IRRIGATION MANAGEMENT SERIES

Important Agricultural Soil Properties

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Soil itself is not essential to a growing plant. Soil serves as a storage reservoir for nutrients and water needed for plant growth. These soil properties are essential to crop production.

Crop production potential is greatly influenced by the physical and chemical properties of soils. These same properties also influence related activities such as tillage, erosion, drainage, and irrigation. Important agronomic soil properties include the soil water-holding capacity, infiltration rate, aggregation, temperature, organic matter content, and nutrient availability.

This publication focuses on physical characteristics of soil that influence how soil retains water and water availability for crop production. Extensive information on soils and their suitability for various applications are available in county soil surveys. These are available at *http://soils.usda.gov/survey*.

The definitions of soil from the Soil Science Society of America is: **soil:** *(i) the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product, soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics.*

As a material medium for plant growth, a given volume of soil is composed of three parts: solids, air, and water, as illustrated in Figure 1. The solid portion can be further divided into mineral and organic matter, while the air and water portion of the soil is called the pore volume. Under normal farming practices, the ratio of solid to pores remains constant and for a given environmental condition, the organic matter remains stable. Organic matter can be altered by changing conditions such as

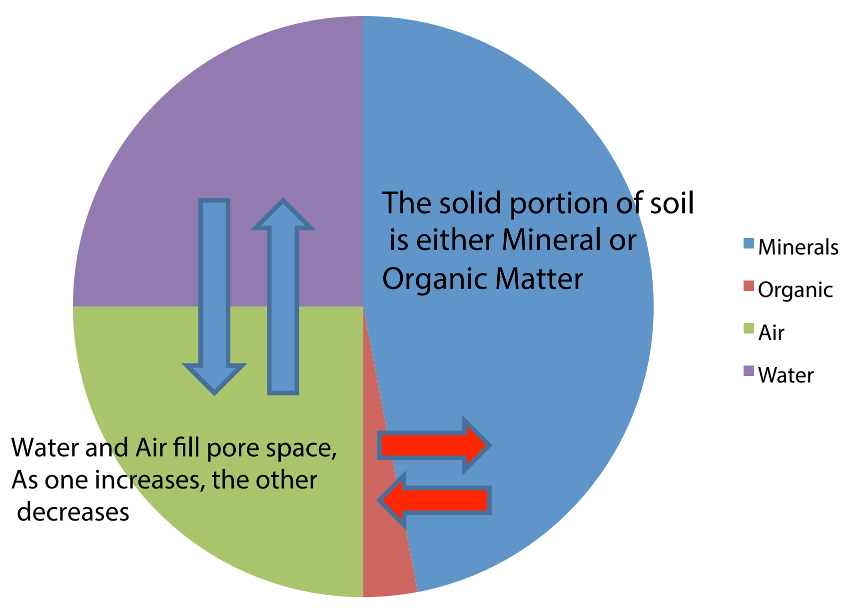

Figure 1. Soil composition components.

erosion or cultural practices. Most soils have an organic matter content of less than 1 percent to about 5 percent by volume. Organic matter consists of decaying plant and animal material, largely microbes and insects. Although it is only a small fraction of the total soil volume, organic matter's role in serving as the primary storage receptor for plant nutrients is extremely important.

The balance between water and air in the soil is important. The ratio of water to air in the pores of the soil volume varies greatly; as one increases, the other must decrease. Soils that are completely filled with water, or saturated, have all air displaced from the soil pores. Without air, or oxygen in particular, root respiration is disrupted, which is an integral part of the plant growth process.

Soil Texture

There are three classes of soil particles — sand, silt, and clay — and their relative proportions determine the soil textural class, as shown in Figure 2. Texture is a way to describe a soil by feel. For example, coarse sand may feel gritty, while a silt loam has the feel of flour. The relative sizes of the three soil particles are shown in Figure 3, while the size classification ranges are depicted in Figure 4. The soil texture is determined using a laboratory analysis that determines the fractions of sand, silt, and clay.

