a short time are not included.)
10. Capability groupings are subject to change as new information about the behavior and responses of the soils becomes available.
11. Distance to market, kinds of roads, size and shape of the soil areas, locations within fields, skill or resources of individual operators, and other characteristics of land-ownership patterns are not criteria for capability groupings.
12. Soils with such physical limitations that common field crops can be cultivated and harvested only by hand are not placed in classes I, II, III, and IV. Some of these soils need drainage or stone removal, or both, before some kinds of machinery can be used. This does not imply that mechanical equipment cannot be used on some soils in capability classes V, VI, and VII.
13. Soils suited to cultivation are also suited to other uses such as pasture, range, forest, and wildlife. Some not suited to cultivation are suited to pasture, range, forest, or wildlife; others are suited only to pasture or

[4] Based on longtime economic trends for average farms and farmers using moderately high level management. May not apply to specific farms and farmers but will apply to broad areas.

[5] Feasible as used in this context means (1) that the characteristics and qualities of the soil are such that it is possible to remove the limitation, and (2) that over broad areas it is within the realm of present-day economic possibility to remove the limitation.

range and wildlife; others only to forest and wildlife; and a few suited only to wildlife, recreation, and water-yielding uses. Groupings of soils for pasture, range, wildlife, or woodland may include soils from more than one capability class. Thus, to interpret soils for these uses, a grouping different from the capability classification is often necessary.

14. Research data, recorded observations, and experience are used as the bases for placing soils in capability units, subclasses, and classes. In areas where data on response of soils to management are lacking, soils are placed in capability groups by interpretation of soil characteristics and qualities in accord with the general principles about use and management developed for similar soils elsewhere.

CAPABILITY CLASSES

Land Suited to Cultivation and Other Uses

Class I—Soils in class I have few limitations that restrict their use.

Soils in this class are suited to a wide range of plants and may be used safely for cultivated crops, pasture, range, woodland, and wildlife. The soils are nearly level [6] and erosion hazard (wind or water) is low. They are deep, generally well drained, and easily worked. They hold water well and are either fairly well supplied with plant nutrients or highly responsive to inputs of fertilizer.

The soils in class I are not subject to damaging overflow. They are productive and suited to intensive cropping. The local climate must be favorable for growing many of the common field crops.

In irrigated areas, soils may be placed in class I if the limitation of the arid climate has been removed by relatively permanent irrigation works. Such irrigated soils (or soils potentially useful under irrigation) are nearly level, have deep rooting zones, have favorable permeability and water-holding capacity, and are easily maintained in good tilth. Some of the soils may require initial conditioning including leveling to the desired grade, leaching of a slight accumulation of soluble salts, or lowering of the seasonal water table. Where limitations due to salts, water table, overflow, or erosion are likely to recur, the soils are regarded as subject to permanent natural limitations and are not included in class I.

Soils that are wet and have slowly permeable subsoils are not placed in class I. Some kinds of soil in class I may be drained as an improvement measure for increased production and ease of operation.

Soils in class I that are used for crops need ordinary management practices to maintain productivity—both soil fertility and soil structure. Such practices may include the use of one or more of the following: Fertilizers and lime, cover and green-manure crops, conservation of crop residues and animal manures, and sequences of adapted crops.

[6] Some rapidly permeable soils in class I may have gentle slopes.

Class II—Soils in class II have some limitations that reduce the choice of plants or require moderate conservation practices.

Soils in class II require careful soil management, including conservation practices, to prevent deterioration or to improve air and water relations when the soils are cultivated. The limitations are few and the practices are easy to apply. The soils may be used for cultivated crops, pasture, range, woodland, or wildlife food and cover.

Limitations of soils in class II may include singly or in combination the effects of (1) gentle slopes, (2) moderate susceptibility to wind or water erosion or moderate adverse effects of past erosion, (3) less than ideal soil depth, (4) somewhat unfavorable soil structure and workability, (5) slight to moderate salinity or sodium easily corrected but likely to recur, (6) occasional damaging overflow, (7) wetness correctable by drainage but existing permanently as a moderate limitation, and (8) slight climatic limitations on soil use and management.

The soils in this class provide the farm operator less latitude in the choice of either crops or management practices than soils in class I. They may also require special soil-conserving cropping systems, soil conservation practices, water-control devices, or tillage methods when used for cultivated crops. For example, deep soils of this class with gentle slopes subject to moderate erosion when cultivated may need one of the following practices or some combination of two or more: Terracing, stripcropping, contour tillage, crop rotations that include grasses and legumes, vegetated water-disposal areas, cover or green-manure crops, stubble mulching, fertilizers, manure, and lime. The exact combinations of practices vary from place to place, depending on the characteristics of the soil, the local climate, and the farming system.

Class III—Soils in class III have severe limitations that reduce the choice of plants or require special conservation practices, or both.

Soils in class III have more restrictions than those in class II and when used for cultivated crops the conservation practices are usually more difficult to apply and to maintain. They may be used for cultivated crops, pasture, woodland, range, or wildlife food and cover.

Limitations of soils in class III restrict the amount of clean cultivation; timing of planting, tillage, and harvesting; choice of crops; or some combination of these limitations. The limitations may result from the effects of one or more of the following: (1) Moderately steep slopes; (2) high susceptibility to water or wind erosion or severe adverse effects of past erosion; (3) frequent overflow accompanied by some crop damage; (4) very slow permeability of the subsoil; (5) wetness or some continuing waterlogging after drainage; (6) shallow depths to bedrock, hardpan, fragipan, or claypan that limit the rooting zone and the water storage; (7) low moisture-holding capacity; (8) low fertility not easily corrected; (9) moderate salinity or sodium; or (10) moderate climatic limitations.

