IRRIGATION MANAGEMENT

S E R I E S

Soil, Water and Plant Relationships

Danny H. Rogers
Extension Agricultural Engineer

William M. Sothers
Extension Assistant

Cooperative Extension Service
Manhattan, Kansas

Plant growth depends on the use of two important natural resources, soil and water. Soil provides the mechanical and nutrient support necessary for plant growth. Water is essential for plant life processes.

Effective management of these resources for crop production requires the producer to understand relationships between soil, water, and plants, Knowledge about available soil water and soil texture will make deciding what crops to plant and when to irrigate, easier. This publication focuses on the physical characteristics of soil, soil and water interactions, and how plants use water.

PHYSICAL CHARACTERISTICS OF SOIL

There are many variables in the physical characteristics of soil. These include soil texture, soil structure, bulk density, and soil porosity. They all impact how soil, water, and air interact.

Soil Composition. Soil is a mixture of mineral matter, organic matter, and pores. The mineral matter makes up about one-half of the total soil volume. This mineral matter consists of small mineral particles of either sand, silt, or clay. Organic matter is made up of decaying plant and animal substances and is distributed in and among the mineral particles. Organic matter accounts for about 1 to 5 percent of the overall soil makeup. The combination of mineral and organic matter is referred to as the solids. The pores, spaces that occur around the mineral particles, are important because they store air and water in the soil. Approximately 50 percent of the soil makeup is pores. The overall composition of soil is 45 to 49 percent mineral particles, 1 to 5 percent organic matter, and 50 percent pores. Figure 1 shows the approximate relationship between the substances in the soil composition with the pore space shown split between air and water. The amount of water and air present in the pore spaces varies over time in an inverse relationship. This means that for more water to be contained in the soil, there has to be less air.

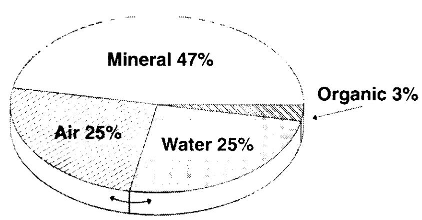
Soil Texture. Soil texture is determined by the size of the particles that make up the soil. The traditional method of determining soil particle size is done by separating the particles into three convenient size ranges. These soil fractions or separates are sand, silt, and clay. Generally, only particles smaller than 2 mm (1/12 inch) in size are categorized as soil particles. Particles larger than this are categorized as gravel, stones, cobbles, or boulders.

Sand particles range in size from 2 mm to 0.05 mm. There are subcategories assigned to this range that include coarse, medium, and fine sand. Silt particles can range in size from 0.05 mm down to 0.002 mm. The physical appearance of silt is much like sand, but the characteristics are more like clay. Clay particles are less than 0.002 mm in size. Clay is an important soil fraction because it has the most influence on such soil behavior as water-holding capacity. Clay and silt particles cannot be seen with the naked eye.

Soil texture is determined by the mass ratios, or the percent by weight, of the three soil fractions. The soil textural triangle, Figure 2, shows the different textural classes and the percentage by weight of each soil fraction. For example, a soil containing 30 percent sand, 30 percent clay, and 40 percent silt by weight is classified as a clay loam.

Soil Structure. Soil structure is the shape and arrangement of soil particles into aggregates. Soil structure is an important characteristic used to classify soils and heavily influences agricultural productivity and other uses. The principal forms of soil structure are platy, prismatic, columnar, blocky, and granular. These soil structure descriptions indicate how the individual particles arrange themselves together into aggregates. Aggregated soils types are generally the most desirable for plant growth. These terms also are used in conjunction with description words to indicate the class and grade of soil. Class refers to the size of the aggregates while grade describes how strongly the aggregates hold together. Structureless soils can be either single grained (individual unattached particles—like a sand dune) or

Figure 1. *Typical Soil Composition*



massive (individual particles adhered together without regular cleavage—like claypans or hardpans.) Soil structure is unstable and can change with climate, biological activity and soil management practices.