Soil Structure

Primary soil particles can be combined into secondary arrangements called peds, which can be of various sizes and shapes. Unlike most soil particles, which are too small to be seen without magnifica-

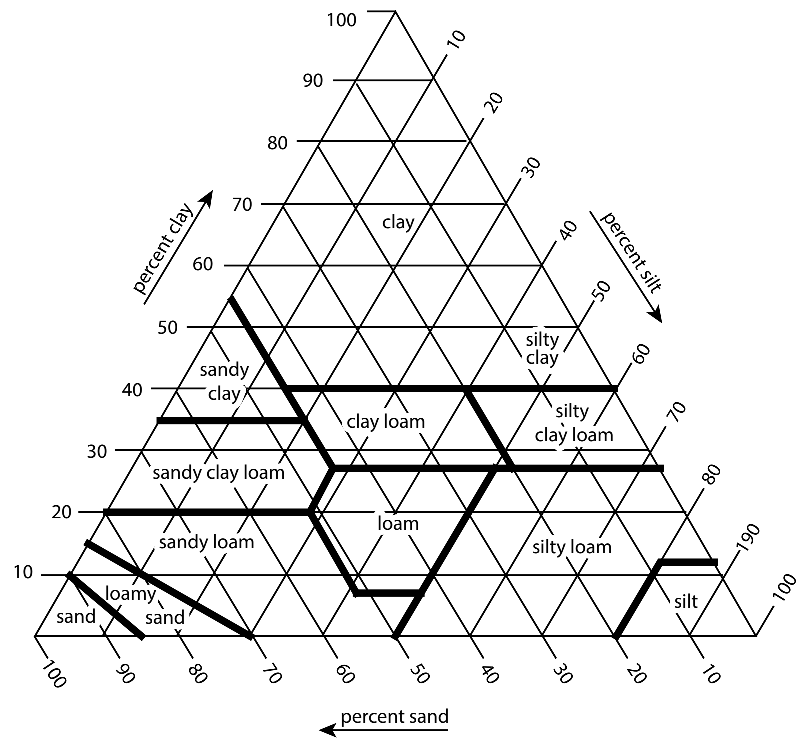

Figure 2. A soil textural classification triangle.

tion, most peds can be seen and are important to maintaining soil tilth and crop productivity.

Unlike soil texture, soil structure can be affected by crop cultural practices. The soil structure develops over time as the result of root penetration, freezing and thawing cycles, the presence of organic and inorganic binding agents, and biological activities. Soil structure is affected by cultural practices that can accelerate the loss of organic materials or destroy aggregates through improper tillage practices.

Generally, productive agricultural soils have a soil structure that allows good root penetration and allows a good exchange of air and water within the soil profile.

Soil Series

Soils classified in the same series are soils that have been formed from the same parent material and are similar in profile arrangement and characteristics, except in the A horizon (upper-

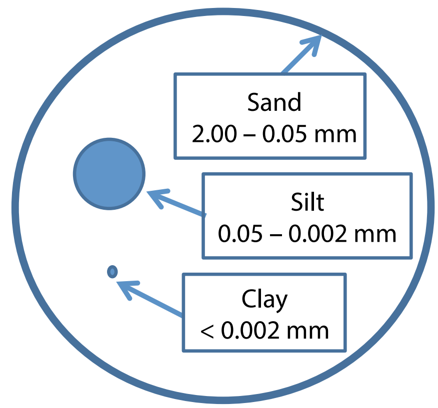

Figure 3. The relative sizes of soil particles.

most layer).

On the series level, one of the properties defined is the soil depth of the various layers, which typically consists of three levels: A (top soil), B, and, C. Progressively downward, each layer is less affected by the five soil forming factors of parent material, climate, topography, biota, and time. Biota refers to the biological organisms and activities.

The layers can be distinctive parent material, such as when a different material is overlain on an existing soil, such as wind-deposited loess on flood sedimentation. The depth of soil and the corresponding thickness of various textural layers have an important influence on irrigation management decisions.

Soil Density

The density of a substance is defined as the mass per unit volume. In soils, this value is called the bulk density:

Bulk density $(P_b) = M_s/V_b$
= mass of dry soil/volume of soil sample

Bulk density is typically expressed in grams/cm^3. Typical soil bulk densities range from 1.1 to 1.7 g/cm^3.

Another soil density term is particle density, which is defined as the mass of the dry soil particles divided by the volume of the soil particles. For all practical purposes, the mass of dry soil particles is the same as the mass of the dry soil, as the weight of air is the only difference.

Particle density $(P_p) = M_s/V_s$
= mass of dry soil/volume of the soil particles or solids

Particle density is typically expressed in grams/cm^3 and the ranges for typical soils is 2.6 to 2.7 cm^3. A P_p value of 2.65 g/cm^3 is used for most soils.

