IRRIGATION PLANNING

SOIL, WATER AND PLANT RELATIONSHIPS

INTRODUCTION

This chapter will introduce you to the basics of what scientists call "soil-water-plant" relationships. The ideas form a model system of how water enters the soil, moves through the soil, into the plant root system, and back to the atmosphere. More important they identify the important components of the system and provide standards of measurement so that we can control this movement.

Major ideas presented are . . .

- Soil "holds" water against the pull of gravity, retaining it for crop use. There are limits to this ability. The upper limit is call FIELD CAPACITY. The lower is called PERMANENT WILTING POINT.
- You can add water to soil above FIELD CAPACITY. It will not hold this additional water. It will drain below the effective root zone to become deep percolation.
- Between field capacity and permanent wilting point is the soil's AVAILABLE WATER HOLDING CAPACITY (AWHC). This is the amount of water that the soil will hold that is available for the crop to use.
- As the crop pulls water from the soil, the soil holds onto the remaining water harder and harder, putting more and more stress on the crop. You will see the crop wilt during the hottest parts of the day. Sooner or later, if the stress gets big enough, the crop will permanently wilt. The soil moisture is at PERMANENT WILTING POINT.
- Soil water can be measured in two ways . . .
  a. Volumetrically, the actual amount of water in the soil.
  b. Tension, a measure of the water-holding forces in the soil.
- The crop doesn't care how much water is physically in the soil, only how hard it is to get out. Thus, although a volumetric measurement will tell us how much water is in the soil and, therefore, how much to irrigate, the tension measurement is more important in terms of preventing crop stress.
- The volumetric standard of measurement is inches of water held per foot of soil or just inches/foot. Available water holding capacities vary from 1 to 2.5 inch/foot.
- The tension standard of measurement is pressure, usually centibars.
- The rate at which crops extract water from the soil is called EVAPO-TRANSPIRATION, ETc. ETc is the combination of soil surface evaporation and plant transpiration and is measured in terms of inches of water per day. Normal ETc rates for cotton are around .05 in/day as seedlings to .35 in/day as a full-grown plant.

- ETc varies with the plant, the climate, the level of soil moisture, and plant condition (fertilizer/pest/disease stress). ETc can be measured and predicted.
- The INFILTRATION RATE, measured in inches/hour, is a measure of how fast water is soaking into the ground. Infiltration rates will decrease during an irrigation.
- The APPLICATION RATE, also measured in inches/hour, is a measure of fast we are applying water. Knowing the application rate of sprinkler systems is especially important. They usually run from .1 to .5 inches/hour.
- If the application rate is higher than the infiltration rate, runoff occurs. There should not be excessive runoff with a trickle or sprinkler irrigation system.
- There are several methods available for measurement of soil moisture both for volumetric (the neutron probe, gravimetric, "feel") and tension (tensiometers, gypsum blocks, leaf pressure chambers). They all have their strengths and weaknesses.
- Very high or out-of-balance salts will modify many of the measurements and results of different measurements (high or low). Refer to the chapter on salinity for further information.

THE SOIL'S AVAILABLE WATER HOLDING CAPACITY

Soil "holds" water available for crop use, retaining it against the pull of gravity. This is one of the most important physical facts for agriculture. If the soil did not hold water, if water was free to flow downward with the pull of gravity as in a river or canal, we would have to constantly irrigate, or hope that it rained every two or three days. There would be no reason to preirrigate. And there would be no such thing as dryland farming.

The soil's ability to hold water depends on both the soil texture and structure. Texture describes the relative percentages of sand, silt, and clay particles. The finer the soil texture (higher percentage of silt and clay), the more water soil can hold.

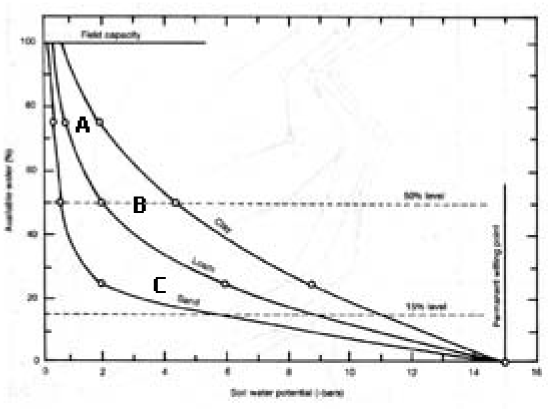
Gravity is always working to pull water downwards below the plant's root zone. To counteract the pull of gravity, soil is able to generate its own forces, commonly called "matric forces" ("matric" because of the soil "matrix" structure that forms the basis for the forces).