When cultivated, many of the wet, slowly permeable but nearly level

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soils in class III require drainage and a cropping system that maintains or improves the structure and tilth of the soil. To prevent puddling and to improve permeability it is commonly necessary to supply organic material to such soils and to avoid working them when they are wet. In some irrigated areas, part of the soils in class III have limited use because of high water table, slow permeability, and the hazard of salt or sodic accumulation. Each distinctive kind of soil in class III has one or more alternative combinations of use and practices required for safe use, but the number of practical alternatives for average farmers is less than that for soils in class II.

Class IV—Soils in class IV have very severe limitations that restrict the choice of plants, require very careful management, or both.

The restrictions in use for soils in class IV are greater than those in class III and the choice of plants is more limited. When these soils are cultivated, more careful management is required and conservation practices are more difficult to apply and maintain. Soils in class IV may be used for crops, pasture, woodland, range, or wildlife food and cover.

Soils in class IV may be well suited to only two or three of the common crops or the harvest produced may be low in relation to inputs over a long period of time. Use for cultivated crops is limited as a result of the effects of one or more permanent features such as (1) steep slopes, (2) severe susceptibility to water or wind erosion, (3) severe effects of past erosion, (4) shallow soils, (5) low moisture-holding capacity, (6) frequent overflows accompanied by severe crop damage, (7) excessive wetness with continuing hazard of waterlogging after drainage, (8) severe salinity or sodium, or (9) moderately adverse climate.

Many sloping soils in class IV in humid areas are suited to occasional but not regular cultivation. Some of the poorly drained, nearly level soils placed in class IV are not subject to erosion but are poorly suited to intertilled crops because of the time required for the soil to dry out in the spring and because of low productivity for cultivated crops. Some soils in class IV are well suited to one or more of the special crops, such as fruits and ornamental trees and shrubs, but this suitability itself is not sufficient to place a soil in class IV.

In subhumid and semiarid areas, soils in class IV may produce good yields of adapted cultivated crops during years of above average rainfall; low yields during years of average rainfall; and failures during years of below average rainfall. During the low rainfall years the soil must be protected even though there can be little or no expectancy of a marketable crop. Special treatments and practices to prevent soil blowing, conserve moisture, and maintain soil productivity are required. Sometimes crops must be planted or emergency tillage used for the primary purpose of maintaining the soil during years of low rainfall. These treatments must be applied more frequently or more intensively than on soils in class III.

Land Limited in Use—Generally Not Suited to Cultivation [7]

Class V—Soils in class V have little or no erosion hazard but have other limitations impractical to remove that limit their use largely to pasture, range, woodland, or wildlife food and cover.

Soils in class V have limitations that restrict the kind of plants that can be grown and that prevent normal tillage of cultivated crops. They are nearly level but some are wet, are frequently overflowed by streams, are stony, have climatic limitations, or have some combination of these limitations. Examples of class V are (1) soils of the bottom lands subject to frequent overflow that prevents the normal production of cultivated crops, (2) nearly level soils with a growing season that prevents the normal production of cultivated crops, (3) level or nearly level stony or rocky soils, and (4) ponded areas where drainage for cultivated crops is not feasible but where soils are suitable for grasses or trees. Because of these limitations cultivation of the common crops is not feasible but pastures can be improved and benefits from proper management can be expected.

Class VI—Soils in class VI have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food and cover.

Physical conditions of soils placed in class VI are such that it is practical to apply range or pasture improvements, if needed, such as seeding, liming, fertilizing, and water control with contour furrows, drainage ditches, diversions, or water spreaders. Soils in class VI have continuing limitations that cannot be corrected, such as (1) steep slope, (2) severe erosion hazard, (3) effects of past erosion, (4) stoniness, (5) shallow rooting zone, (6) excessive wetness or overflow, (7) low moisture capacity, (8) salinity or sodium, or (9) severe climate. Because of one or more of these limitations these soils are not generally suited to cultivated crops. But they may be used for pasture, range, woodland, or wildlife cover or for some combination of these.

Some soils in class VI can be safely used for the common crops provided unusually intensive management is used. Some of the soils in this class are also adapted to special crops such as sodded orchards, blueberries, or the like, requiring soil conditions unlike those demanded by the common crops. Depending upon soil features and local climate the soils may be well or poorly suited to woodlands.

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[7] Certain soils grouped into classes V, VI, VII, and VIII may be made fit for use for crops with major earthmoving or other costly reclamation.

Class VII—Soils in class VII have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland, or wildlife.

Physical conditions of soils in class VII are such that it is impractical to apply such pasture or range improvements as seeding, liming, fertilizing, and water control with contour furrows, ditches, diversions, or water spreaders. Soil restrictions are more severe than those in class VI because of one or more continuing limitations that cannot be corrected, such as (1) very steep slopes, (2) erosion, (3) shallow soil, (4) stones, (5) wet soil, (6) salts or sodium, (7) unfavorable climate, or (8) other limitations that make them unsuited to common cultivated crops. They can be used safely for grazing or woodland or wildlife food and cover or for some combination of these under proper management.

Depending upon the soil characteristics and local climate, soils in this class may be well or poorly suited to woodland. They are not suited to any of the common cultivated crops; in unusual instances, some soils in this class may be used for special crops under unusual management practices. Some areas of class VII may need seeding or planting to protect the soil and to prevent damage to adjoining areas.

Class VIII—Soils and landforms in class VIII have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, or water supply or to esthetic purposes.

Soils and landforms in class VIII cannot be expected to return significant on-site benefits from management for crops, grasses, or trees, although benefits from wildlife use, watershed protection, or recreation may be possible.

Limitations that cannot be corrected may result from the effects of one or more of the following: (1) Erosion or erosion hazard, (2) severe climate, (3) wet soil, (4) stones, (5) low moisture capacity, and (6) salinity or sodium.

