Irrigation Principles and Practices

LEARNING OBJECTIVES

- Describe the role of irrigation water in agricultural systems
- Understand the movement and cycling of water in agricultural systems:
- Understand water quantity measurements: E.g., acre/feet, acre/inch, and gallons/minute (GPM)
- Understand relevant measurements of soil moisture: Soil saturation, gravitational water, field capacity, permanent wilting point
- Understand environmental factors that influence the type, frequency, and duration of irrigation

The Role of Irrigation Water in Agriculture Systems

- Sustains soil biological and chemical activity and mineralization during dry periods
  - In seasonally dry areas, irrigation water artificially extends the time period in which soil biological activity and nutrient release are elevated, creating more optimal growing conditions for cultivated crops.
- Promotes soil solution and nutrient uptake o Irrigation water becomes the medium into which soil nutrients are dissolved (soil solution) and through which nutrients are made available for plant uptake.
- Provides carbohydrate building block: $6CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$
  - Through the process of photosynthesis, water molecules taken up by plants are broken down and heir constituent atoms rearranged to form new molecules: Carbohydrates and oxygen.
- Provides plant structure/support
  - Water molecules contained within the water-conducting vascular bundles and other tissues of plants serve to provide physical support for the plant itself
- Promotes the maintenance of optimal temperatures within the plant

    - The loss of water through the process of evapotranspiration liberates heat from the plant, thereby regulating plant temperature

Water Cycling in Agricultural Systems

Definition of terms

- **Transpiration**: The loss of water through the stomata of plants as it changes from a liquid to a gas form
- **Capillary action**: The movement of water through very small pores in the soil from wetter areas to drier areas. Water may move vertically and horizontally.
- **Evaporation**: The loss of water from the soil as it changes from a liquid to a gas form and is no longer available to crop plants
- **Evapotranspiration (ET):** The combination of water being lost from a soil through the processes of evaporation and transpiration
- **Evapotranspiration rate (ETo):** The volume of water lost through evapo-transpiration in a given time period
- **Percolation**: The gravitational process of water moving downward and through the soil horizons

Units of Water Measurement

Definition of terms

- **Acre inch:** The equivalent volume of water application that would cover one acre of land one inch deep in water. Example: On average, approximately one inch of water is lost through evaporation and plant transpiration each week from May 15th-October 15 along the central coast of California.
- **Acre foot:** The equivalent volume of water application that would cover one acre of land one foot deep in water
- **Gallons per minute (GPM):** The number of gallons being delivered through an irrigation system in one minute

Soil Moisture, Plant Stress, and Crop Productivity

- Reduction of yield due to water stress - Crops repeatedly subjected to water stress will be less resistant and resilient to both pest and pathogens.
- Water-stress-sensitive stages of crop development (prioritized)
    - Flowering
    - Yield formation/fruit set

    - Early vegetative growth/seedling stage
    - Fruit ripening
- **Permanent wilting point** -Crop plants reaching permanent wilting point often die, do not grow well thereafter, or are non-productive

Determining When to Irrigate and How Much Water to Apply

Water budgeting approach:

- When seasonal ET > precipitation, irrigation is required
- Determining site specific ETo
    - The evapotranspiration rate for your farm may be determined by averaging the time period required for the evaporation of 1 inch of water from a given vessel
- Replacing ET with calibrated irrigation systems.
    - Once the ET rate of your site is determined, this known volume of water may be replaced through the use of calibrated irrigation systems that deliver water at a known rate and volume.
- Irrigation scheduling in different systems based on water budgeting approach.
    - Once the evapotranspiration rate (in gallons/week) and the water delivery rates (in gallons/ hour) of the irrigation system are known, the amount of time required to replace water lost may be calculated by dividing ET by the water delivery rate. This will provide the total number of hours required to replace the water lost through evapotranspiration. (An additional 10% should be calculated in to compensate for water loss inefficiencies.)
    - The frequency of irrigation should correspond to the time period required for the soil in the root zone of the crop to dry to approximately 50% of field capacity. Due to shallow root systems and greater susceptibility to water stress, annual crop culture often requires a higher frequency of irrigation (2-3 times/week for many crops). Established orchards, which have deep root systems and are less susceptible to water stress, often require less frequent but larger volumes of water to be delivered in each irrigation. In both situations the amount of water lost through ET is replaced. It is only the frequency of irrigation that is different.
- Disadvantages: Root restriction and drought susceptibility ◎ Advantages of water budgeting approach: Efficiency in time and water resources
- Measuring soil moisture by feel approach