An important fact about the soil's water-holding forces is that as the level of soil moisture goes down, the soil generates more force. This is the reason that some water will move up into the root zone from a shallow ground water table. As the plant extracts water in the root zone, the soil pulls water up from the area with more water to the area with less.

As you would expect, the rate at which the water-holding forces go up with decreasing soil moisture is different for different soils. In a coarse soil, they will go up slowly. This means that plants can extract a great amount of water from coarse soils before they stress. In contrast, these forces rise quickly in finer soils.

Graphically, the relationship can be described by the Figure 1. Looking at the lowest line for a coarse soil. You can see that at A, the soil moisture level is very high and the water-holding forces are low. This means that the plant can extract water easily from the soil. At B, the soil moisture level is lower but the water-holding forces haven't gone up that much. The plant can still extract water easily. However at C, the soil moisture level is very low and the water-holding forces have increased greatly. The plant cannot extract water easily and will be stressed.

FIGURE 1: Soil Moisture Level (Depletion, %) vs. Soil Moisture Tension (Bars).



Looking at the top line for a finer soil. At A, as with the coarse soil, the water-holding forces are low when the soil moisture level is high. However, at B, the soil moisture level has dropped somewhat but the water-holding forces have gone up greatly. And at C, where the soil moisture level is low, the water-holding forces have gone up very high.

We will be coming back to this idea of increasing soil water-holding forces with decreasing soil moisture many times.

AVAILABLE WATER AND THE EFFECTIVE ROOT ZONE

The water held by the soil between field capacity and permanent wilting point is termed the "available water holding capacity" of the soil. It is water that is "available" for the plant to use. Water added to the soil in excess of field capacity will drain down, below the active root system. Water held by the soil that is below the permanent wilting point is of no use, the plant has died.

As a crop manager you are concerned with the soil moisture throughout the depth of the plant's active root system, the "effective root zone". The effective root zone is that depth of soil where you want to control soil moisture (just as you control fertility and weed/pest pressures). The effective root zone may or may not be the actual depth of all active roots. It may be shallower because of concerns for crop quality or development (as with many vegetable crops). For a preirrigation though, you may want to consider the maximum potential root zone as the effective root zone for that irrigation.

For example, with cotton you may estimate the effective root zone as 6 feet for a preirrigation, 2 feet for the first seasonal irrigation, 4 feet for the second seasonal, and 6 feet thereafter. For an almond orchard, you may estimate the effective root zone as four feet for the entire season. With onions, the major concern is with the top 2 feet.

Table-1 shows some estimates for effective root zones healthy crops grown on deep well-drained soils.

TABLE 1. Normal Crop Rooting Depths (feet).

Alfalfa	5-10	Grain	3-4
Asparagus	6-10	Grass	2-4
Beans	3-4	Lettuce	1-1.5
Beets(sugar)	4-6	Melons	6
Broccoli	2	Onions	1
Cabbage	2	Peas	3-4
Carrots	2-3	Peppers	2-3
Cauliflower	2	Potatoes	3-4
Celery	3	Spinach	2
Citrus	4-6	Squash	3
Corn(sweet)	3	Strawberry	3-4
Corn(field)	4-5	Tomatoes	6-10
Cotton	6-8	Walnuts	12
Deciduous tree	6-8		
Grapes	4-6		

Note the wide range in some of the root zones in the table above. This is an example of irrigation as both an art and a science. There are scientific ideas like "effective root zones" and "field capacity" that provide a way to think about water management. But it is up to you, the grower, to apply these ideas, to pick the effective root zone, to estimate the field capacity and permanent wilting points

MEASUREMENT STANDARDS FOR SOIL WATER

To make use of the ideas of available soil moisture and effective root zones, we need standards of measurement (as the "foot" is a standard of measurement for length or a "gallon" is a standard for volume). The standard of measurement for effective root zones is depth, either inches or more commonly, feet. But how do we measure soil moisture?

First consider a cubic foot of soil that has just been taken from a field. Soil is not completely solid. It has mineral solids held in a matrix-type structure intermixed with open spaces, pores. Assume we were somehow able to compress the soil so that all the solids were together. We would have a depth of solids (mineral and organic particles), a depth of water that had been held by the soil, and a depth of air that had also been within the soil pores. See figure-2. We measure soil moisture in terms of that depth of water held by a depth of soil.