Badlands, rock outcrop, sandy beaches, river wash, mine tailings, and other nearly barren lands are included in class VIII. It may be necessary to give protection and management for plant growth to soils and landforms in class VIII in order to protect other more valuable soils, to control water, or for wildlife or esthetic reasons.

CAPABILITY SUBCLASSES

Subclasses are groups of capability units within classes that have the same kinds of dominant limitations for agricultural use as a result of soil and climate. Some soils are subject to erosion if they are not protected, while others are naturally wet and must be drained if crops are to be grown. Some soils are shallow or droughty or have other soil deficiencies. Still

other soils occur in areas where climate limits their use. The four kinds of limitations recognized at the subclass level are: Risks of erosion, designated by the symbol (e); wetness, drainage, or overflow (w); rooting-zone limitations (s); and climatic limitations (c). The subclass provides the map user information about both the degree and kind of limitation. Capability class I has no subclasses.

Subclass **(e) erosion** is made up of soils where the susceptibility to erosion is the dominant problem or hazard in their use. Erosion susceptibility and past erosion damage are the major soil factors for placing soils in this subclass.

Subclass **(w) excess water** is made up of soils where excess water is the dominant hazard or limitation in their use. Poor soil drainage, wetness, high water table, and overflow are the criteria for determining which soils belong in this subclass.

Subclass **(s) soil limitations within the rooting zone** includes, as the name implies, soils that have such limitations as shallowness of rooting zones, stones, low moisture-holding capacity, low fertility difficult to correct, and salinity or sodium.

Subclass **(c) climatic limitation** is made up of soils where the climate (temperature or lack of moisture) is the only major hazard or limitation in their use.[8]

Limitations imposed by erosion, excess water, shallow soils, stones, low moisture-holding capacity, salinity, or sodium can be modified or partially overcome and take precedence over climate in determining subclasses. The dominant kind of limitation or hazard to the use of the land determines the assignment of capability units to the (e), (w), and (s) subclasses. Capability units that have no limitation other than climate are assigned to the (c) subclass.

Where two kinds of limitations that can be modified or corrected are essentially equal, the subclasses have the following priority: e, w, s. For example, we need to group a few soils of humid areas that have both an erosion hazard and an excess water hazard; with them the e takes precedence over the w. In grouping soils having both an excess water limitation and a rooting-zone limitation the w takes precedence over the s. In grouping soils of subhumid and semiarid areas that have both an erosion hazard and a climatic limitation the e takes precedence over the c, and in grouping soils with both rooting-zone limitations and climatic limitations the s takes precedence over the c.

Where soils have two kinds of limitations, both can be indicated if needed for local use; the dominant one is shown first. Where two kinds of problems are shown for a soil group, the dominant one is used for summarizing data by subclasses.

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[8] Especially among young soils such as alluvial soils, although not limited to them, climatic phases of soil series must be established for proper grouping into capability units and into other interpretive groupings. Since the effects result from interactions between soil and climate, such climatic phases are not defined the same in terms of precipitation, temperature, and so on, for contrasting kinds of soil.

CAPABILITY UNITS

The capability units provide more specific and detailed information than the subclass for application to specific fields on a farm or ranch. A capability unit is a grouping of soils that are nearly alike in suitability for plant growth and responses to the same kinds of soil management. That is, a reasonably uniform set of alternatives can be presented for the soil, water, and plant management of the soils in a capability unit, not considering effects of past management that do not have a more or less permanent effect on the soil. Where soils have been so changed by management that permanent characteristics have been altered, they are placed in different soil series. Soils grouped into capability units respond in a similar way and require similar management although they may have soil characteristics that put them in different soil series.

Soils grouped into a capability unit should be sufficiently uniform in the combinations of soil characteristics that influence their qualities to have similar potentialities and continuing limitations or hazards. Thus the soils in a capability unit should be sufficiently uniform to (a) produce similar kinds of cultivated crops and pasture plants with similar management practices, (b) require similar conservation treatment and management under the same kind and condition of vegetative cover, and (c) have comparable potential productivity. (Estimated average yields under similar management systems should not vary more than about 25 percent among the kinds of soil included within the unit.)

OTHER KINDS OF SOIL GROUPINGS

Other kinds of interpretive soil groupings are necessary to meet specific needs. Among these are groupings for range use, woodland use, special crops, and engineering interpretation.

The range site is a grouping of soils with a potential for producing the same kinds and amounts of native forage. The range site for rangeland is comparable to the capability unit for cultivated land. The purpose of such a grouping is to show the potential for range use and to provide the basis for which the criteria for determining range condition can be established. The soils grouped into a single range site may be expected to produce similar longtime yields and respond similarly to alternative systems of management and to such practices as seeding, pitting, and water spreading.

Soils suitable for range but not for common cultivated crops may be placed in capability classes V and VI if they are capable of returning inputs from such management practices as seeding, fertilizing, or irrigating and in class VII if they are not. If these soils do not give economic returns under any kind of management when used for cultivated crops, pasture, woodland or range, they fall in class VIII.

Soil-woodland site index correlations are essential for interpreting the potential wood production of the individual soil units that are mapped.

Woodland-site indices are commonly developed for individual kinds of soils. Soil-mapping units can be placed in woodland groupings according to site indices for adapted species and other responses and limitations significant to woodland conservation. Such groupings do not necessarily parallel those for capability units or range sites; however, in some areas capability units may be grouped into range sites and woodland-suitability groups.

Rice has soil requirements unlike those of the common cultivated crops requiring well-aerated soils. Some fruits and ornamentals do not require clean cultivation. Therefore, these crops are not given weight in the capability grouping. Instead, special groupings of the soils for each of these crops are made in the areas where they are significant.

With a good basic table of yields and practices the soils can be placed in any number of suitability groups. Commonly, five groups—unsuited, fairly suited, moderately suited, well suited and very well suited—are sufficient.