Soil Bulk Density and Porosity. Soil dry bulk density expresses the ratio of the weight of a soil to its total volume. Wet bulk density is the ratio of the soil and water weight to the total volume. The total volume includes both the solids and the pore spaces. The soil bulk density is important because it is a measurement of the porosity of the soil. The porosity of a soil is defined as the volume of pores in a soil. A compacted soil has low porosity and thus a higher bulk density. A loose soil has a higher porosity and a lower bulk density. Like soil structure, a soil's bulk density and porosity can be affected by climate, biological activities, and soil management practices. Table 1 lists typical wet bulk densities for Kansas soils.

Table 1: Average Water Holding Capacities of Kansas Soils (Source: NRCS Kansas Irrigation Guide)

Soil Texture	Percent Water Content					Inches per Foot		
	Wet Bulk Density At F.C.	1/ F.C.	2/ W.P.	3/ A.W.C.	4/ W.P./F.C.	1/ F.C.	1/ W.P.	3/ A.W.C.
Sand	1.70	7.0	3.0	4.0	43	1.44	0.60	0.84
Loamy sand	1.70	10.0	4.2	5.8	42	2.04	0.84	1.20
Sandy loam	1.65	13.4	5.6	7.8	42	2.64	1.08	1.56
Fine sandy loam	1.60	18.2	8.0	10.2	44	3.48	1.56	1.92
Loam	1.55	22.6	10.3	12.3	46	4.20	1.92	2.28
Silt loam	1.50	26.8	12.9	13.9	48	4.80	2.28	2.52
Silty clay loam	1.45	27.6	14.5	13.1	52	4.80	2.52	2.28
Sandy clay loam	1.50	26.0	14.8	11.2	57	4.68	2.64	2.04
Clay loam	1.50	26.3	16.3	10.0	62	4.68	2.88	1.80
Silty clay	1.40	27.9	18.8	9.1	67	4.68	3.12	1.56
Clay	1.35	28.8	20.8	8.0	72	4.68	3.36	1.32

1/ Field capacity
2/ Wilting point
3/ Available water capacity
4/ Percent of field at wilting point

SOIL AND WATER INTERACTIONS

It is important to understand the interactions between the soil and water, which include soil water content, how the soil holds the water, and soil water tension. Understanding these interactions can be very helpful when making planting and irrigation decisions.

Soil Water Content. Soil water content must be defined to indicate the amount of water stored in the soil at any given time. The most commonly defined soil water content are saturation, field capacity, wilting point, and oven dried. At saturation, which usually occurs immediately after a heavy rainfall or an irrigation, all pore spaces in the soil are filled with water. When the soil is at or near saturation, some of the water is free to drain or percolate due to the force of gravity. This excess water is referred to as gravitational water. Since this percolation takes time, some of this extra water can be used by plants or lost to evaporation. Field capacity is defined as the amount of water remaining in the soil after percolation has occurred. This is not a very definite soil water point; therefore, field capacity often is defined as approximately one-third atmosphere tension. Tension will be defined in a following section. Wilting point is defined as the soil water content at which the potential of the plant root to absorb water is balanced by the water potential of the soil. Crops will die if soil water is allowed to reach the wilting point. Soil that has been oven dried is used as a reference point for determining soil water content. This is when all soil water has been removed from the soil.