Commonly this is inches of water per foot of soil, or just "inches/foot". For example, we might say . . . "the field capacity of this soil is 2.0 inches/ft". This means that the most water this soil will hold is 2.0 inches per foot. We might say . . . "the current soil moisture is 1.7 inches/foot".

FIGURE 2

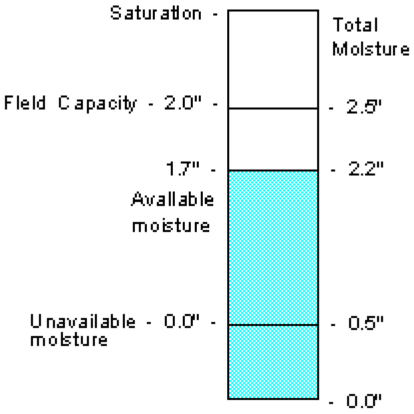


TABLE 2. Representative Available Water Holding Capacities

Soil Class	Range/Average in/ft
VeryCoarse to Coarse Sand	0.50-1.25/.90
Moderately Coarse Sandy Loams	1.25-1.75/1.50
Medium Loams	1.50-2.30/1.90
Clays and Clay Loams	1.60-2.50/2.10
Peats and Mucks	2.00-3.00/2.50

The numbers in Table-2 are ranges of normal available water holding capacities. The Reference chapter of this handbook contains specific numbers for common soils of the District. The maximum depth of water available to the plant in the effective root zone can be determined by adding the available water holding capacity for each foot of soil in the effective root zone.

For example, assume you have an effective root zone that is four feet deep. The first two feet are Medium Loam, the third foot is a Sandy Loam, and the last foot is a Coarse Sand. The estimated maximum available water (using the example numbers from Table -2) is . . .

Medium Loam - 1-2 ft (2 x 1.9) = 3.8 inches
Sandy Loam - 2-3 ft = 1.5
Coarse Sand - 3-4 ft = <u>.9</u>
Maximum AWHC = 6.2 inches

If the soil in the entire four-foot effective root zone was at field capacity, there would be 6.2 inches of water available to the crop to use. It's as if there was a 6 inch deep pan of water that the crop was growing in.

PLANT EVAPOTRANSPIRATION

Water is extracted from the soil by evaporation at the soil and plant surfaces (crop transpiration). The combination of the two is termed "crop evapotranspiration", or ETc. (It has also been termed "consumptive use" or "crop water use".)

ETc is affected by many factors. ETc will vary with the type of plant and growth stage. Some plants just use less water than others. And obviously, a seedling is going to extract less water than a full grown plant.

ETc varies with the climate. Up to a certain point, increasing temperature and wind will increase ETc. (There is usually a maximum ETc rate for any plant, beyond which it just stops transpiring due to stress.) Increasing humidity and cloud cover will decrease ETc.

ETc varies with the amount of soil moisture in the effective root zone. Remember that the soil's water-holding forces increase as the soil moisture decreases. Thus, as the plant uses up soil moisture, it becomes harder and harder to extract more. Past a certain point, which depends on the plant, the soil's texture and structure, and the root zone salinity, the ETc rate will decrease. Below-normal ETc rates will place stress on the crop. Depending on the crop and growth stage, more or less stress is desirable. Knowing the acceptable level of stress and knowing what level of soil moisture will cause this stress is an important function of modern crop management. The Reference chapter of this Handbook contains information sheets for all major crops describing critical growth stages, ETc rates throughout the season, and desirable water management.

The standard for measurement of ETc is inches of water use per day or "inches/day". You may see ETc described in terms of inches of water use per season if someone is talking of seasonal ETc. Table-3 contains approximate ETc's of common crops. The reference section of this handbook contains full information on ETc for most common crops grown in the District.

TABLE 3. Approximate ETc at maturity of some crops at Five Points (mid-July)

CROP	ETc (inches/day)
Alfalfa	.12 - .30
Almond	.27
Corn	.35
Cotton	.28
Melon	.20
Onion	.20
Tomato	.30
Sugar beet	.30

MOVEMENT OF WATER INTO AND THROUGH THE SOIL

During an irrigation or rain, water soaks into the soil at a rate dependent on the soil type/structure, the soil/water chemistry, and the current soil moisture. Usually, the soil's "infiltration rate" will decrease with time during an irrigation or rain. This is graphically illustrated in Figure-3.

FIGURE 3: Soil Infiltration Curves, Rate (in/hr) vs. Time.

