

Irrigating Crops

Water Budgeting and Irrigation Systems

Overview

Irrigation is the controlled application of water to meet crop water requirements not satisfied by rainfall. Careful and efficient irrigation is becoming increasingly important throughout the world and such irrigation can improve crop yields and quality, optimize water use, and protect natural resources.

Many farmers determine how much water to apply and how often to apply it through a water budgeting approach. Water budgeting strives to balance water use with water inputs. This method is similar to balancing a checkbook. Water inputs may include rainfall, irrigation, and capillary rise from ground water. The outputs may include evaporation, transpiration (evaporation through plant tissues, most often leaves), runoff, and percolation below the root zone.

The goal of this activity is to expose students to water budgeting and teach them how farmers use this approach to maximize irrigation efficiencies.

Resource References

California Irrigation Management Information System. California Department of Water Resources.

<http://www.cimis.water.ca.gov/Resources.aspx>

Reference Evapotranspiration Zones

<http://www.cimis.water.ca.gov/Content/pdf/CimisRefEvapZones.pdf>

Irrigation: Principles and Practices. Center for Agroecology and Sustainable Food Systems. University of California Santa Cruz

http://63.249.122.224/wp-content/uploads/2010/05/unit_1.5_irrigation.pdf

Vegetable Root Depth Chart To Gauge Watering Depth, UC Cooperative Extension, Los Angeles County Division of Agriculture and Natural Resources

<http://celosangeles.ucdavis.edu/files/121762.pdf>

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Water Budgeting and Irrigation Systems

Introduction

This unit introduces students to the basic concepts, tools, and skills used to make irrigation decisions so that they can supply water to plants efficiently and effectively on any scale. Students will learn about the role of irrigation water in agriculture, the movement and cycling of water, and the factors that influence the type, frequency, and duration of irrigation. Students will practice calculating water budgets used to develop irrigation schedules and determine total water volume needs.

Plant roots absorb water from the soil, water travels up the plant (in the plant's vascular system, specifically the xylem) and evaporates through stomata on the surface of the plant's leaves (primarily). This "evaporation through plant tissues" is called *transpiration*. If there isn't sufficient water readily available in the soil to keep up with a crop's needs, several negative things start to happen in the plant. These may include stomatal closure (thus photosynthesis stops), various physiological stresses, wilting, and, eventually, death of plant parts or whole plants.

The amount of available water that a soil can store in the root zone of crops is typically several times less than the total amount of water that crops use over the season (e.g., summer) in a place like California's Central Valley. Therefore, irrigation is used on most crops to replenish the water stored in the soil.

It is useful to think of the soil as a big sponge that can hold water for plants to extract. The amount of water that a soil can hold and release for plant use varies from soil to soil, but it is typically equal to about 5% to 15% of the total soil volume. When measuring water as related to irrigation, we typically measure it in inches. Most of us are used to thinking of inches of rainfall. Inches of evaporation or of water stored in the soil are similar measurements. The amount of water stored per foot (depth) of soil tends to increase as we move from coarse textured soils, such as sands, to finer textured soils, such as clays. When dealing with soils containing clays, structure can have an impact on water-holding capacity. Thus, as indicated below, clays hold more available water than sands, and clays with good structure hold more water than those with poor structure.

