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Soil Moisture Management

Guy Fipps*

Water is essential for normal plant growth and makes up to 90 percent or more of the weight of fresh growing plants. Irrigation is used to maintain proper soil moisture for achieving optimal yields and maximizing return on investment. Understanding the basic principles of soil moisture storage and management is necessary for the efficient use of water in irrigated agriculture. It also helps to reduce the pollution potential from runoff and deep percolation.

Soil Water

Sources and losses of soil moisture are illustrated in Figure 1. Water is usually supplied by rainfall or irrigation. Some of this water is lost due to direct evaporation and runoff, while some infiltrates into the soil. When adequate soil moisture levels exist, plants can extract water from the soil through their root systems. Much of the water that the plant intakes eventually is transpired to the atmosphere through the leaves.

If excess soil moisture levels exist, the infiltrating water will continue to move below the root zone and be lost to deep percolation. Thus, moisture and nutrients for plant use are also lost. In addition, deep percolation can carry pollutants to underlying aquifers. Water quality problems caused by deep percolation have been identified in some areas of the state. Locations with high water tables may experience water moving up through the soil due to capillary forces.

Various terms are used to describe soil moisture content and the forces that move and hold water in the soil. Three classes of soil water describe the principal forces at work: gravitational, capillary, and hygroscopic. *Gravitational water* is the water that moves in response to gravity, usually under saturated conditions (Fig. 2a). This water drains downward, leaving plants only a short period to access any of it. *Capillary water* is held against gravity in the pore spaces of the soil and is the most important for crop production. The capillary and gravitational water that can be used by plants is plant-available water. *Hygroscopic water* is held so tightly by individual soil particles that roots cannot extract it. This water is associated with the soil moisture content at and below the wilting point (Fig. 2c), and is referred to as unavailable water.

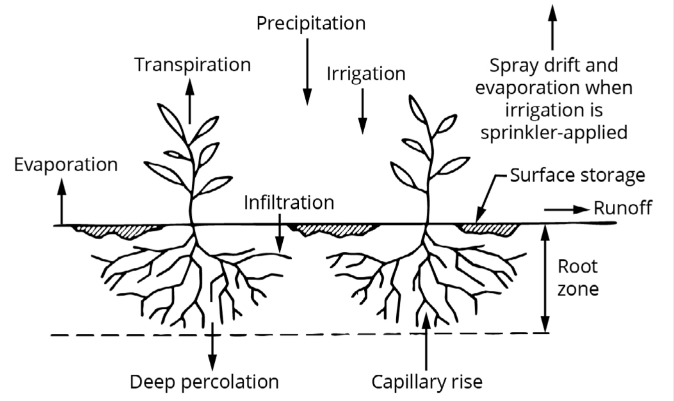

Figure 1. Sources and losses of soil moisture and factors are important in soil moisture management.

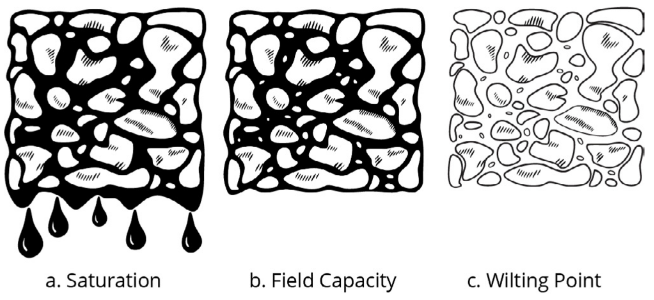

Figure 2. Here are three important soil moisture conditions: a) saturation, b) field capacity, and c) wilting point. At the wilting point, plants can extract little soil moisture.

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* Professor and Extension Agricultural Engineer, Texas A&M AgriLife Extension Service

Soil Moisture Storage

In general, soils are made up of: 1) mineral matter, 2) organic matter, 3) water, and 4) air. Mineral and organic matter are the solids in soil, and frequently occupy 35 to 75 percent of the total soil volume. The remaining volume, or pore space, is occupied by air and water. A medium-textured soil typically contains about 50 percent solid material and 50 percent pore space.