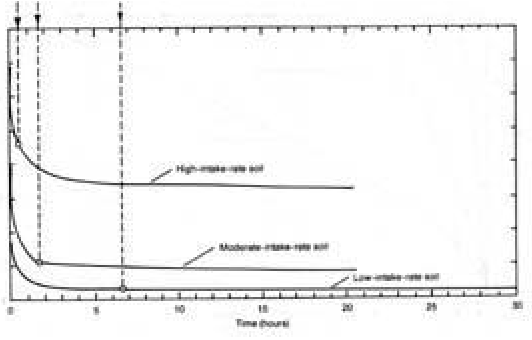


Figure-3 is a graph of the infiltration rate at the head of a furrow during an irrigation. At the left the irrigation has just started (elapsed time = 0) and the infiltration rate is high. The water is taking in water very quickly. But 20 hours into the irrigation, the infiltration rate has dropped dramatically.

Water movement into and through soil is very much influenced by the soil/water chemistry and soil structure. A "sodic" soil will usually have an imbalance in salts that reduces the permeability of the soil. More is said about salts and managing their effects in the Salts and Drainage section.

Water moves through the soil due to a combination of gravitational and matrix forces. Water always tends to move down. However, as described previously, soil water-holding forces are higher in areas with low soil moisture. Thus, water will also tend to move from soil with high soil moisture to areas of less. This is why water can move up into the root zone from a shallow ground water table. As the plant's root system extracts water in the immediate vicinity of the root, water from the wetter surrounding soil will move towards the drier area around the root. As the soil moisture goes down, less and less water will move towards the root and that water surrounding the root is held tighter. Thus, the root can extract less and less water and stress is put on the plant as the soil dries.

RUNOFF AND THE IRRIGATION SYSTEM APPLICATION RATE VERSUS THE SOIL'S INFILTRATION RATE

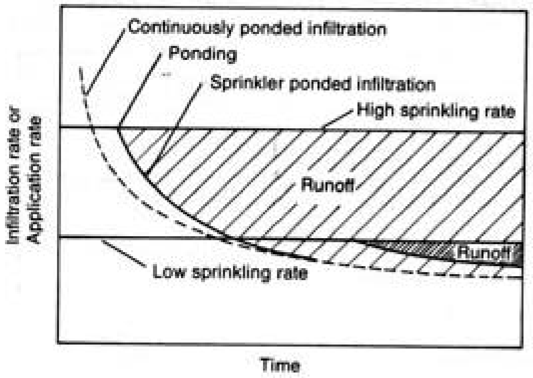
The rate at which water soaks into the soil is called the "infiltration rate". The rate at which we apply water through irrigation, or the rate that water falls during a rain storm is called the "application rate". Surface runoff occurs when the application rate of the irrigation/rainfall is greater than the infiltration rate of the soil.

Infiltration rates and application rates are both measured in terms of inches of water applied per hour, or "inches per hour".

For example, a standard field sprinkler system using 7/64" nozzles and running at 50 psi applies water at about .2 inches of water per hour. (That is, for every hour the system runs, an equivalent depth of about .2 inches of water is sprayed onto the ground.) If the soil's infiltration rate is greater than .2 inches/hour, then all water applied by the sprinkler system will soak in. If it is less, then you will see water standing on the surface or running off.

Figure-4 is a graph of infiltration rate versus time during an irrigation. The infiltration rate at the start of the irrigation(the left side) is very high, while at near the end of the irrigation(the right side) it has dropped greatly. The straight horizontal line represents the application rate of a sprinkler system that could have been used during the irrigation, high and low rate. It is straight because the application rate of the sprinkler system doesn't change. It pumps out the same amount of water all through the irrigation.

FIGURE-4: Sprinkler Infiltration Rates



The infiltration rate is higher than the application rate at the start of the irrigation. Thus, all water applied by the sprinklers soaks into the soil. However, by the end of the irrigation, the infiltration rate has dropped below the application rate. Now the sprinkler system is applying more water than the soil can soak in. You will see standing water or runoff occur.

If you see excess surface runoff with sprinkler (or trickle) systems, then either the system is being run too long per set or the design of the system is not matched to the soil (it applies water too fast). Note that sprinkler systems do not spray water on all parts of the field at equal rates. Because of this you may see standing water close to sprinkler heads and not further away during an irrigation. If this occurs continually check your spacings or the length of your sets.

Also see this link to a United Nations soil and water training manual (http://www.fao.org/docrep/R4082E/r4082e03.htm) that covers this same material, but describes things in metric units. Another link to material on this topic is the NRCS National Engineering Handbook, part 652 (http://www.wcc.nrcs.usda.gov/nrcsirrig/irrig-handbooks-part652-chapter2.html).