The amount of water at any soil water content varies by soil type. Specific water-holding capacities can be obtained from various sources, however NRCS County Soil Surveys are probably the most readily accessible. Figure 3 illustrates typical amounts of water held at

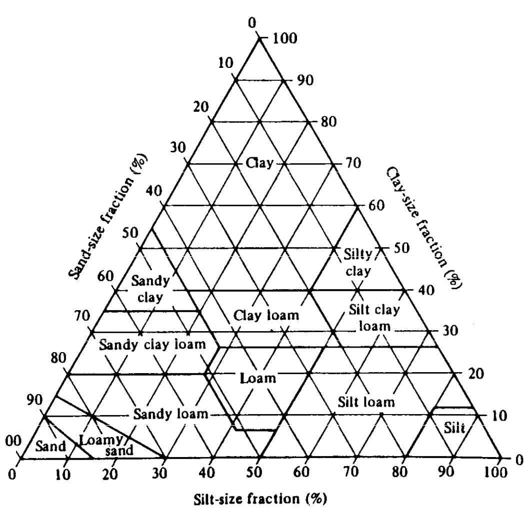


Figure 2. *A soil textural classification triangle.*

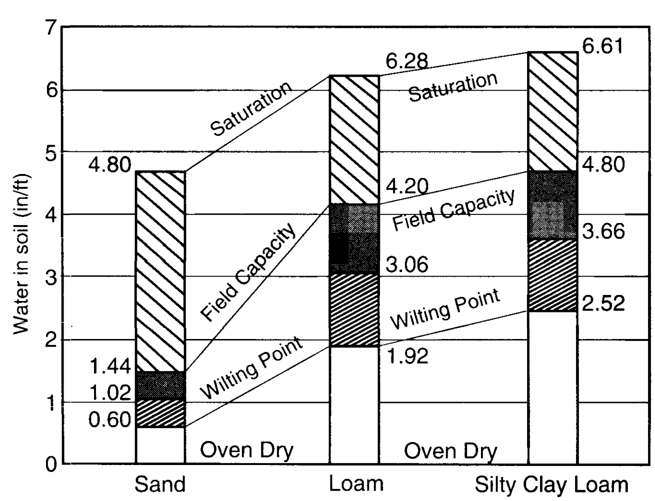


Figure 3. *Typical soil water content within three soil textures.*

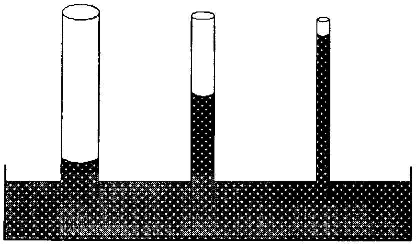


Figure 4. *Capillary forces illustrated by how far water rises to tubes of various diameters.*

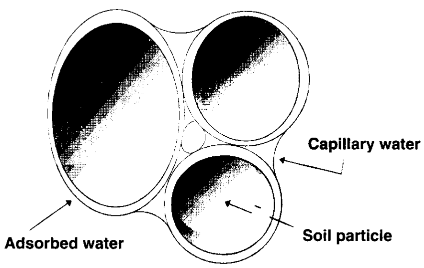


Figure 5. *How Soil Holds Water.*

the defined soil water content for sand, loam and silty clay loam soils. The reason for the differences between soil types is explained in the next sections. Water content can be expressed as inches of available water or as a percentage. Typical values of both expressions are shown in Table 1.

How Soil Holds Water. Soil holds water in two ways, as a thin film on individual soil particles, and as water stored in the pores of the soil. Water stored as a thin film on individual soil particles is said to be in adsorption. Adsorption involves complex chemical and physical reactions but in simple terms, a thin film of water adheres to the outside layers of soil particle molecules. Water stored in the pores of the soil is said to be in capillary storage. An example of this phenomenon would be to place one end of a glass capillary tube in a pan of water. Water in the tube will rise to a certain height, which depends on the diameter of the capillary tube (Figure 4). This phenomenon can act in any direction and is the key to water being stored in soil pores as illustrated in Figure 5.