Kinds of soil shown on the soil map are also grouped according to need for applying engineering measures including drainage, irrigation, land leveling, land grading; determining suitability as subgrade for roads; and constructing ponds and small dams. Such groupings may be unlike those made for other purposes.

CRITERIA FOR PLACING SOILS IN CAPABILITY CLASSES

Soil and climatic limitations in relation to the use, management, and productivity of soils are the bases for differentiating capability classes. Classes are based on both degree and number of limitations affecting kind of use, risks of soil damage if mismanaged, needs for soil management, and risks of crop failure. To assist in making capability groupings, specific criteria for placing soils in units, subclasses, and classes are presented here. Because the effects of soil characteristics and qualities vary widely with climate, these criteria must be for broad soil areas that have similar climate.

Capability groupings are based on specific information when available—information about the responses of the individual kinds of soil to management and the combined effect of climate and soil on the crops grown. It comes from research findings, field trials, and experiences of farmers and other agricultural workers. Among the more common kinds of information obtained are soil and water losses, kinds and amounts of plants that can be grown, weather conditions as they affect plants, and the effect of different kinds and levels of management on plant response. This information is studied along with laboratory data on soil profiles. Careful analysis of this information proves useful not only in determining the capability of these individual kinds of soil but also in making predictions about the use and management of related kinds of soil.

Basic yield estimates of the adapted crops under alternative, defined systems of management are assembled in a table. Where data are few, the

estimates should be reasonable when tested against available farm records and studies of the combinations of soil properties.

Where information on response of soils to management is lacking, the estimates of yields and the grouping of soils into capability units, subclasses, and classes are based on an evaluation of combinations of the following:

1. Ability of the soil to give plant response to use and management as evidenced by organic-matter content, ease of maintaining a supply of plant nutrients, percentage base saturation, cation-exchange capacity, kind of clay mineral, kind of parent material, available water holding capacity, response to added plant nutrients, or other soil characteristics and qualities.
2. Texture and structure of the soil to the depth that influences the environment of roots and the movement of air and water.
3. Susceptibility to erosion as influenced by kind of soil (and slope) and the effect of erosion on use and management.
4. Continuous or periodic waterlogging in the soil caused by slow permeability of the underlying material, a high water table, or flooding.
5. Depth of soil material to layers inhibiting root penetration.
6. Salts toxic to plant growth.
7. Physical obstacles such as rocks, deep gullies, etc.
8. Climate (temperature and effective moisture).

This list is not intended to be complete. Although the soils of any area may differ from one another in only a few dozen characteristics, none can be taken for granted. Extreme deficiencies or excesses of trace elements, for example, can be vital. Commonly, the underlying geological strata are significant to water infiltration, water yield, and erosion hazard.

Any unfavorable fixed or recurring soil or landscape features may limit the safe and productive use of the soil. One unfavorable feature in the soil may so limit its use that extensive treatment would be required. Several minor unfavorable features collectively may become a major problem and thus limit the use of the soil. The combined effect of these in relation to the use, management, and productivity of soils is the criterion for different capability units.

Some of the criteria used to differentiate between capability classes are discussed on the following pages. The criteria and ranges in characteristics suggested assume that the effects of other soil characteristics and qualities are favorable and are not limiting factors in placing soils in capability classes.

Arid and Semiarid, Stony, Wet, Saline-Sodic, and Overflow Soils

The capability-class designations assigned to soils subject to flooding, poorly or imperfectly drained soils, stony soils, dry soils needing supplemental water, and soils having excess soluble salts or exchangeable sodium are made on the basis of continuing limitations and hazards after removal of excess water, stones, salts, and exchangeable sodium.

When assessing the capability class of any soil the feasibility of any necessary land improvements must be considered. Feasible as used here means

(1) that the characteristics and qualities of the soil are such that it is possible to remove the limitation, and (2) that over broad areas it is within the realm of economic possibility to remove the limitation. The capability designation of these areas is determined by those practices that are practical now and in the immediate future.

The following kinds of soil are classified on the basis of their present continuing limitations and hazards: (1) Dry soils (arid and semiarid areas) now irrigated, (2) soils from which stones have been removed, (3) wet soils that have been drained, (4) soils from which excess quantities of soluble salts or exchangeable sodium have been removed, and (5) soils that have been protected from overflow.

The following kinds of soil are classified on the basis of their continuing limitations and hazards as if the correctable limitations had been removed or reduced: (1) Dry soils not now irrigated but for which irrigation is feasible and water is available, (2) stony soils for which stone removal is feasible, (3) wet soils not now drained but for which drainage is feasible, (4) soils that contain excess quantities of soluble salts or exchangeable sodium feasible to remove, and (5) soils subject to overflow but for which protection from overflow is feasible. Where desirable or helpful, the present limitation due to wetness, stoniness, etc., may be indicated.

The following kinds of soil are classified on the basis of their present continuing limitations and hazards if the limitations cannot feasibly be corrected or removed: (1) Dry soils, (2) stony soils, (3) soils with excess quantities of saline and sodic salts, (4) wet soils, or (5) soils subject to overflow.

Climatic Limitations

Climatic limitations (temperature and moisture) affect capability. Extremely low temperatures and short growing seasons are limitations, especially in the very northern part of continental United States and at high altitudes.

Limited natural moisture supply affects capability in subhumid, semiarid, and arid climates. As the classification in any locality is derived in part from observed performance of crop plants, the effects of the interaction of climate with soil characteristics must be considered. In a subhumid climate, for example, certain sandy soils may be classified as class VI or class VII, whereas soils with similar water-holding capacity in a more humid climate are classified as class III or IV. The moisture factor must be directly considered in the classification in most semiarid and arid climates. The capability of comparable soils decreases as effective rainfall decreases.