Definition of terms

- **Soil saturation**: When all the pores of a given soil are filled with water
- **Gravitational water**: The water that will drain from a saturated soil if no additional water is added. This water is not available for plant growth.
- **100% of field capacity**: The point reached when no additional gravitational water drains from a previously saturated soil
- **50% of field capacity**: The amount of water remaining in the soil when 1/2 of the water held in the soil at field capacity has evaporated, drained, and/or has been transpired by growing plants. 50% of field capacity is the soil moisture level at which most crops should be irrigated.
- **Permanent wilting point:** The point at which soil moisture has been reduced to where the plant cannot absorb it fast enough to grow or stay alive
- **Plant available water:** The water content held in the soil between field capacity and permanent wilting point that is available for uptake by plants
- **Soil water potential:** The amount of energy required to remove water from the soil. This measurement increases as soils dry, which then increases the possibility of transpiration rates exceeding the rate of uptake, leading to plant stress.

Tools for determining soil moisture in root zone of crop

- Soil auger
- Tensiometers
- Gypsum blocks

Environmental Factors Influencing Frequency and Volume of Irrigation

Climate

- Air temperature: Increased air temperatures will increase the rate of ET
- Precipitation: In areas of regular summer rainfall, where precipitation exceeds ET, irrigation is seldom required. Irrigation demands are based on ET rates. Where ET exceeds precipitation, irrigation is required.
- Humidity: Increased humidity will decrease the rate of ET
- Wind: High wind speeds increase ET

Soils

- Sandy soils drain rapidly and do not hold water well
- Silty soils drain slowly and hold water well
- Clay soils drain very slowly and hold water tightly

- Loam soils both drain well and hold water well
- Well-improved agricultural soils maintain good drainage and moisture retention properties

Stage of development and crop natural history

- "Water-loving" crops (e.g., celery) demand less fluctuation in soil moisture levels Drought-tolerant crops (e.g., tomato varieties, winter squash varieties, Amaranth, etc.) may require little or no irrigation
- Maturation period: Prior to harvest, many crops (e.g., onions and garlic) require reduced irrigation inputs to encourage maturation.

Environmental Factors Influencing the Type of Irrigation Used

◎ Climate and incidence of plant pathogens Overhead irrigation may encourage he growth and spread of certain plant pathogens on crops in certain climates.

Irrigation Delivery Systems

- Sprinklers
- Micro-sprinklers
- Hand-moved aluminum pipe with impact heads
- Drip irrigation
- In-line emitters
- T-tape
- Header design
- Management
- Filtration
- Pressure regulation
- Flushing
- Fertigation

Hands-On Exercises 1- 3 (Sample Calculations): Replacing Water Lost through

Evapotranspiration (ET) Using the Water Budgeting Approach

EXERCISE 1

The following sample calculation will show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the amount of water lost through evapotranspiration from a 1-acre block of vegetables using drip irrigation.

A. NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET) IN A 1-ACRE FIELD

• Daily average summer evapotranspiration rate (ETo) for an actively growing crop in full canopy in Wailae = 0.15 inch/day

• Multiply this by 7 days/week = 1.05 inches/week

• There are 27,158 gallons of water in an acre inch (the volume of water needed to cover an acre of land to a 1-inch depth)

• An acre = 43,560 square feet (roughly 208 feet x 208 feet)

• Multiplying 1.05 inches/week (ETo) x 27,158 gallons/acre inch = 28,516 gallons/acre of water lost each week through evapotranspiration in an actively growing crop in full canopy in Wailae .

B. DRIP IRRIGATION OUTPUT CALCULATIONS

• Flow rate of high flow T-tape drip irrigation ribbon with 8-inch emitter spacing at 10 pounds per square inch (psi) = .74 gallons/ minute/100 feet

• There are 14,520 feet of row per acre when beds are spaced 36 inches center-to-center

• To determine gallons/hour/acre emitted from one acre of drip irrigation ribbon, divide

14,520 (the number of row feet/acre) by 100 = 145 (the number of 100-foot lengths of drip irrigation ribbon in 1 acre). Multiply 145 by .74 gallons/minute/100 feet (the amount of water delivered through each 100 feet of ribbon) = 107.4 gallons/minute/acre.

