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How Soil Holds Water

This NebGuide describes the physical characteristics that influence how soil holds water.

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Dryland and irrigationd agriculture depend on the management of two basic natural resources, soil and water. Soil is the supporting structure of plant life and water is essential to sustain plant life. The wise use of these resources requires a basic understanding of soil and water as well as the crop.

The available water capacity and characteristics of soils are critical to water management planning for irrigationd and dryland crops. The management decisions of what crops to plant, plant populations, when to irrigation, how much to irrigation, when to apply nitrogen, and how much nitrogen to apply depend in part on the water holding capacity of soils. These management decisions are critical to the long term quantity and quality of Nebraska's water resources.

Some of the water in soil is retained and some moves through the soil. It moves readily downward after an irrigation or rain and eventually reaches the ground water. It is taken up by plant roots, moves through the plant to the leaves, and transpires to the atmosphere. Water also moves toward the soil surface where it evaporates directly into the atmosphere. Water is retained in or moves through the pore spaces as a result of the size, number, and continuity of the pores. Textural, structural, and organic matter characteristics determine how water is held in soils.

This NebGuide provides basic information on how soil holds water. Physical characteristics that influence how soil retains water are outlined. Soil water definitions and soil water retention characteristics of different soil types are discussed.

Soil Physical Characteristics

Soil Composition

A given volume of soil consists of four parts: mineral matter, organic matter, water, and air (*Figure 1*). The amount of mineral and organic matter remains fairly constant in a given environment. Nebraska soils range from less than 1 percent to 5 percent organic matter. Changes in environment, erosion and, cultural practices can change soil makeup. The relative amounts of mineral and organic matter determine the physical properties of soil.

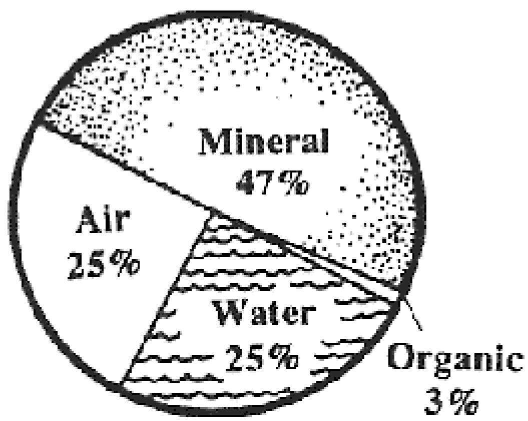


Figure 1. The composition of soil.

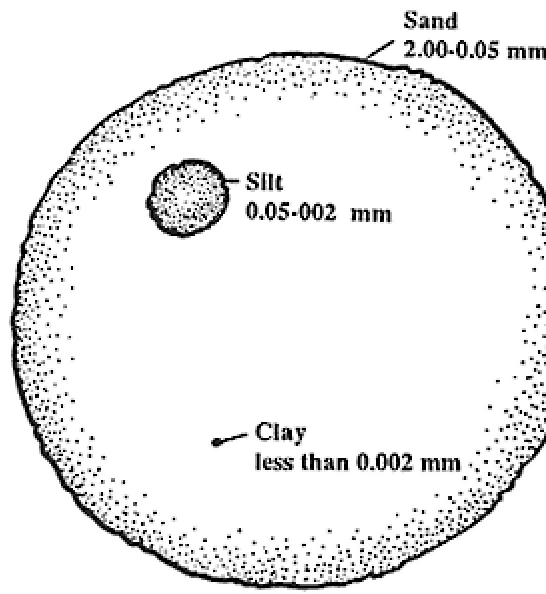


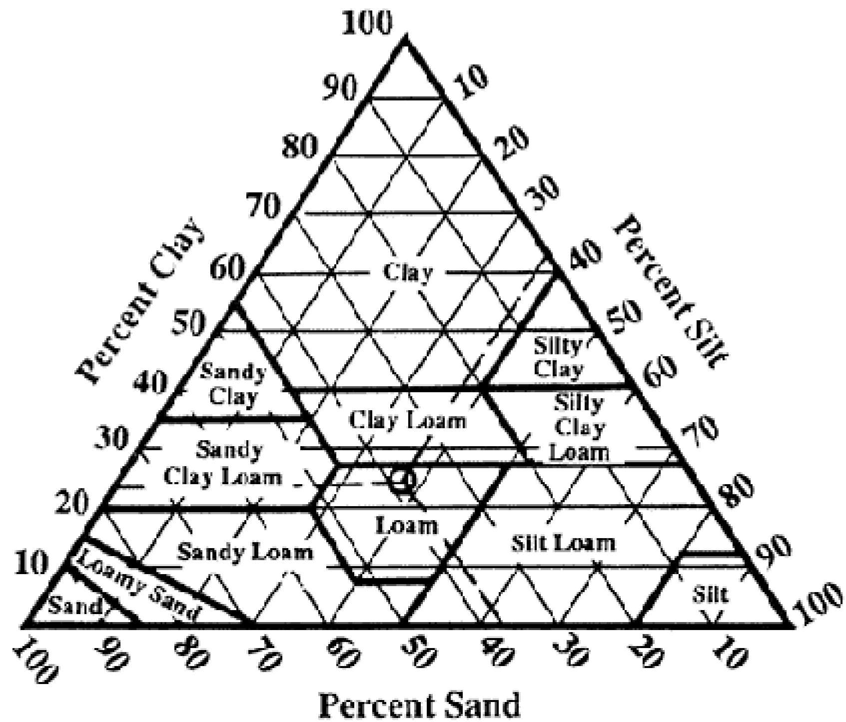
Figure 2. The relative sizes of three soil samples.