In an arid climate the moisture from rain and snow is not enough to support crops. Arid land can be classed as suited to cultivation (class I, II, III, or IV) only if the moisture limitation is removed by irrigation. Wherever the moisture limitation is removed in this way, the soil is classified according to the effects of other permanent features and hazards that limit its use and permanence, without losing sight of the practical requirements of irrigation farming.

Wetness Limitations

Water on the soil or excess water in the soil presents a hazard to or limits its use. Such water may be a result of poor soil drainage, high water table, overflow (includes stream overflow, ponding, and runoff water from higher areas), and seepage. Usually soil needing drainage has some permanent limitation that precludes placing it in class I even after drainage.

Wet soils are classified according to their continuing soil limitations and hazards after drainage. In determining the capability of wet areas emphasis is placed on practices considered practical now or in the foreseeable future. The vast areas of marshland along the seacoast or high-cost reclamation projects not now being planned or constructed are not classified as class I, II, or III. If reclamation projects are investigated and found to be feasible, the soils of the area are reclassified based on the continuing limitations and hazards after drainage. This places the classification of wet soils on a basis similar to that of the classification of irrigated, stony, saline, or overflow soils. Some large areas of bottom land subject to overflow are reclassified when protected by dikes or other major reclamation work. There are examples of these along streams where levees have been constructed. Land already drained is classified according to the continuing limitations and hazards that affect its use.

Needs for initial conditioning, such as for clearing of trees or swamp vegetation, are not considered in the capability classification. They may be of great importance, however, in making some of the land-management decisions. Costs of drainage, likewise, are not considered directly in the capability classification, although they are important to the land manager.

Toxic Salts

Presence of soluble salts or exchangeable sodium in amounts toxic to most plants can be a serious limiting factor in land use. Where toxic salts are the limiting factor, the following ranges are general guides until more specific criteria are available:

Class II—Crops slightly affected. In irrigated areas, even after salt removal, slight salinity or small amounts of sodium remains or is likely to recur.

Class III—Crops moderately affected. In irrigated areas, even after salt removal, moderate salinity or moderate amounts of sodium remains or is likely to recur.

Classes IV–VI—Crops seriously affected on cultivated land. Usually only salt-tolerant plants will grow on noncultivated land. In irrigated areas, even after leaching, severe salinity or large amounts of sodium remains or is likely to recur.

Class VII—Satisfactory growth of useful vegetation impossible, except possibly for some of the most salt-tolerant forms, such as some Atriplexes that have limited use for grazing.

Slope and Hazard of Erosion

Soil damage from erosion is significant in the use, management, and response of soil for the following reasons:

1. An adequate soil depth must be maintained for moderate to high crop production. Soil depth is critical on shallow soils over nonrenewable substrata such as hard rock. These soils tolerate less damage from erosion than soils of similar depth with a renewable substrata such as the raw loess or soft shale that can be improved through the use of special tillage, fertilizer, and beneficial cropping practices.
2. Soil loss influences crop yields. The reduction in yield following the loss of each inch of surface soil varies widely for different kinds of soil. The reduction is least on soils having little difference in texture, consistence, and fertility between the various horizons of the soil. It is greatest where there is a marked difference between surface layers and subsoils, such as among soils with claypans. For example, corn yields on soils with dense, very slowly permeable subsoils may be reduced 3 to 4 bushels per acre per year for each inch of surface soil lost. Yield reduction is normally small on deep, moderately permeable soils having similar textured surface and subsurface layers and no great accumulation of organic matter in the surface soil.
3. Nutrient loss through erosion on sloping soils is important not only because of its influence on crop yield but also because of cost of replacement to maintain crop yields. The loss of plant nutrients can be high, even with slight erosion.
4. Loss of surface soil changes the physical condition of the plow layer in soils having finer textured layers below the surface soil. Infiltration rate is reduced; erosion and runoff rates are increased; tilth is difficult to maintain; and tillage operations and seedbed preparation are more difficult.
5. Loss of surface soil by water erosion, soil blowing, or land leveling may expose highly calcareous lower strata that are difficult to make into suitable surface soil.
6. Water-control structures are damaged by sediments due to erosion. Maintenance of open drains and ponds becomes a problem and their capacity is reduced as sediment accumulates.
7. Gullies form as a result of soil loss. This kind of soil damage causes reduced yields, increased sediment damage, and physical difficulties in farming between the gullies.

The steepness of slope, length of slope, and shape of slope (convex or concave) all influence directly the soil and water losses from a field. Steepness of slope is recorded on soil maps. Length and shape of slopes are not recorded on soil maps; however, they are often characteristic of certain kinds of soil, and their effects on use and management can be evaluated as a part of the mapping unit.

Where available, research data on tons of soil loss per acre per year under given levels of management are used on sloping soils to differentiate between capability classes.

Soil Depth

Effective depth includes the total depth of the soil profile favorable for root development. In some soils this includes the C horizon; in a few only the A horizon is included. Where the effect of depth is the limiting factor, the following ranges are commonly used: Class I, 36 inches or more; class II, 20–36 inches; class III, 10–20 inches; and class IV, less than 10 inches. These ranges in soil depth between classes vary from one section of the country to another depending on the climate. In arid and semiarid areas, irrigated soils in class I are 60 or more inches in depth. Where other unfavorable factors occur in combination with depth, the capability decreases.

Previous Erosion

On some kinds of soil previous erosion reduces crop yields and the choice of crops materially; on others the effect is not great. The effect of past erosion limits the use of soils (1) where subsoil characteristics are unfavorable, or (2) where soil material favorable for plant growth is shallow to bedrock or material similar to bedrock. In some soils, therefore, the degree of erosion influences the capability grouping.