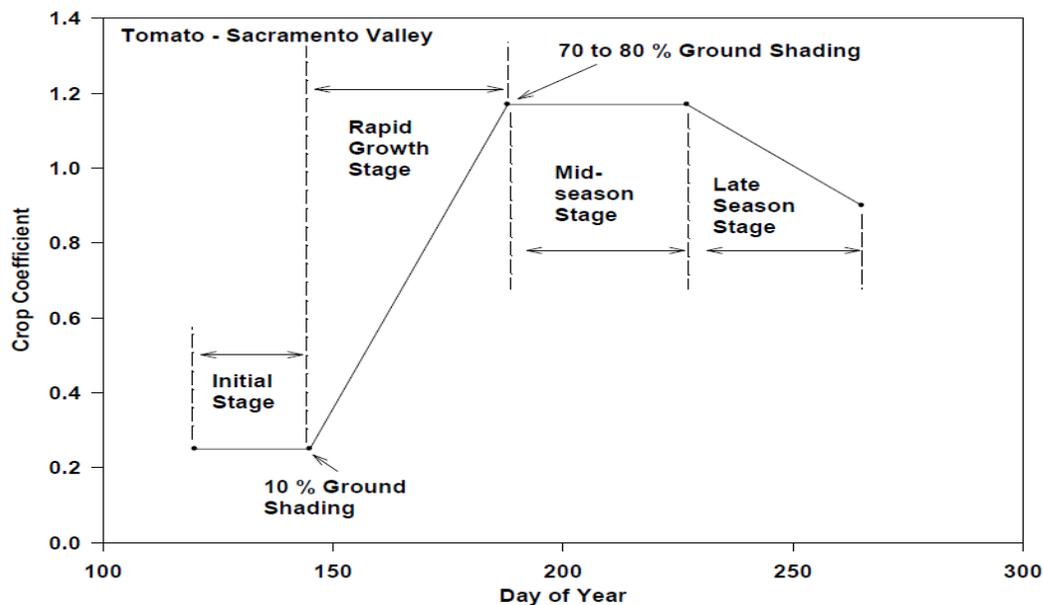
<u>Soil Type</u>	<u>Available water - typical (inches of water/foot of soil)</u>
Sand	0.6 +/- 0.1
Fine sandy loam	1.2 +/- 0.2
Silt loam	1.4 +/- 0.3
Clay loam (good structure)	1.6 +/- 0.4
Clay loam (poor structure)	1.0 +/- 0.2

Thus, the soil type and the rooting depth of the crop determine the total amount of water that the soil can store for a given crop. For example, if a crop's roots go three feet deep and it is growing on a fine sandy loam, we can estimate that the soil can hold up to 3.6''

of water for the crop. This tells us how much available water the soil can hold, but we need to remember that we don't want to purposely wait until all of the available water is gone before irrigating. Rather, a rule of thumb is to irrigate when about half the available water is gone. In our example, this would be when about 1.8" of water has been used (and 1.8" of available water remains).

Now that we know how to estimate the amount of available water the soil can store, we need to estimate the rate at which it is used up. Water use is the combination of any evaporation (E) from the soil surface and any transpiration (T) out of plant surfaces (e.g., leaves). Typically we combine these two and talk about evapotranspiration (ET). ET is controlled by two main factors:

1. Potential Evapotranspiration (ET_0): ET_0 is the amount of ET that would occur if the crop were a mature, well managed grass with plenty of moisture in the soil. ET_0 is a function of weather. It is greatest under hot, dry, sunny, windy conditions. In much of California it may vary from 0.0" per day in the winter to about 0.35" (or more) per day during the summer.
2. Crop factors: When crops are young and small, actual ET is only about 1/3 of ET_0 because the small plants don't transpire much and soil surfaces typically dry out quite a bit between irrigations (there is very little evaporation off a dry soil surface). When a crop is full sized and still green, actual ET will be closer to ET_0 and is often actually slightly greater than ET_0 . The "Crop Coefficient" (K_c) quantifies the ratio between actual ET and ET_0 . K_c tends to increase with the size of the plant (in the case of annual crops) or the amount of foliage (in the case of deciduous perennials). A typical seasonal pattern of K_c for an annual crop (in this case, tomato) is depicted in the figure below.



Therefore, actual evapotranspiration is a product of both weather conditions (which determine ET_0) and crop factors (which determine K_c). Mathematically, $ET = ET_0 \times K_c$.

Thus, in our example, if it is a relatively hot, sunny period and the crop is full sized we'll guess that $K_c = 1.0$, so $ET = ET_0$; we'll assume this would be 0.3"/day. Since we are willing to use up 1.8" of water before we irrigate, it would be 6 days between irrigations. When we irrigate, we would want to replace the 1.8" of water that had been lost to ET. However, in reality, we would also want to add a little more water than that because irrigation applications are never completely efficient and uniform. For this reason, we might want to add another 20% (0.36" in this example) to our irrigation (for a total of 2.16" of water).