The particle density of a soil is typically constant, changing only slightly if the organic matter content changes, whereas bulk density depends on the amount of pore space in a soil. Soil pore space can be altered. In agricultural settings, increasing bulk density indicates compaction is occurring, which could cause detrimental growing conditions, such as limiting root penetration or decreasing the soil aeration process.

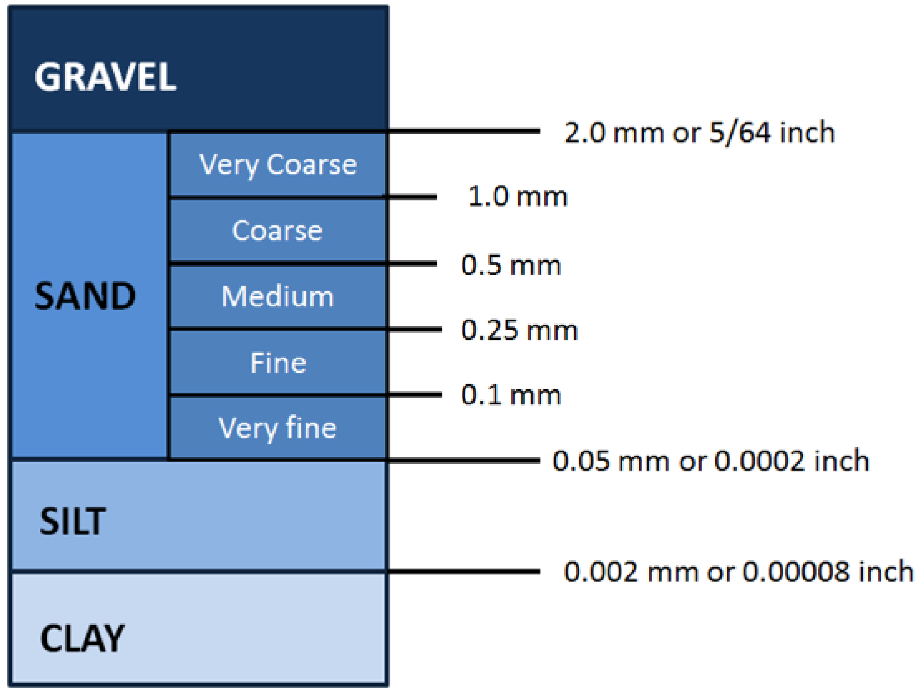

Figure 4. USDA soil classification of primary soil particles by size.

Soil Water

The space between soil solids or particles is called the pore space. Soil porosity describes this portion of the soil volume that can hold either air or water. Porosity is generally expressed as a percentage.

Porosity (ϕ) =
volume of pores/volume of soil

The porosity of a soil can be calculated using bulk density and the typical estimate of particle density of 2.65g/cm^3.

Porosity (%) = $(1-(P_b / P_p)) \times 100$

Most agricultural soils have a porosity of about 50 percent, but if they become compacted, porosity decreases, which limits the space available for water and air and restricts root development.

Soil infiltration and permeability describe the movement of water in soils. Infiltration is the movement of water into the soil from the soil surface. The infiltration rate, also called the intake rate, is a measurement of the ability of a soil to absorb rainfall or applied irrigation water over a given time. The infiltration rate of a soil is not constant and depends on many factors, including the surface conditions, such as residue cover and surface roughness; soil water content; and slope.

The infiltration rate for soils is high at the initiation of infiltration and decreases as the infiltration process continues. The elapsed time between the initiation of infiltration and the current time of an event is called the opportunity time.

The infiltration rate relationship with time is shown in Figure 5 for the various soils. As the opportunity time increases, the infiltration rate decreases until it becomes relatively constant. The infiltration rate for this condition is called the basic infiltration rate or steady state infiltration rate. Soils that have similar intake rates are classified as being from the same intake family. Soils with high clay content tend to have low intake rates, silt soils have higher intake rates than clay, and sands tend to have the highest intake rates.

After water has entered a soil, the term to describe the water movement within the soil profile is permeability. Soils with larger and connected pore spaces are more permeable than soil with small, disconnected pore spaces, even if the porosity values are similar. The downward movement of water within a soil profile is called percolation. The measure of the rate of water movement is called hydraulic conductivity and measured in units of inches/hour. These rates can be quite variable.