Soil Texture

Soil texture is determined by the relative amounts of three groups of soil particles. The three **soil separates** are sand, silt, and clay. Texture provides a means to physically describe soil by feel. A coarse soil has a relatively large amount of sand. A silt soil has the texture of flour. A loam soil has nearly equal amounts of sand, silt, and clay. The relative sizes of the three soil separates are compared in *Figure 2*. Sand particles can be seen by the naked eye. A microscope must be used to see silt particles. An electron microscope is needed to see clay particles.

The laboratory procedure used to find proportions of soil separates in a soil is called *mechanical analysis*. A *textural triangle* (*Figure 3*) is used to determine soil texture after the mechanical analysis. The three sides of the triangle represent the percentages of sand, silt, or clay. The intersection points of three lines from each side of the triangle determine how the soil texture will be classified. For example, if a soil has 20 percent clay, 40 percent sand, and 40 percent silt, it is a loam.

Figure 3. A textural triangle is used to determine soil texture.



Soil Structure

Soil structure refers to the arrangement of soil separates or individual soil particles into units called soil aggregates. The arrangements of soil aggregates gives soil its structure. The principal types of soil structure are platy, prismatic, columnar, blocky, granular, and crumb. The aggregates in these structure types vary in size and degree of stability.

The processes that form aggregates from unconsolidated parent material are (1) wetting and drying, (2) freezing and thawing, (3) decaying organic matter, (4) activity of roots and small animals, (5) absorbed nutrients, and (6) soil tillage. Bulk Density *Bulk density* of a soil is defined as the weight per unit volume of soil. The volume includes both the solids and the pore space. Bulk density is important because it reflects the porosity of a soil. Loose, porous soils have lower bulk densities than tight, compacted soil. The bulk density of a soil increases with compaction. Bulk density indicates how easily a soil will till, how easily water will infiltrate, how it will hold water, and its suitability for growing plants. Typical soil bulk densities for fine sands, silt loams, and silty clay loams are 1.5, 1.35, and 1.25 grams per cubic centimeter, respectively.

Soil Porosity

The space between soil particles (mineral and organic), is the *pore space* and consists of varying amounts of water and air. Soil porosity depends on soil texture and structure. Silty and clayey soils have smaller pores but many more pores than a sandy soil. Even though the individual soil particles and pores are larger in sands, the porosity or total pore volume is less in sands than in silty or clayey soils. This characteristic causes the bulk density to be higher for sands.

Water can be held tighter in small pores than in large pores. For this reason a clay loam with its many small pores can hold more water than a sand. The small pores allow the soil to hold more water by *capillary forces*. Capillary forces and available water capacity will be discussed in more detail later.

Soil Water

Soil Water Definitions

Soil water is classified into three categories: (1) excess soil water or gravitational water, (2) available soil water, and (3) unavailable soil water. See *Figure 4* for a schematic representation of soil water.