Available Moisture Holding Capacity

Water-holding capacity is an important quality of soil. Soils that have limited moisture-holding capacity are likely to be droughty and have limitations in kinds and amounts of crops that can be grown; they also present fertility and other management problems. The ranges in water-holding capacity for the soils in the capability classes vary to a limited degree with the amount and distribution of effective precipitation during the growing season. Within a capability class, the range in available moisture-holding capacity varies from one climatic region to another.

Glossary

Alluvial soils Soils developing from transported and relatively recently deposited material (alluvium) with little or no modification of the original materials by soil-forming processes. (Soils with well-developed profiles that have formed from alluvium are grouped with other soils having the same kind of profiles, not with the alluvial soils.)

Available nutrient in soils The part of the supply of a plant nutrient in the soil that can be taken up by plants at rates and in amounts significant to plant growth.

Available water in soils The part of the water in the soil that can be taken up by plants at rates significant to their growth; usable; obtainable.

Base saturation The relative degree to which soils have metallic cations absorbed. The proportion of the cation-exchange capacity that is saturated with metallic cations.

Cation-exchange capacity A measure of the total amount of exchangeable cations that can be held by the soil. It is expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7) or at some other stated pH value. (Formerly called base-exchange capacity.)

Clay mineral Naturally occurring inorganic crystalline material in soils or other earthy deposits of clay size—particles less than 0.002 mm. in diameter.

Deep soil Generally, a soil deeper than 40 inches to rock or other strongly contrasting material. Also, a soil with a deep black surface layer; a soil deeper than about 40 inches to the parent material or to other unconsolidated rock material not modified by soil-forming processes; or a soil in which the total depth of unconsolidated material, whether true soil or not, is 40 inches or more.

Drainage, soil (1) The rapidity and extent of the removal of water from the soil by runoff and flow through the soil to underground spaces. (2) As a condition of the soil, soil drainage refers to the frequency and duration of periods when the soil is free of saturation. For example, in well-drained soils, the water is removed readily, but not rapidly; in poorly drained soils, the root zone is waterlogged for long periods and the roots of ordinary crop plants cannot get enough oxygen; and in excessively drained soils, the water is removed so completely that most crop plants suffer from lack of water.

Drought A period of dryness, especially a long one. Usually considered to be any period of soil-moisture deficiency within the plant root zone. A period of dryness of sufficient length to deplete soil moisture to the extent that plant growth is seriously retarded.

Erosion The wearing away of the land surface by detachment and transport of soil and rock materials through the action of moving water, wind, or other geological agents.

Fertility, soil The quality of a soil that enables it to provide compounds, in adequate amounts and in proper balance, for the growth of specified plants, when other growth factors such as light, moisture, temperature, and the physical condition of the soil are favorable.

Field capacity The amount of moisture remaining in a soil after the free water has been allowed to drain away into drier soil material beneath; usually expressed as a percentage of the ovendry weight of soil or other convenient unit. It is the highest amount of moisture that the soil will hold under conditions of free drainage after excess water has drained away following a rain or irrigation that has wet the whole soil. For permeable soils of medium texture, this is about 2 or 3 days after a rain or thorough irrigation. Although generally similar for one kind of soil, values vary with previous treatments of the soil.

First bottom The normal flood plain of a stream, subject to frequent or occasional flooding.

Parent material The unconsolidated mass of rock material (or peat) from which the soil profile develops.

Permeability, soil The quality of a soil horizon that enables water or air to move through it. It can be measured quantitatively in terms of rate of flow of water through a unit cross section in unit time under specified temperature and hydraulic conditions. Values for saturated soils usually

are called hydraulic conductivity. The permeability of a soil may be limited by the presence of one nearly impermeable horizon even though the others are permeable.

Phase, soil The subdivision of a soil type or other classificational soil unit having variations in characteristics not significant to the classification of the soil in its natural landscape but significant to the use and management of the soil. Examples of the variations recognized by phases of soil types include differences in slope, stoniness, and thickness because of accelerated erosion.

Profile (soil) A vertical section of the soil through all its horizons and extending into the parent material.

Range (or rangeland) Land that produces primarily native forage plants suitable for grazing by livestock, including land that has some forest trees.

Runoff The surface flow of water from an area; or the total volume of surface flow during a specified time.

Saline soil A soil containing enough soluble salts to impair its productivity for plants but not containing an excess of exchangeable sodium.

Series, soil A group of soils that have soil horizons similar in their differentiating characteristics and arrangement in the soil profile, except for the texture of the surface soil, and are formed from a particular type of parent material. Soil series is an important category in detailed soil classification. Individual series are given proper names from place names near the first recorded occurrence. Thus names like Houston, Cecil, Barnes, and Miami are names of soil series that appear on soil maps and each connotes a unique combination of many soil characteristics.

Sodic soil (alkali) Soil that contains sufficient sodium to interfere with the growth of most crop plants; soils for which the exchangeable-sodium-percentage is 15 or more.

Soil (1) The natural medium for the growth of land plants. (2) A dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms. (3) The collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time.

A soil is an individual three-dimensional body on the surface of the earth unlike the adjoining bodies. (The area of individual soils ranges from less than ½ acre to more than 300 acres.)

A kind of soil is the collection of soils that are alike in specified combinations of characteristics. Kinds of soil are given names in the system of soil classification. The terms "the soil" and "soil" are collective terms used for all soils, equivalent to the word "vegetation" for all plants.

Soil Characteristic A feature of a soil that can be seen and/or measured in the field or in the laboratory on soil samples. Examples include soil slope and stoniness as well as the texture, structure, color, and chemical composition of soil horizons.

Soil management The preparation, manipulation, and treatment of soils for the production of plants, including crops, grasses, and trees.