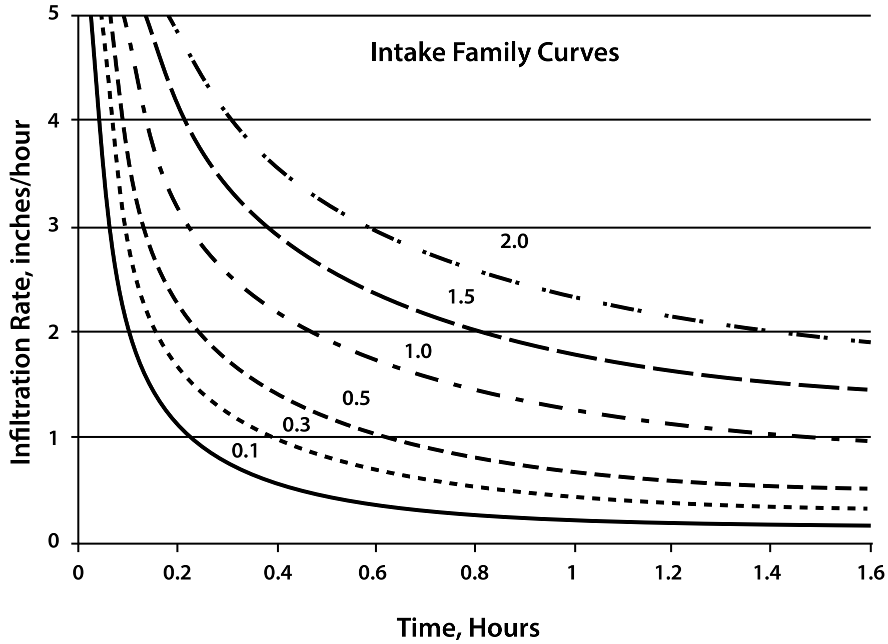

Figure 5. Infiltration rate curves from the Natural Resources Conservation Service.

Soil permeability is grouped into classes ranging from very slow to very rapid, as shown in Table 1.

Table 1. Soil Permeability Classes

Classification	Infiltration Rate (in/hr)
Very Slow	< 0.06
Slow	0.06 – 0.2
Moderately Slow	0.2 – 0.6
Moderate	0.6 – 2.0
Moderately Rapid	2.0 – 6.0
Rapid	6.0 – 20.0
Very Rapid	> 20.0

Soil Water Content

The amount of water in a soil available for plant use is one of the most important measurements needed for proper irrigation management. While the porosity of most agricultural soils is similar, the amount of plant-available water varies greatly. This is due to size of the pore space in a soil and the way water is held within the pores of a soil. Figure 6 illustrates that for a given soil volume, larger particle sizes are associated with larger pore size. Since all soils have about the same porosity, this means smaller-sized particle soils will have smaller, but more, pore spaces. Soils can be a mixture of particle sizes and this also affects the size and number of pores. Soil geometry is also much more complex than these circular depictions.

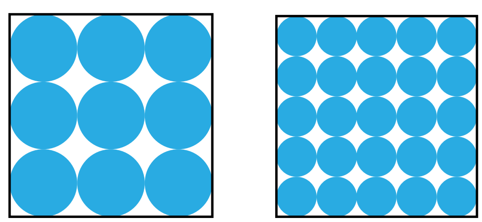

Illustration of the effect of particle size on the size and number of pore spaces within a fixed soil volume.

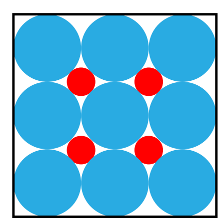

Illustration of the effect of a mixture of soil particle size on the number and size of pores within a given soil volume.

Figure 6. The effect of soil particle size and particle mixture on pore space.

Four important terms are used to describe the water level within a soil (Figure 7). When all the soil pores are filled with water, the soil is said to be saturated. However, the gravitational pull on the water causes some of it to drain. While this water could be used by plants, the gravitational drainage is generally too rapid to allow plants to capture much of this water.

Water retained by the soil after gravitational drainage is held in place by capillary and adsorption forces. This occurs due to the surface tension (cohesion) of water and the attraction of the water to the soil particle by adhesion. Some of the water is available to plants for removal.

The amount of water retained in the soil after gravitational drainage is the field capacity of the soil. As plants extract water, the remaining water is held more tightly until eventually the plant cannot extract additional water.

The soil water content at this point is called the wilting point. The film of water that remains around the soil particles is held by adsorption forces and is called hygroscopic water. It is not available for plant use. Several of these conditions are illustrated in Figure 8.