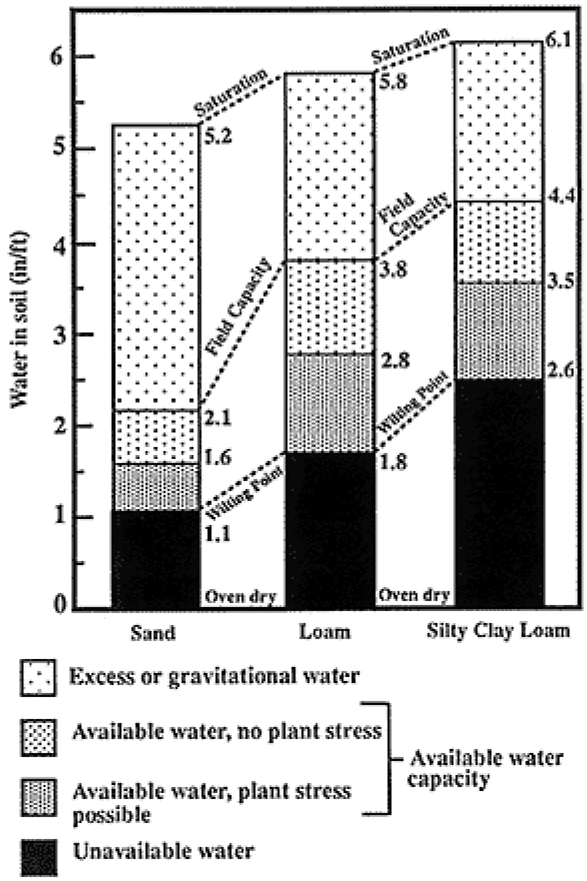


Figure 4. Soil water levels within three soil types.

Excess soil water or *gravitational water* drains or percolates readily by gravitational force. Since drainage takes time, part of the excess water may be used by plants before it moves out of the root zone.

Available soil water is retained in the soil by capillary forces and can be extracted by the plant. This soil water is most important for crop production. It is the water held by the soil between field capacity and wilting point. Plants can use approximately 50 percent of the available water without stress. When less than 50 percent of available water remains, stress can occur.

Field capacity is the water content of a soil at the upper limit of the available water range. It is the amount of water remaining in a soil after it has been saturated and allowed to drain for 24 hours.

Permanent wilting point is the lower limit of the available water range. When plants have removed all of the available water from a given soil, they wilt and do not recover. Thus, the water available for plant growth exists between the range of field capacity and wilting point.

Available water capacity is all the water that a soil can possibly hold between field capacity and wilting point. The capacity varies with soil texture.

Unavailable water is soil water held so firmly to soil particles by adsorptive soil forces that it cannot be extracted by plants. Unavailable water remains when soil is direr than wilting point.

Volumetric water content is the total amount of water that a soil holds at a particular time. It includes the available, unavailable, and gravitational water, if present. Volumetric water content is the fraction or percent of water in the total soil volume. Sands, loams, and clay loams reach saturation when volumetric water content is 45 percent, 48 percent, and 52 percent, respectively.

Soil Water Retention

The soil holds water in two ways: (1) as a film coating on soil particles, and (2) in the pore space between particles. When water infiltrates into the soil from rain or irrigation, the pore spaces are nearly filled with water. During and immediately after a rain or irrigation the greatest movement of water occurs in the soil. Afterward, water movement continues due to gravity and capillary forces. Capillary forces are also important for retaining water in soil pores.

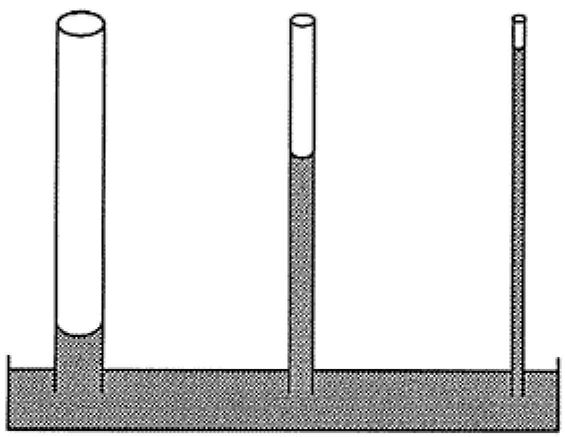


Figure 5. Capillary force is illustrated by how far water rises in tubes of various diameters.

Capillary forces can be illustrated by a group of small capillary tubes with different diameters (see *Figure 5*). If the capillary tubes are placed with one end in a pan of water, the water would rise into each tube. The height of the water in each tube would depend on the diameter of the tube. The smaller the tube, the higher the rise. The surface tension of the water itself and the diameter of the tube cause the water to rise. The water must be under negative pressure to rise. Because this capillary phenomenon can operate in any direction, it is the key to water retention in soil pores. The pore geometry is much more complex than the simple capillary tubes, but the water is under negative pressure due to the capillary forces.

Soil Water Tension

Different diameters of capillary tubes illustrate how water is held in soils. The capillary force or *tension* with which water is held in the soil is most important to plant growth. Smaller pores hold water with more tension (negative pressure) than larger pores. Also, as films of water around soil separates or aggregates get thinner, water tension increases. As soil dries, the tension of the remaining water increases. Plants can extract water more readily when water tension is small.

Soil water tension measures the force with which water is retained by the soil. Tension is a measure of negative pressure. Commonly, tension units are *bars* which are nearly equivalent to 1 atmosphere (14.7 psi). A plant which is extracting water from a soil at 1/2 bar means it is exerting a negative pressure of about 7 psi. The same plant would exert -147 psi if the soil were at 10 bars of tension. *Table I* illustrates typical soil water tensions for three soil textures.