Soil Water Tension. The ease by which water can be extracted from the soil depends on the soil water tension, also known as the soil water potential. Water being held in pores by the capillary storage is held in the soil at a certain tension. The same is true for water held with the adsorption phenomenon. As the soil dries, these tensions become larger. It is easier for a plant to extract water being held at lower tensions. The tensions that correspond to the soil water equilibrium points that were discussed above is a good example of water tensions that affect plant water use. At saturation, the soil water tension is approximately 0.001 bars. One bars tension is equivalent to 1 atmosphere of pressure (14.7 psi). Thus, from the above discussion, it would be very easy for a plant to extract water from a saturated soil. Saturation only lasts a short time, so plants extract only a small portion of the water above field capacity. Field capacity is defined to be at approximately one-third atmosphere pressure

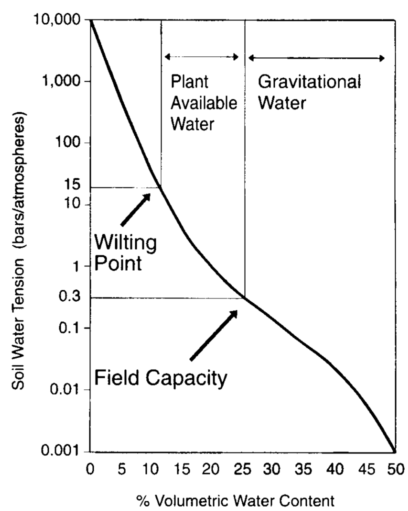


Figure 6. *The relationship between soil water content and soil water tension for a loam and type.*

or approximately 0.3 bars. At this content, it is still easy for the plant to extract water from the soil. The wilting point occurs when the potential of the plant root is balanced by the soil water potential, thus plants are unable to absorb water beyond this tension. This commonly occurs at approximately 15 bars. At this soil water tension, the plant will die. As a reference, the soil water tension in an oven-dried soil sample is approximately 10,000 bars. A soil water retention or soil water characteristic curve illustrates the tension relationships (Figure 6). These curves are slightly different for different types of soils due to different soil textures and structures. Water between the field capacity and the wilting point is water that is available to the plant. However best plant growth

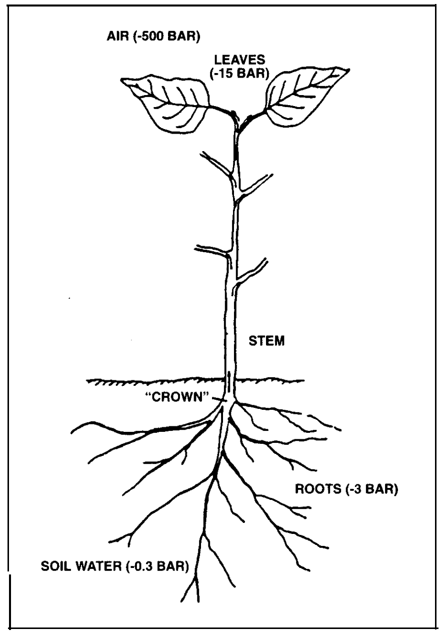


Figure 7. *Illustration of decreasing water potential for a plant.*

and yield occur when the soil water content remains in the upper half of the plant available soil water range.

Plants develop the tension, or potential, to move soil water from the soil into the roots and distribute the water through the plant by adjusting the water potential, or tension, within their plant cells. Water potential is made up of several components, but one of particular importance is the osmotic or solute potential. Solute potential is due to the presence of dissolved solutes, such as sugars and amino acids, in the plant cell. The essence of the process is that water always moves from higher to lower water potential. For water to move from the soil, to roots, to stems, to leaves, to air the water potential must always be decreasing. This is illustrated in Figure 7, moving from the high water potential soil (less negative) to the lower water potential air (more negative). Tension is often represented by the symbol y. Air water potential is always low, so water movement is toward the air through the plants. However, plants are restricted in the amount of adjustment they can make.

USE OF WATER BY PLANTS

A plant's root system must provide a negative tension (pressure) to extract water from the ground. This tension must be equivalent to the tension that holds the water in the soil. For example, if the water in the soil is at 0.3 bars

Table 2. Depth of root penetration and 70% of their water extraction for several common field crops.