The amount of water between field capacity and wilting point is called plant available water. Average water-holding capacities for various soil textural classes are shown in Tables 2 and 3. Table 2 values tend to be larger for the surface layers than for the Table 3 subsoil layers. Of course, the holding capacity can vary from site to site. The effect of different water holding capacities for three soil types is illustrated in Figure 9. Even though all three soils hold over 5 inches of water at saturation, the sand only holds about 1 inch of plant available water. The silty clay loam soil has the largest amount of water in storage but has a larger amount not plant available, so the loam soil ends up with the most plant available water. Figure 10 graphically illustrates typical field capacity and wilting point values for 11 soil textures. At field capacity, the available water is said to be 100 percent available in reference to plant use, while at wilting point, the available water to plants is 0 percent available.

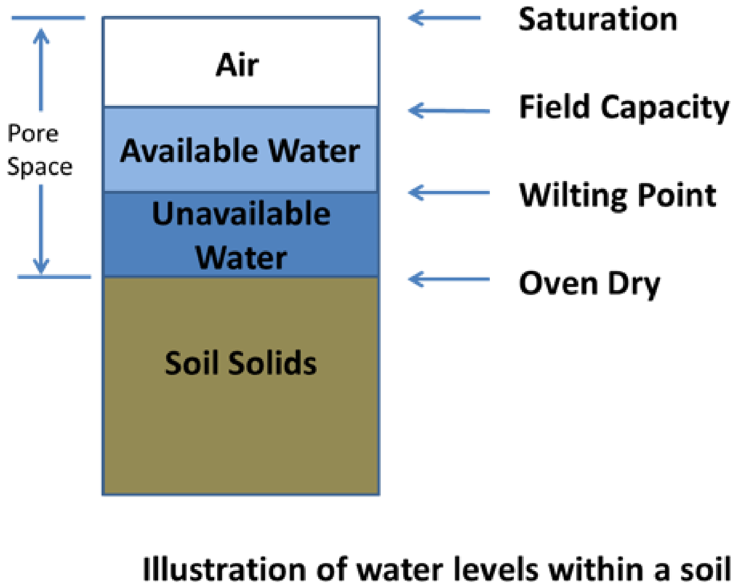

Figure 7. Illustration of water levels within a soil.

Calculating Soil Water Content

The amount of water in a soil can be measured directly using the gravimetric method, which is simply the weight of the water in a soil sample in proportion to the dry soil sample weight. See Formula A.

The soil water content by volume is volume of water in a soil sample in proportion to the volume of the soil sample. See Formula B.

It is relatively easy to collect samples and measure the gravimetric water content of a soil, but the more useful value is the volumetric water content. The gravimetric water content is related to the volumetric content by the following relationship shown in Formula C.

Soil bulk density values are given in tables 2 and 3. The density of water is 1.0 gram/cm^3 or 62.4 pounds/ ft^3.

Example calculations: Determine the gravimetric water content for a silt loam soil sample collected from the surface 12-inch layer and weighing 105 grams. After drying, the sample weighs 85 grams. The gravimetric water content is 24% (see Formula D).

Determine the volumetric water content for the same sample. The bulk density from Table 2 for a silt loam is 1.40. The volumetric water content is 34%, as shown in Formula E.

Formula A

$$\text{Gravimetric water \%} = \frac{(\text{wet sample weight} - \text{dry sample weight}) \times 100}{(\text{dry sample weight})}$$

Formula B

$$\text{Volumetric water \%} = \frac{(\text{volume of water in sample}) \times 100}{(\text{volume of the soil sample})}$$

Formula C

$$\text{Volumetric water \%} = \frac{(\text{gravimetric water \%} \times \text{Bulk Density})}{\text{density of water}}$$

Formula D

$$\text{Gravimetric water \%} = \frac{(105 - 85)\ \times 100}{85} = 24\%$$

Formula E

Volumetric water % = (gravimetric water % × Bulk Density) / Density of water

$= (24 \times 1.4)/ 1.0 = 34\%$

Table 2. Average available water capacity for Kansas soils in the 0- to 12-inch layer.