When crops have shallower roots, the amount of water applied per irrigation is less and the irrigation frequency increases. With deeper roots, irrigations can be less frequent but larger amounts of water must be applied during each irrigation. (Note that the total amount of water applied over the season would be the same in the two cases.)

Characteristics of Common Irrigation Methods

Furrow:

- water moves by gravity at (or near) 'zero pressure' in open furrows and ditches (or sometimes pipes)
- requires: 'level' field (actually, constant slope; engineering required) ; a high volume (low pressure) water source; labor to set up and manage each irrigation; relatively few materials
- saturated infiltration - furrows typically remain wet for a few to several days
- not possible to put on small amounts of water
- water 'subs' laterally (e.g., into bed) by capillary action; there is more lateral (capillary) movement in clay; water infiltrates into sand much more rapidly (see diagram below)
- uniformity/efficiency: quite variable; function of field layout and management; typically somewhat lower than other systems

Sprinkler:

- water moves through pipes at high pressure (e.g 45 - 55 psi)
- requires: significant material costs (capital); labor to move pipe (in some systems); energy to develop pressure; (does *not* require 'level' field)
- do not want saturated infiltration (this results in ponding, which can lead to soil crusting and water runoff)
- maximum application rates: should be less than the soil's minimum infiltration rate (so that saturated infiltration is avoided. Thus, rates range from ~ 0.15"/hour (e.g., a clay) to 0.75"/hour (e.g., a sand)
- application frequency and amount often flexible, especially if permanent (e.g., "solid set) system in use
- uniformity/efficiency: usually relatively high; if system is well designed and managed (wind can compromise this)

Drip:

- water moves through drip line at low pressure (e.g., 10 - 15 psi; however, pressure needed 'upstream' from filter may be 25 – 30 psi)
- requires: frequent purchases of drip line; moderate pressure (see above); management to keep emitters free of sediments, salts and algae and to detect and fix breaks and leaks; relatively low in-season labor
- drip line can be above or below ground (below ground is especially good at reducing weeds)
- wetting pattern is similar to that for furrow, but the source is typically near the center of the bed, not the furrow
- may result in only a portion of the soil volume being wet, especially if irrigations are of short duration; this can limit root growth and 'exploration' of the soil volume and, thus, nutrient availability
- application frequency and amount very flexible - often can irrigate daily with little effort
- uniformity/efficiency: can be quite high, with proper design and management.

To Lead This Activity You Need to Know

Facilitators of this activity need to have basic understanding of the following concepts in order to effectively lead students through this activity:

- Basic plant physiology
- Reasons why farmers irrigate agricultural crops
- How soil structure and texture influences soil water holding capacity
- Water budgeting to maximize irrigation efficiencies
- Environmental/crop quality consequences of inefficient irrigation
- Water delivery systems commonly used by farmers

Key Concepts

- Water needs of plants
- Crop yield, quality effects and environmental impacts of too little or too much irrigation
- Evaporation and transpiration
- Water holding capacities of different soil types (textures, structures)
- Water budgeting

Objectives

- Learn about the importance of irrigation management
- Learn key concepts associated with irrigation management
- Learn how water budgeting can significantly increase irrigation efficiencies
- Learn some of the technologies farmers use to irrigate crops

Materials

- Farm with growing crops
- Clipboard with pencil (one for every student)
- Common irrigation equipment (e.g. irrigation pipe with sprinklers, drip tape, micro sprinklers, furrow irrigation pipe or ditch and siphon tubes)
- Water budgeting worksheet
- Whiteboard/chalkboard for demonstrating calculations
- Calculators (one for each person)
- Sponge with bowl of water
- Root depth chart (download via the link in the last item in the resource section).