The size and total volume of pore space are a function of both the soil's texture and structure. Clay soils can hold a significant amount of water because of the relatively large surface areas of individual clay particles and the large number of very small pores. In contrast, sand particles have relatively small surface areas, and sandy soils contain a smaller number of pores which are larger in size. Water drains more easily from these larger pores due to gravitational forces. Figure 3 illustrates the relationship between soil texture and the amount of water held in the soil. Both the amounts of available and unavailable water increase as the clay content of the soil increases. Thus, sands have a much lower water-holding capacity than clay soils.

Knowing the water holding capacity of soils is important in determining both the amount and frequency of irrigation. Soils with low water holding capacity must be irrigated more frequently with smaller amounts of water than soils with higher water holding capacity. In Table 1, approximate water storage capacities are listed for agricultural soils in inches of water per foot of soil depth. These values can be used as a general guide in absence of specific field data. A good source of specific soil information is contained in the county soil survey reports published by the USDA Natural Resources Conservation Service.

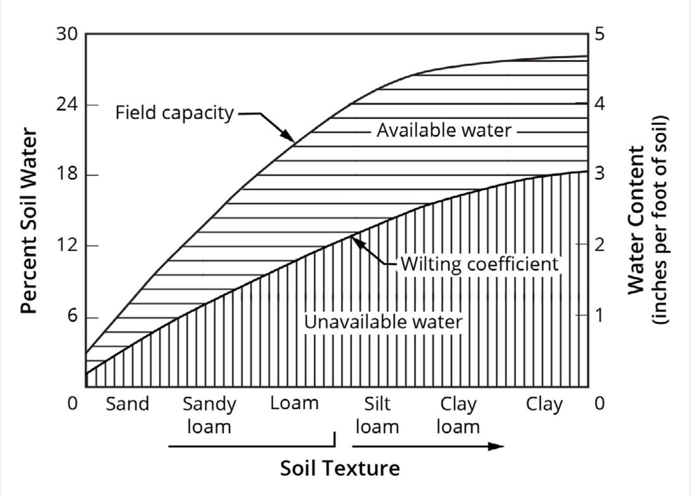

Figure 3. Notice the relationship between soil texture and the soil moisture content. Both the amounts of available and unavailable water increase as the clay content increases.

Table 1. Approximate water-holding capacity of soils given in inches of water per foot of soil (inches per foot).

Soil texture	Moisture held at field capacity	Moisture held at permanent wilting point	Available moisture
Sands	1.0 to 1.4	0.2 to 0.4	0.8 to 1.0
Sandy loams	1.9 to 2.3	0.6 to 0.8	1.3 to 1.5
Loams	2.5 to 2.9	0.9 to 1.1	1.6 to 1.8
Silt loams	2.7 to 3.1	1.0 to 1.2	1.7 to 1.9
Clay loams	3.0 to 3.4	1.1 to 1.3	1.9 to 2.1
Clays	3.5 to 3.9	1.5 to 1.7	2.0 to 2.2

Soil, Plant, and Water Relationships

Water is essential for plant growth. Without enough water, normal plant functions are disturbed, and the plant gradually wilts, stops growing, and dies. Plants are most susceptible to damage from water deficiency during reproductive stages of growth (i.e., flowering, pollinating, and fruiting).

Water also dissolves plant nutrients and carries them into the plant, chiefly through the roots. A small amount of the water taken up by the plant (less than one percent) is used in photosynthesis and to maintain turgidity (turgidity is the proper form and position of stems, leaves, and shoots for capturing sunlight). The rest of the water moves to the leaf surfaces where it is transpired to the atmosphere.

Available Soil Moisture

Soil moisture tension is a measurement of the energy or the force in which water is held by the soil and is expressed in units of pressure. The plant must use energy to extract water from the soil. When soil water is at field capacity and soil moisture tension is low, the plant can readily extract water from the soil. As the soil moisture is depleted, the soil moisture tension increases, and it becomes increasingly difficult for the plant to extract water. At the permanent wilting point, the soil contains some moisture. However, this water is held so tightly that the plant cannot extract it. The term "available moisture" is used to refer to soil moisture that can be used by the plant.