		Percentage by Mass			Fraction by Volume		
Soil Texture	Bulk Density	Field Capacity	Wilting Point	Available Water Capacity	Field Capacity	Wilting Point	Available Water Capacity
Sand	1.60	8.7	3.5	5.2	0.14	0.06	0.08
Loamy Sand	1.60	11.9	4.5	7.4	0.19	0.07	0.12
Sandy Loam	1.55	15.4	5.8	9.6	0.24	0.09	0.15
Fine sandy Loam	1.50	19.5	7.5	12.0	0.29	0.11	0.18
Loam	1.45	23.6	9.2	14.4	0.34	0.13	0.21
Silt Loam	1.40	27.2	10.9	16.3	0.38	0.15	0.23
Silty Clay Loam	1.35	28.8	13.0	15.8	0.39	0.18	0.21
Sandy Clay Loam	1.40	27.0	13.5	13.5	0.38	0.19	0.19
Clay Loam	1.40	27.3	15.1	12.2	0.38	0.21	0.17
Silty Clay	1.30	28.7	18.0	10.7	0.37	0.23	0.14
Clay	1.25	29.4	20.1	9.3	0.37	0.25	0.12
Source: NRCS Kansas Irrigation Guide							

Table 3. Average available water capacity for Kansas soils for depth greater than 12 inches.

		Percentage by Mass			Fraction by Volume		
Soil Texture	Bulk Density	Field Capacity	Wilting Point	Available Water Capacity	Field Capacity	Wilting Point	Available Water Capacity
Sand	1.70	7.0	3.0	4.0	0.12	0.05	0.07
Loamy Sand	1.70	10.0	4.2	5.8	0.17	0.07	0.10
Sandy Loam	1.65	13.4	5.6	7.8	0.22	0.09	0.13
Fine sandy Loam	1.60	18.2	8.0	10.2	0.29	0.13	0.16
Loam	1.55	22.6	10.3	12.3	0.35	0.16	0.19
Silt Loam	1.50	26.8	12.9	13.9	0.40	0.19	0.21
Silty Clay Loam	1.45	27.6	14.5	13.1	0.40	0.21	0.19
Sandy Clay Loam	1.50	26.0	14.8	11.2	0.39	0.22	0.17
Clay Loam	1.50	26.3	16.3	10.0	0.39	0.24	0.15
Silty Clay	1.40	27.9	18.8	9.1	0.39	0.26	0.13
Clay	1.35	28.8	20.8	8.0	0.39	0.28	0.11
Source: NRCS Kansas Irrigation Guide							

Since the sample represents the 12-inch soil layer, the depth of water in the layer can be calculated by multiplying the soil depth by the volumetric soil water content fraction or:

Depth of water in the soil layer = 12 inches × (34/100) = 4.08 inches

Similarly, the depth of water in the 12-inch soil layer at field capacity can be calculated using the field capacity value from Table 2 as

Depth of water in soil at field capacity = 12 inches × (38/100) / 1.0 = 4.56 inches

The amount of plant available water in the soil sample can be estimated by subtracting the amount of water in the soil at wilting point.

From Table 2 silt loam soil water content at wilting point is 10.9% by mass, which is 0.15 by volume.

The plant available portion of the water content from the sample is therefore 34% minus 15% or 19% by volume.

The plant available water depth in the 12 inch soil layer is

12 inches × (19/100) = 2.28inches.

Direct measurement of soil water content by gravimetric sam-

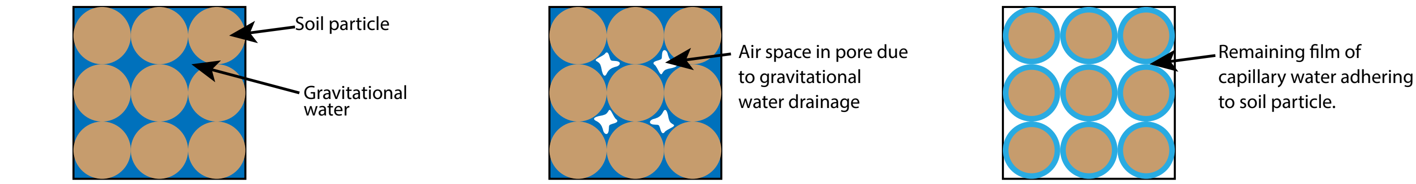

Illustration of a water saturated soil, all the pore spaces are filled with water.

Illustration of a soil that has had gravitational water drained from the pores.

Illustration of a soil that has reached wilting point, when capillary water can no longer be extracted by plants.