Soil quality An attribute of a soil that cannot be seen or measured directly from the soil alone but which is inferred from soil characteristics and soil behavior under defined conditions. Fertility, productivity, and erodibility are examples of soil qualities (in contrast to soil characteristics).

Soil survey A general term for the systematic examination of soils in the field and in the laboratories, their description and classification, the mapping of kinds of soil, and the interpretation of soils according to their adaptability for various crops, grasses, and trees, their behavior under use or treatment for plant production or for other purposes, and their productivity under different management systems.

Structure, soil The arrangement of primary soil particles into compound particles or clusters that are separated from adjoining aggregates and have properties unlike those of an equal mass of unaggregated primary soil particles. The principal forms of soil structure are platy, prismatic, columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are (1) single grain—each grain by itself, as in dune sand, or (2) massive—the particles adhering together without any regular cleavage as in many claypans and hardpans. ("Good" or "bad" tilth are terms for the general structural condition of cultivated soils according to particular plants or sequences of plants.)

Subsoil The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil), in which roots normally grow. Although a common term, it cannot be defined accurately. It has been carried over from early days when "soil" was conceived only as the plowed soil and that under it as the "subsoil."

Surface soil The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, about 5 to 8 inches in thickness.

Texture, soil The relative proportions of the various size groups of individual soil grains in a mass of soil. Specifically, it refers to the proportions of sand, silt, and clay.

Type, soil A subgroup or category under the soil series based on the texture of the surface soil. A soil type is a group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile and developed from a particular type of parent material. The name of a soil type consists of the name of the soil series plus the textural class name of the upper part of the soil equivalent to the surface soil. Thus Miami silt loam is the name of a soil type within the Miami series.

Water table The upper limit of the part of the soil or underlying rock material that is wholly saturated with water. In some places an upper, or perched, water table may be separated from a lower one by a dry zone.

Water-holding capacity The capacity (or ability) of soil to hold water against gravity (see **Field capacity**). The water-holding capacity of sandy soils is usually considered to be low while that of clayey soils is high. It is often expressed in inches of water per foot depth of soil.

Waterlogged A condition of soil in which both large and small pore spaces are filled with water. (The soil may be intermittently waterlogged because of a fluctuating water table or waterlogged for short periods after rain.)

GUIDE FOR PLACING SOILS IN LAND CAPABILITY SUBCLASSES IN MONTANA

Groups of Soils as Defined by Selected Features as Follows:[1]	Subclass by Slope Classes A	B	C	D
1. Moderately Slowly, Moderately, and Rapidly Permeable, Well Drained Soils (Over 20" deep) with Following Surface Textures:				
a. Fine textured	s[2]	e	e	e
b. Moderately fine textured	c,e[2]	e	e	e
c. Medium textured	c,e[2]	e	e	e
d. Medium textured, high lime content	c,e	e	e	e
e. Moderately coarse textured (Textural B)	e	e	e	e
f. Coarse textured	e	e	e	e
2. Slowly Permeable, Well and Moderately Well Drained Soils (Over 20" deep):	c,e[2]	e	e	e
3. Very Slowly Permeable, Fine Textured, Well Drained and Moderately Well Drained Soils (Over 20" deep):	e,s[3]	e	e	e
4. Wet, Somewhat Poorly, Poorly, and Very Poorly Drained Soils (Water table at less than 3 feet):				
a. Moderately coarse to fine textured surface soils	w	w	w	w
b. Coarse textured	w	w	w	
c. Deep organic soils	w	w	w	
5. Well and Moderately Well Drained Shallow Soils:				
a. Rock within 10-20" of surface	s	e	e	e
b. Rock within 0-10" of surface	s	s	s	s
6. Excessively, Well, and Moderately Well Drained Saline and Alkali Soils (Moderate to strongly saline and alkali):				
a. If capability class is 4 or 6	s	s	e	e
b. If capability class is 7	s	s	s	e
7. Stony Soils (Class 2, 3, 4, or 5 stoniness):				
a. Stony (class 2 and 3 stoniness) 15+% slope = subclass "e"	s	s	s	s
b. Very stony (class 4 stoniness)	s	s	s	s
c. Extremely stony (class 5 stoniness)	s	s	s	s

	Subclass by Slope Classes			
	A	B	C	D
8. Other Soils with Coarse Fragments (Very Cobbly, Very Flaggy, Extremely Gravelly, and Extremely Channery)	s	s	s	e
9. Soils Subject to Damaging Overflow: (Occasionally and Frequently Flooded)	w	w	w	
10. Available Water Capacity				
a. IRR (<2.5 inches in 60-inch profile)	s	e	e	e
b. NIRR (2.0 to 3.75 inches in 60-inch profile)	s	s	s	e
c. NIRR (<2.0 inches in 60-inch profile)	s	s	s	s

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[1]Many kinds of soil differing in other characteristics are included in each group. See Soil Survey Manual, p. 213, for texture; pp. 169-172 for drainage; p. 168 for permeability; and pp. 217 and 218 for stoniness.

[2]Slight hazards of soil blowing and water erosion, use "c" subclass.

[3]Slight hazards of soil blowing and water erosion, use "s" subclass.

LAND _ITY GUIDE

(When used as a key and switching of next lower class, soil must satisfy all criteria for that class.)