Allowable Soil Moisture Depletion

Although plants can withdraw water to the permanent wilting point, their growth is usually decreased before signs of permanent wilting occur. To obtain good yields, soil moisture must be maintained above the wilting point. For many plants, irrigation water should be applied before 50 to 60 percent of the available water is depleted. However, the amount of soil moisture depletion that can be sustained without yield reduction varies among some plants. For example, many vegetable crops require high soil moisture levels and can withstand no more than 25 percent soil moisture depletion.

On the other hand, grain sorghum is more drought-resistant and can withstand drier soil conditions. Table 2 gives some ranges of allowable soil moisture depletion that have been established for a few crops. However, soil conditions, climate, and other local factors may influence these ranges.

Table 2. Allowable root zone water depletion between irrigations for near maximum yield *(adapted from Jensen, 1980).*

Crop	Allowable water depletion (%)	Root zone depth normally irrigated in deep soils (feet)
Alfalfa	30 to 50	4.0 to 6.0
Beans, dry	50 to 70	2.0 to 3.0
Corn	40 to 60	2.5 to 4.0
Cotton	50 to 65	3.0 to 4.0
Deciduous fruit	50 to 70	4.0 to 6.0
Pasture/turf	55 to 65	1.0 to 2.5
Peanuts	45 to 50	2.0 to 2.5
Potatoes	25 to 50	2.0 to 3.0
Sugar beets	30 to 60	2.0 to 4.0
Grain sorghum	50 to 70	2.0 to 3.0
Soybeans	50 to 60	2.0 to 3.0
Wheat	50 to 70	3.0 to 4.0
Vegetable crops	25 to 50	2.0 to 4.0

Rooting Depth

The crop root zone is often viewed as a reservoir. Irrigation is used to fill the soil reservoir or to bring the soil moisture content up to field capacity in order to store water for crop use. Thus, knowing the depth of the root zone is necessary to determine how much irrigation water is needed. The rooting depth is not constant and increases as the plant grows. In addition, many factors may restrict root development such as high water tables, shallow soils, changes in soil type, or compacted and plow layers. Fertility and soil salinity also influence the rooting depth.

The depth that soil moisture is managed in irrigation is often referred to as the "effective root zone" or "effective rooting depth." The effective depths given in Table 2 are for mature crops on uniform, deep, and well-drained soils. Such values should be used with caution since rooting depth is so dependent on local conditions. Generally, the depth containing about 80 percent of the total root mass is used for estimating effective root zone depth from field observations. The maximum effective rooting depth for a crop often occurs when the full crop canopy develops.

The root mass is not evenly distributed throughout the root zone. For most well-watered crops on deep, uniform soils, there is a greater concentration of root mass in the upper portion of the root zone. As a result, more moisture is extracted from the upper portion than from the lower portion of the root zone. As a general rule, crops obtain about 40 percent of their total water requirement from the top one-fourth of the root zone. Figure 4 illustrates the basic moisture extraction pattern of plants. In the absence of specific crop data, this figure can be used to estimate soil moisture needs within the effective root zone.