Activity (45-50 minutes)

(This activity is best performed in the field, but can be done in the classroom)

1. After welcoming the students to the farm or garden and describing it briefly, tell them that the focus of today's visit is going to be learning about irrigation. Discuss the following:
 - What is irrigation? Why is it important? What happens if we don't have enough water for irrigation?
 - What are some of the consequences if done poorly (e.g., too little water or too much water is applied)?
2. Dig up a few plants with different root systems (if available) making sure to minimize damage to the root system. Show the students the different root systems and explain that a plant's ability to forage for water is related to the type of root system it has.
 - Explain that different plants have different rooting depths. Ask the students why having deep root can be beneficial for plants. Ask them if they know of a common vegetable that has deep roots. (Tomatoes, winter squash, watermelons can have roots that go deeper than 4 feet, while the roots of some other crops are generally don't go beyond 1.5 – 2 ft deep, e.g., lettuce, broccoli, cabbage, onion, garlic, spinach).
 - Look at the Vegetable Root Depth Chart that can be downloaded from the link provided in the Resource References section of this activity guide. Please note that the second column of the chart is the root depth, and the third is the lateral root spread. For the purpose of this activity, you will want to estimate the root depth using the information from the second column. When making calculations, use the average of the depth estimates for the root depth (S, M, and D) categories.
3. Grab a handful of soil.
 - Explain that there are a lot of different soil types in the world and different soil types can hold different amounts of water. Explain that sand, with its large soil particles, can hold the least amount of water while clay, with its small particles, can hold the most.
4. Dip a sponge in a bowl of water making sure it is fully saturated. Pull it out allowing it to drip.
 - Explain that this sponge represents what happens in the soil after a heavy rain or irrigation. When all the pores in the water are full of water, the soil is said to be

“saturated.” However, soils are not usually saturated. Typically after, or maybe even during, rainfall or irrigation gravity pulls water out of some of the soil pore spaces into the deeper layers below ground. In this case, the soil is not saturated, and the pore spaces occupied partly by water and partly by air. When gravity has drained the soil as much as it can, the soil still holds some water that the plants can use and the soil is said to be at “field capacity.”

5. Quickly demonstrate some of the irrigation technology used on the farm (e.g., drip, sprinklers, furrow).
 - Explain the pros and cons of each system discussed in the introduction.
6. Discuss the water budget concept.
 - Explain to the students that efficient irrigation management is good for crops, the environment, and the farmer’s financial bottom line. Many farmers develop a water budget to figure out how much water to apply to their crops.
 - To develop a water budget, farmers need to know the evapotranspiration rate. Explain what evapotranspiration is and tell them that it changes based on weather related factors (e.g. temperature, wind, and humidity) and crop related factors (e.g., crop size and maturity)
 - Explain that, in California, the government manages a system called the California Irrigation Management Information System (CIMIS), which has stations all over the state that measures what we call potential evapotranspiration. Farmers can go on-line and get daily current and past potential evapotranspiration rates. For the purpose of this activity you will take the monthly averages for your area as indicated in *Reference Evapotranspiration Zones* publication listed in the Resource References section on p 1. Simply divide the current month’s total ET_0 rate by the number of days in the month. You will use this as your estimate of your daily ET_0 rate.
7. Tell the students that they are going to create a water budget. Hand out the water budget data sheet and walk them through the exercise doing calculations together and on the board.

Discussion and Reflection (10-15 minutes)

Once finished, ask the following discussion questions:

- Why is irrigation management so important?
- How can farmers maximize the efficiency of their irrigation systems?
- What management tools can farmers use to manage irrigation?
- What irrigation system(s) do you think would work well in this situation?

Student Worksheet One

Water Budgeting Worksheet

First, choose a soil type from Table 1. From the table, determine the typical available water it can hold. Record this information below.

_____ Available Water-typical
Soil Type

Table 1. Available water in various soil types giving in inches of water/foot of soil	
<u>Soil Type</u>	<u>Available water - typical (inches of water/foot of soil)</u>
Sand	0.6
Fine sandy loam	1.2
Silt loam	1.4
Clay loam (good structure)	1.6
Clay loam (poor structure)	1.0

Now choose a crop. Determine the typical root depth of this crop, using the Vegetable Root Depth Chart. Determine the total amount of water available to your crop based on the soil type you chose and the root depth of your crop.