Crop	Depth of Root Penetration (Feet)	70% of their Water Extraction (Feet)
Corn	4-6	2-3
Grain Sorghum	4.5-6	2-3
Alfalfa	6-10	3-4
Soybeans	5-6	2-3
Wheat	4-6	3
Sugar Beets	5-6	3

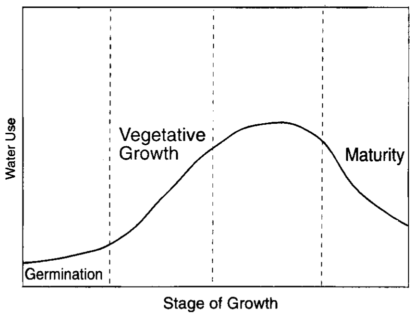


Figure 8. *Typical season water use curve.*

(around field capacity), the plant must provide at least 0.3 bars of negative tension to pull the water from the ground. At the wilting point, the maximum negative tension that a plant can provide is balanced by the soil water tension. At this point, the plant can no longer extract water from the soil and will be permanently stressed. There are several factors that determine when, where, and how much water a plant will use. These factors include daily plant water need as influenced by climatic conditions and stage of growth, plant root depth, and soil and water quality.

Plant Water Need. A plant has different water needs at different stages of growth. While a plant is young it requires less water than when it is in the reproductive stage. When the plant approaches maturity, its water need drops. Curves have been developed that show the daily water needs for most types of crops. Figure 8 shows a typical crop water curve. Perennial crops, such as alfalfa, have crop water use curves similar to those in Figure 8, except the crop water use curve has a saw-tooth pattern-water use drops sharply with each cutting and slowly increases until the next cutting.

Plant Root Depth. A plant's root depth determines the depth to which soil water can be extracted. A young plant has only shallow roots and soil water deeper than rooting depth is of no use to the plant. Plants typically extract about 40 percent of their water needs from the top quarter of their root zone, then 30 percent from the next quarter, 20 percent from the third quarter, taking only 10 percent from the deepest quarter. Therefore, plants will extract about 70 percent of their water from the top half of their total root penetration. Table 2 shows the depth of root penetration and 70 percent water extraction for several common field crops. Deeper portions of the root zone can supply a higher percentage of the crop's water needs if the upper portion is depleted. However, reliance on utilization of deeper water will reduce optimum plant growth.

Soil and Water Quality. Another factor on the amount of soil water available to the plant is the soil and water quality. For good plant growth, a soil must have adequate room for water and air movement, and for root growth. A soil's structure can be altered by certain soil management practices. For example, excessive tillage can break apart aggregated soil and excessive traffic can cause compaction. Both of these practices reduce the amount of pore space in the soil, and thus reduce the availability of water and air, and reduce the room for root development.

The quality of the water is also important to plant development. Irrigation water with a high content of soluble salt is not as available to the plant, so a higher soil water content must be maintained in order to have water available to the plant. Increasing salt content of the water reduces the potential to move water from the soil to the roots. Some additional water would also be needed to leach the salt below the crop root zone to prevent build-up in the soil. Poor quality water can affect soil structure. Most Kansas crops are only intermediate in their salt tolerance.

SUMMARY

Basic knowledge of soil-plant-water relationships make it possible to better manage and conserve irrigation water. Some of the important factors to remember include:

1. Soil water holding capacity varies with soil texture. It is high for medium- and fine-textured soils but low for sandy soils.
2. Plant roots can use only available soil water—the stored water between field capacity and permanent wilting point. However, as a general rule, plant growth and yields can be reduced if soil water in the root zone remains below 50 percent of the water holding capacity for a long period of time, especially during critical stages of growth.
3. Although plant roots may grow to deep depths, most of the water and nutrients are taken from the upper half of the root zone. Plant stress and yield loss can occur even with adequate water in the lower half of the root zone.
4. Poor irrigation water quality can reduce the plant's ability to take up water and can affect soil structure.

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