Table I. Soil water tension for three soil textures.			
	Sand	**Loam**	**Silty Clay Loam**
	-----Soil Water Tension (bars)----		
Field Capacity	0.1	0.3	0.2
50% Available Water Remaining	0.4	1.5	2.0
Wilting Point	15.0	15.0	15.0

Soil Water Retention Curves

In unsaturated soils, water is under tension and it takes energy to remove it from the soil. The negative pressure to remove water from soil at a given water content can be measured. As the water content of a soil decreases from the saturation point, the tension used to hold water increases. In the range of water available for plant growth, not all water is equally available.

The relationship of soil water content and soil water tension is represented in *Figure 6*. Curves like *Figure 6* are called *water retention* or *soil water characteristic curves*. They are different for each soil because of differences in soil textures and structures. At field capacity the soil water is held with a certain tension. For most soils this corresponds to a negative pressure of 0.1-0.3 atmospheres.

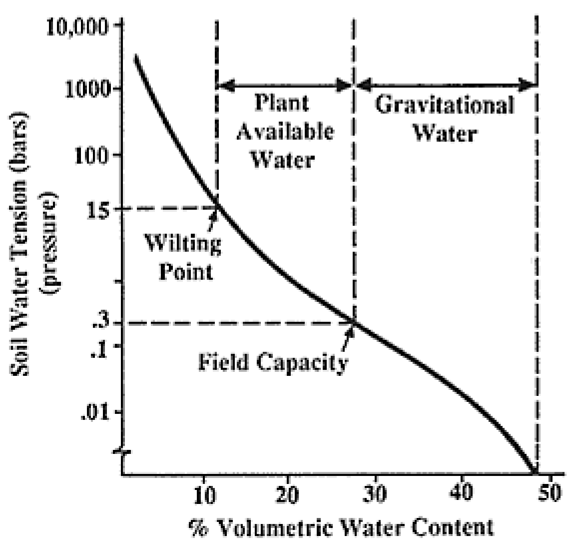


Figure 6. The relationship of soil water content and soil water tension.

The approximate range of available water content for a loam soil is depicted in *Figure 6*. As the soil dries, a plant may begin to wilt during the day but will recover at night. When the soil water content decreases until the plant cannot extract enough water to recover from its wilted condition, the soil water is at *wilting point*. This soil water content corresponds to a tension of about 15 bars. Loam soil has about an 11 percent volumetric water content at wilting point. The soil still contains water but it is held too tightly for plant root extraction.

Available Water Capacities

A soil's water storage characteristics are very important for irrigation management. Since the size and number of pores in soils are directly related to soil texture (particle sizes), soil texture is the indicator for the amount of water a soil can hold. *Table II* is based on soil texture and can be used to determine the amount of available soil water that a given soil profile will hold. This is its *available water capacity*.

Table II. Available water capacity based on soil texture.

Textural Classes		Available Water Capacity in Inches/Food of Depth
Coarse Sands		0.25 - 0.75
Fine Sands		0.75 - 1.00
Loamy Sands		1.10 - 1.20
Sandy Loams		1.25 - 1.40
Fine Sandy Loam		1.50 - 2.00
Silt Loams		2.00 - 2.50
Silty Clay Loams		1.80 - 2.00
Silty Clay		1.50 - 1.70
Clay		1.20 - 1.50

Plant available water capacity changes with soil textures. Soil texture often changes with depth because the soil horizons differ. *Table III* gives an example for two soils.

Table III. Effect of soil depth on plant available water capacity for two Nebraska soils.

Depth from surface (inches)		Available Water Total		
		in/ft	in/layer	in/5 ft
	Valentine fine sand			
0 - 6	loamy fine sand	1.2	0.6	
6 - 24	loamy fine sand	1.0	1.4	
24 - 60	fine sand	0.7	2.2	
				4.2
	Hastings silt loam			

0 - 6	silt loam	2.6	1.3	
6 - 48	silt clay loam	2.2	7.6	
48 - 60	silt loam	2.4	2.4	
				11.3

Application of Soil Water Information

Soil water holding characteristics are important for irrigation system selection, irrigation scheduling, crop selection, and ground water quality. Soil water content in the crop's active root zone and available water capacity are the key indicators for applying the right amount of irrigation at the right time. This is irrigation scheduling. Whether sprinkler (center pivot) or surface (gravity) irrigation systems will work on a particular field depends on the soil texture.

Since soil can hold only so much water, excess or gravitation water moves out of the crop root zone toward the groundwater table. Any dissolved nutrients or chemicals move with the water and can eventually end up in ground water.

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