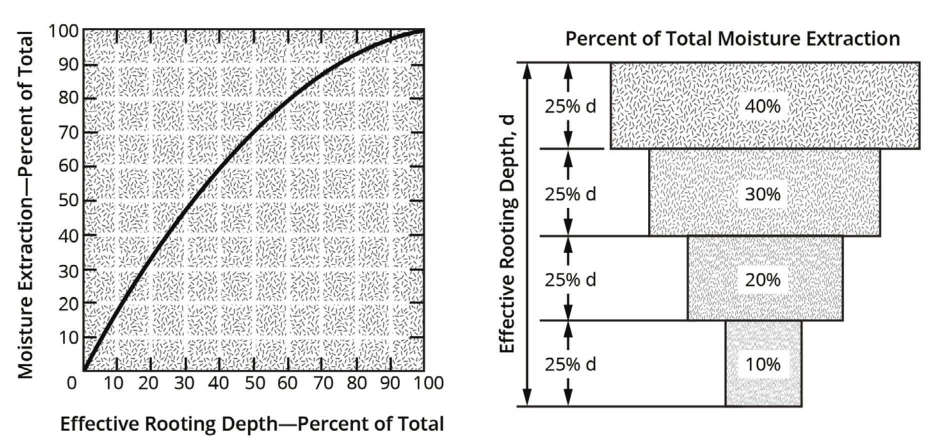

Figure 4. The basic soil moisture extraction pattern for many plants in deep, well-drained soil is shown here. Approximately 40 percent of the total water used by a plant is extracted from the top quarter of the effective root zone.

Soil Moisture Balance

It is important to maintain high levels of available soil moisture. Soil moisture depletion due to plant transpiration, deep seepage, or evaporation must be balanced by irrigation and rainfall. Water stored in the root zone is used to meet plant demands between irrigations. These factors are balanced against each other to ensure that the soil moisture in the root zone is not depleted so that yield reductions do not occur. These factors are also used to project when the root zone soil moisture will reach a level that requires replenishment.

Irrigation Amounts

Water requirements for crops are not constant, but increase as the plants grow. When planning for irrigation, you must determine both the seasonal and peak water requirements for the crops to be irrigated. The peak daily water use of some crops in Texas are listed in Table 3 (McDaniels, 1960). This publication also contains estimates for crop water use for each month and each area of the state.

In addition to the peak water use period, many crops have certain stages of growth when significant yield or quality reductions will occur if adequate soil moisture levels are not maintained. Not only must irrigation be timed to minimize periods of water stress, but also to not exceed the available root zone storage, except as needed for leaching excess salts.

Table 3. Average daily peak water use for some crops in Texas *(McDaniels, 1960)*.

Crop	Peak water use (inches per day)
Alfalfa	0.26 to 0.36
Perennial pasture	0.23 to 0.32
Corn	0.26 to 0.47
Cotton	0.22 to 0.38
Small grains	0.22 to 0.37
Orchards	
Citrus	0.16 to 0.21
Deciduous fruit	0.22 to 0.31
Pecans	0.21 to 0.28
Peanuts	0.21 to 0.28
Grain sorghum*	0.21 to 0.35
Vegetables*	
Deep rooted	0.22 to 0.30
Shallow rooted	0.21 to 0.34

**Summer crops*

An effective method for determining the amount of water to apply per irrigation involves using soil moisture monitoring sensors and devices. The total amount of water necessary to bring the soil up to field capacity can be calculated using the effective rooting depth and the soil's water-holding capacity. The total irrigation water needed is then determined by increasing this amount to account for losses due to the application efficiency of the irrigation system (Table 4). Useful units and conversions for calculating irrigation amounts are given in Table 5.

Table 4. Typical overall on-farm efficiencies for various types of irrigation systems *(adapted from James, 1988)*.

System	Overall efficiency (%)
Surface	50 to 80
a. Average	50
b. Land-leveling and delivery pipeline meeting design standards	70
c. Tailwater recovery with (b)	80
d. Surge	60 to 90*
Sprinkler	55 to 75
Center pivot	55 to 85
LESA (low elevation spray application)	95
LEPA (low energy precision application)	95 to 98
Drip	80 to 95**

**Surge has been found to increase efficiencies 8 to 28 percent over non-surge furrow systems.*

***Drip systems are typically designed at 90 percent efficiency. Short laterals (less than 100 feet) or systems with pressure-compensating emitters may have higher efficiencies.*

Table 5. Irrigation water units and conversions.