Figure 8. Illustration of gravitational and capillary held water in the soil pore spaces.

pling is an accurate and reliable method to determine soil water content, and the sampling can be done at multiple locations within a field. However, it is not commonly used as it is labor intensive and, because of the sample drying requirements, there is a time delay between collection and the results. A specific site also cannot be resampled since a physical sample is removed. Other indirect measurement methods to determine soil water content are discussed in other publications.

More discussion on crop water requirements and how plants extract water are in publication L934, *Agricultural Crop Water Use*.

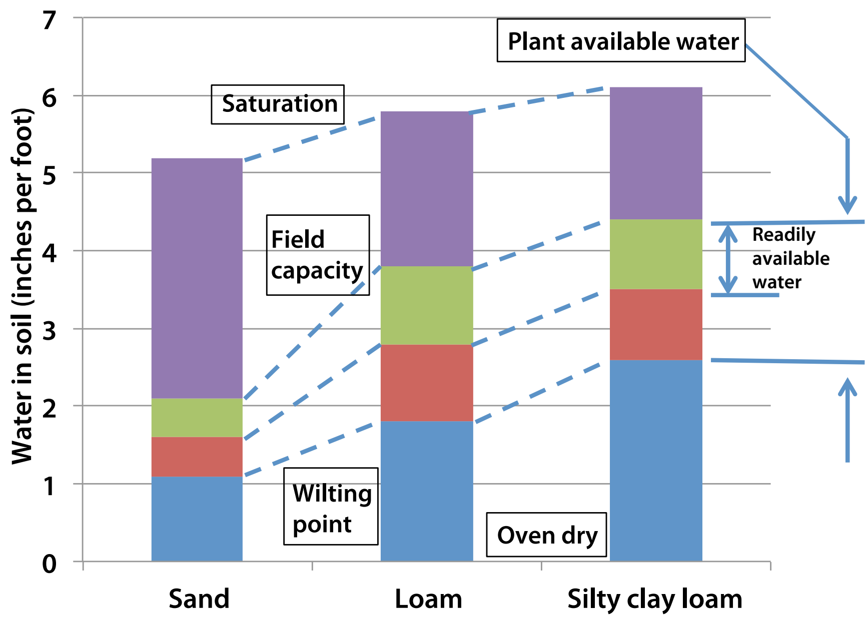

Figure 9. Illustration of soil water levels for three soil types.

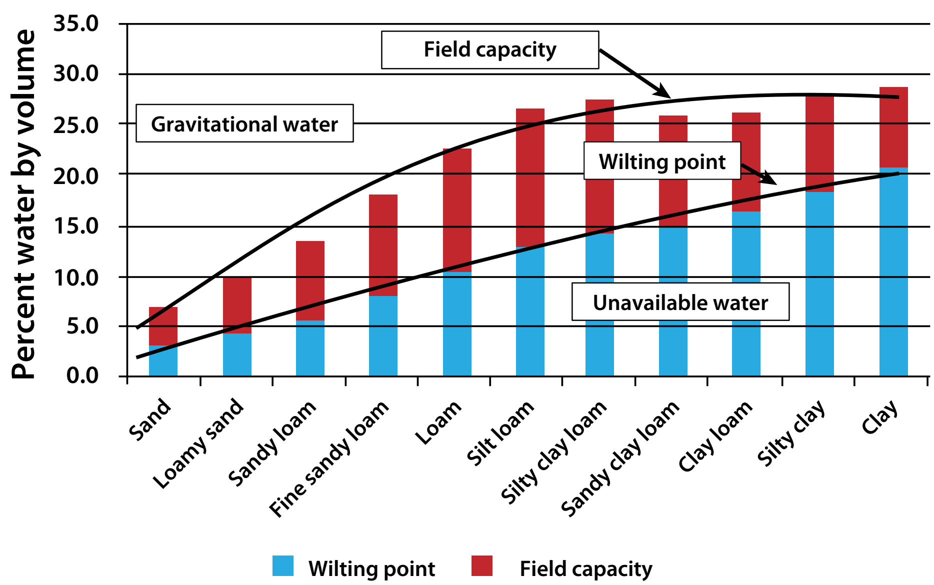

Figure 10. Illustration of percentage term definitions for available water by volumetric measure and as a percentage of available water for soil textures.

Related Information

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www.ksre.ksu.edu/irrigate

Mobile Irrigation Lab
http://www.bae.ksu.edu/mobile-irrigationlab

Subsurface Drip Irrigation
www.ksre.ksu.edu/sdi

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