_____ X _____ = _____
 Typical Available Water Root Depth Total Amount of
 For Chosen Soil (Inches (Feet) Available Water
 of Water/Foot of Soil) (Inches)

Because we only want to use half of the available water to avoid water stress in the crop calculate the amount of water you willing to use before the next irrigation using the following equation:

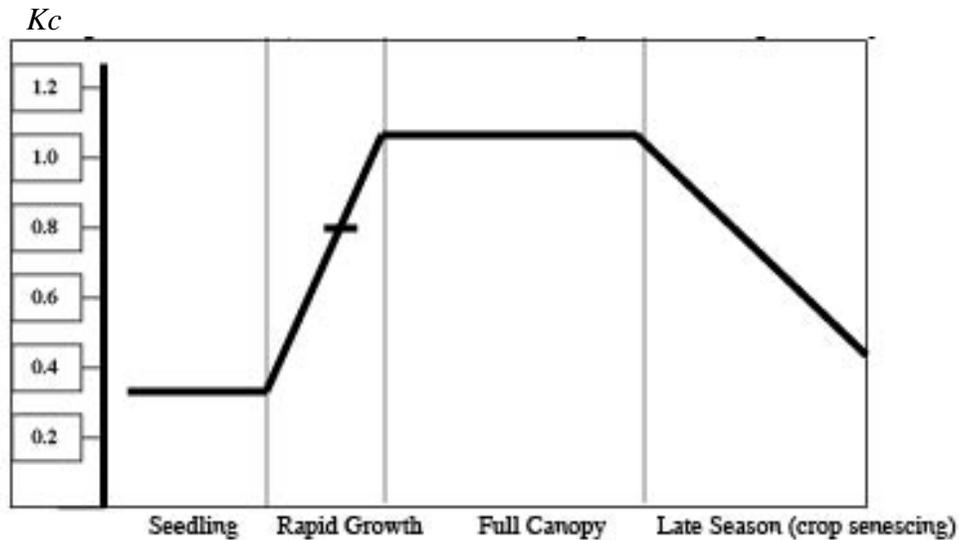
_____ x 1/2 = _____
 Total Amount of Amount of Water We are Willing to Use
 Available Water (Inches) Before Irrigating Again (Inches)

Now we know how much water we are willing to use before irrigating again. The next step is to determine the rate at which water is being used, known as the actual evapotranspiration rate (ET). ET is the product of two factors: the potential evapotranspiration rate (ET₀) and the crop coefficient (Kc). ET₀ is determined by weather conditions (hot, dry windy conditions lead to high ET₀). Kc is determined by crop factors (mainly crop size and maturity). For this exercise, find the evapotranspiration rate in your area for the current month from the Reference Evapotranspiration Zones Publication. Divide the monthly total ET₀ by the number of days in the month to get an estimate of your Daily ET₀.

Look at the graph “Crop Coefficient (K_c) based on crop stage” (below) to estimate the crop coefficient for your chosen crop. Using this for your K_c and the Daily ET_0 that you calculated above, perform the calculation below.

$$\frac{\text{Daily } ET_0 \text{ [Inches of Water/Day]}}{\text{Daily } ET \text{ [Inches of Water/Day]}} = \frac{K_c}{1}$$

Crop Coefficient (K_c) based on crop stage



Now, use the equation below to calculate how many days it will be before we need to irrigate again.

$$\frac{\text{Amount of Water We are Willing to Use Before Irrigating Again}}{\text{Actual Transpiration Rate (ET) per Day}} = \text{Number of Days Before Irrigating Again}$$

Now you know when you will need to irrigate again. Your last question asks how much water you will need to add at that time. The amount of water we will need to add will be equal the amount of water that was lost from the soil via ET, plus some extra amount to make up for any inefficiency or non-uniformity in the application of the water. Often, depending upon the irrigation system and how carefully it is managed, this extra amount is to 10% - 20% of the amount of water needed to replace the amount of water lost via ET.