One cubic foot	= 7.48 gallons
Once acre-inch	= 3,630 cubic feet = 27,154 gallons
Once acre-foot	= 12 acre-inches = 43,560 cubic feet = 325,851 gallons
450 gallons per minute	= ~1 acre-inch per hour = ~1 cubic foot per second

Terms Used in Soil Moisture Management

Allowable water depletion: the amount of available water that can be depleted from the soil without adverse effects on plant growth and yield. Some plants are more "drought-tolerant" than others and can tolerate drier soil conditions.

Available water: the amount of water held in the soil between field capacity and the permanent wilting point that is readily available for use by plants. It is usually expressed in inches of water per foot of soil.

Effective root zone: the depth from which the roots of a plant are capable of reducing soil moisture to the extent that it should be replaced by irrigation.

Field capacity: the amount of water a soil will hold against gravity when allowed to drain freely. This moisture content is reached one or two days after irrigation or rainfall in well-drained soils (Figure 2b).

Infiltration: usually defined as the entry of water into the soil profile. The infiltration or intake capacity of the soil determines the rate that water can be applied on the surface without runoff.

Irrigation efficiency: the ratio of the amount of water consumed by the crop divided by the total amount pumped or supplied from the water source. The term is used to account for losses in an irrigation system due to wind drift, evaporation, runoff, etc. (Table 4).

Permanent wilting point: the soil moisture content at which plants permanently wilt. At the permanent wilting point, water is held so tightly by the soil particles that it cannot be extracted by plant roots (Figure 2c).

Saturation: a condition in which all pore spaces of a soil are completely filled with water (Figure 2a).

Soil moisture content: the quantity of moisture contained in a soil, expressed as a percentage of volume, as a given weight of dry soil, or in inches of water per foot of soil.

Soil moisture tension: the force or energy that must be exerted to remove water from the soil. Moisture tension is usually expressed in terms of atmospheres of pressure and is directly related to the moisture content of the soil.

References

James, L. G. (1988). *Principles of Farm Irrigation System Design*. John Wiley and Sons.

Jensen, M. E. (Ed.). (1980). *Design and Operation of Farm Irrigation Systems* (2nd ed.). American Society of Agricultural Engineers.

McDaniels, L. L. (1960). *Bulletin 6019: Consumptive Use of Water by Major Crops in Texas.* Texas Board of Water Engineers.

Appendix: Sample Calculations

I. Determine the irrigation amount needed for a mature corn crop being grown in a deep and uniform loamy soil.

Step 1: The following data is measured or estimated for the particular field, crop, and irrigation system in question.

Parameter	Value Assumed
Rooting depth	3.5 feet
Current soil moisture content	2.4 inches per foot
Moisture held at field capacity	2.9 inches per foot
Irrigation efficiency	75 percent

Step 2: Calculate the soil moisture deficit in the root zone (units in inches and feet)

[(moisture at field capacity) – (current soil moisture)] × (rooting depth) = (soil moisture deficit)

$$\left(2.9\frac{in.}{ft.} - 2.4\frac{in.}{ft.}\right) \times 3.5\,ft. = 1.75\,in.$$

Step 3: Calculate the required irrigation amount (units in inches).

(soil moisture deficit) ÷ (irrigation efficiency) = (irrigation amount)

$$1.75\text{ in.} \div 0.75 = 2.33\text{ in.}$$

II. Determine the maximum number of days between irrigations for corn during the peak use period if the soil moisture is at field capacity.

Step 1: The following additional data is measured or estimated.

Parameter	Value Assumed
Available soil water holding capacity	1.8 inches per foot
Peak crop water use (corn)	0.35 inches per day
Allowable water depletion	50 percent

Step 2: Calculate the total water that can be used by the crop without yield reduction.

(available soil water holding capacity) × (rooting depth) × (allowable water depletion) = (usable water)

$$1.8\frac{in.}{ft.} \times 3.5\,ft. \times 0.50 = 3.15\,in.$$

Step 3: Calculate the maximum time between irrigations (units in inches and days).

(usable water) ÷ (peak crop water use) = (maximum time between irrigations)

$$3.15\,in. \times \frac{day}{0.35\,in.} = 9\,days$$