Capability class	Minimum: Depth To Root-Limiting Layer (IRR and NONIRR)	Soil Texture for Surface 7 Inches (IRR and NONIRR)	Permeability Classes Below 7" (IRR and NONIRR)	Maximum Slope (IRR and NONIRR)	Maximum Erosion Hazard (Wind and/or water)	Minimum AWC[7] Surface-foot Profile to 60": IRR	Minimum AWC: NON-IRR	Drainage Class / Water Table (Inches)	Maximum Overflow (flooding): Fall: Winter: Spring: (Thru June)	Maximum Overflow: Summer	Minimum: Frost-Free Days 32°F	Minimum: PE Index DRY	Salinity (E.C.): IRR	Salinity (E.C.): NONIRR 0-16" / 16-30"	Sodicity--SAR, Surface 7 inches[4], <35% Clay: EC <4	<35% Clay: EC >4	>35% Clay: EC <4	>35% Clay: EC >4	7 to 30"[5]
															With SAR of:				
1	40 6	COSL, SL, FSL, VFSL, L, SIL, SI, SCL, CL, and SICL	Mod. slow thru mod. rapid	2	None or Slight	1.5 7.5	1.5 7.5	Well and mod. well >60"	Rare	None	140	44	<4	<4 <4	<4	NA	<4	NA	<13
2	40	COSL, SL, FSL, VFSL, L, SIL, SI, SCL, CL, SICL; may be gravelly, organic	Mod. slow thru mod. rapid	4	Moderate	1.0 5.0	1.0 5.0	Well thru somewhat poorly >36"	Occas.	Rare	105	28[6]	<4	<4 <4	<4	NA	<4	NA	<13
3	20	COSL, SL, FSL, VFSL, L, SIL, SI, SCL, CL, SICL, SC, SIC, C; may be cobbly or gravelly[8]	Slow thru rapid[3] May be very slow below 20"	8	Moderate	0.75 3.75	1.0 4.5	Somewhat excessively thru poorly[3] >18"	Freq.	Occas.	90+	::::::::::	<8[3]	<4 <8	<4	<13	<4	<13	<20
4	20	COSL, SL, FSL, VFSL, L, SIL, SI, SCL, CL, SICL, SC, SIC, C Also LFS and LVFS if: IRR. May be cobbly or very gravelly.	Very slow thru very rapid[2]	15	High	0.6 2.5	0.75 3.75	Somewhat excessively thru[2] poorly[3] >18"	Freq.	Occas.	70+	::::::::::	<16[2]	<4[1] <16 or if <8 <8	<13	<20	<4	<13	<60
5	10	All textures	Very slow thru very rapid	4	None or Slight	::::::::::	::::::::::	Poorly or very poorly[3]	Freq.	Freq.	Any frost-free period	::::::::::	<8	<8 <8	<4	<13	<4	<13	<20
6+	10	All textures except sand. Extremely gravelly, stony, very cobbly (classes 2 and 3)	Very slow thru very rapid	35 (for shallower soils above 15% go to class 7	NOTE: Severely eroded lands gullied or channeled areas are class 6 or 7	0.3 2.0	0.3 2.0	Excessively thru very poorly	Freq.	Freq.	Any frost-free period	::::::::::	<20	<16 <16	<20	<40	<20	<20	<100
7	Any Depth	NONIRR. Any--dunes and stony (classes 4 and 6). Also any extremely cobbly or extreme flaggy textures.	Very slow thru very rapid	70		Any AWC		Excessively thru very poorly	Freq.	Freq.	Any frost-free period	::::::::::	Any EC	Any SAR	Any SAR	Any SAR	Any SAR	Any SAR	
8	Miscellaneous land types such as rock outcrop, rubble land, riverwash, badlands, slickspots, etc.																		

Note: Factors not considered for a capability class are blocked out.

Footnotes:

*Some soils placed in capability class 6 are known to have produced various cultivated crops successfully. They are not, however, known to produce crops successfully on a dependable or consistently long term basis (at least seven out of ten years). The base reference crop is spring wheat.

[1]If permeability is slow or very slow and EC values between 16 and 30 inches are 8 to 16 mmhos, place in class 6.

[2]Irrigated soils that are very slowly permeable with:
a. EC values of 8 to 16 mmhos, place in class 6.
b. EC values of >16 mmhos, place in class 7.

[3]Irrigated soils that are slowly permeable and poorly drained with:
a. EC values of 4 to 8 mmhos within a depth of 30 inches, place in class 4.
b. EC values of >16 mmhos within a depth of 30 inches, place in class 7.

[4]Reflects soil dispersion as it affects seedling emergence. Class limits for SARs were interpreted from the publication "Water Quality for Agriculture" sponsored by the Food and Agriculture Organization of United Nations--Rome, Italy, 1976. The class limits and reasoning for them are as follows:

a. Less than 4—effects of sodicity is none or minimal.

b. From 4 to 13--effects of sodicity are visibly recognized by clay dispersion, surface crusting, and effects on plant growth and plant species.

c. From 13 thru 20—based on laboratory data on soils in Montana, the majority of them are placed in capability class 6 because reasonable response can be expected from mechanical treatment for range improvement.

d. Greater than 13--can be determined in field by: Ethanol-Cresol red test; by use of Hach testing kit; or from laboratory data.

[5]Reflects sodium effects on plant production.

[6]For nonirrigated crops, need 80 percent probability of receiving 7 inches of moisture from April 1 to July 31. Refer to Bulletin 712, Precipitation Probabilities in Montana, Montana Agricultural Experiment Station.

[7]When AWC ranges significantly into two capability classes, the most limiting class is selected. Soils that have insufficient available water for growing dryland crops due to lack of timely precipitation may be placed in a land capability class 4 or 6.

[8]If the texture of the surface 7 inches is more than 55 percent clay, go to class 4.

Abbreviations: AWC = Available Water Capacity; EC = Electrical Conductivity; PE = Precipitation Effectivity;
SAR = Sodium Adsorption Ratio

Definitions of flooding frequency: Rare = floods less than once in 20 years; Occasional = floods once in 2 to 20 years;
Frequent = floods at least once every 2 years.

Additional References Cited:

Ag. Handbook No. 60, USDA
National Soils Handbook, SCS, USDA
Soil Survey Manual, Chapters 4 and 5, SCS, USDA
Ag. Handbook No. 210, SCS, USDA