• 107.4 gallons/minute x 60 minutes = 6,446 gallons/hour/acre. Two lines of drip tape would provide twice this volume, or 12,892 gallons/ hour/acre.

C. CALCULATING IRRIGATION REQUIREMENTS

• 28,516 gallons/acre are lost through evapotranspiration each week from an actively growing crop in full canopy. The drip system described above is capable of delivering 6,450 gallons/hour/acre @ 10 psi. To calculate the amount of irrigation time required to replace the amount of water lost through Et complete the following:

• Divide 28,516 gallons/acre (ETo) by 6,450 gal/hour/acre (irrigation system application rate) = 4.4 hours of irrigation time required each week. Running the one acre of single line drip irrigation with 8 inch emitter spacing for 4.4 hours each week will apply 28,516 gallons/acre (~1.05 inches/acre), which is the amount of water needed to replace what is lost through ET. This total of 4.4 hours/week should be divided into 2-3 evenly timed irrigation sets.

EXERCISE 2

The following sample calculation will show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the amount of water lost through evapotranspiration from a 1-acre block of vegetables using sprinkler irrigation.

A. NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET) IN A 1-ACRE FIELD

• Daily average summer evapotranspiration rate (ETo) for an actively growing crop in full canopy in Wailae = .15 inch/day

• Multiply this by 7 days/week = ~1.05 inches/week

• There are 27,158 gallons of water in an acre inch (an acre inch is the amount of water needed to cover an acre to a 1-inch depth)

• An acre = 43,560 square feet (roughly 208 feet x 208 feet)

• Multiplying 1.05 inches/week (ETo) x 27,158 gallons/acre inch = 28,516 gallons/acre of water lost each week through evapotranspiration in an actively growing crop in full canopy in Wailae.

B. SPRINKLER IRRIGATION OUTPUT CALCULATIONS

• Flow rate from a 1/8 inch nozzle running at an operating pressure of 45 psi is about 3 gallons per minute (gpm)

• There are roughly 109 sprinkler heads per acre using 20-foot pipes set 20 feet apart (20 feet x 20 feet = 400 square feet. 43,560 square feet/acre divided by 400 = 109)

• 109 sprinkler heads x 3 gpm each = 330 gallons per minute

• 330 gal/min x 60 minutes/hour = 19,800 gallons/hour/acre

C. CALCULATING IRRIGATION REQUIREMENTS:

• 28,516 gallons/acre are lost through evapotranspiration each week from an actively growing crop in full canopy. The sprinkler system is capable of delivering 19,800 gallons/ hour/acre @ 45psi. To calculate the amount of irrigation time required to replace the amount of water lost through Et complete the following:

• Divide 28,516 gallons/acre (ETo) by 19,800 gallons/hour/acre (irrigation system application rate) = 1.4 hours of irrigation time required each week.

• Running the one acre sprinkler system for 1.4 hours each week will apply 28,516 gallons/acre (~1.05 inches/acre), which is the amount of water needed to replace that lost through ET. This total of 1.4 hours/week should be divided in to 2-3 evenly timed irrigation sets/ week of 40 or 30 minutes respectively.

*Note: It is also important to factor in an additional 10-20% for evaporative loss due to extreme heat and wind conditions. It is further advisable to use several rain gauges to check the actual amount applied and to assess uniformity of applications.

D. CALCULATING AN ADDITIONAL 10-20% WOULD PROCEED AS FOLLOWS:

• 28,516 + 10% (.10 x 28,516) = 31,368 gallons/ acre; 28,516 + 20% (.20 x 28,516) = 34,239 gallons/acre. Dividing each of the above by the irrigation system output results in the following: 31,368 gallons/acre divided by 19,800 gallons/hour/acre = 1.6 hours of irrigation time each week. 34,239 gallons/acre divided by 19,800 gal/hour/acre = 1.7 hours of irrigation time each week. These totals of 1.6 and 1.7 hours/week should also be divided into 2-3 irrigation sets each week for annual vegetables.

EXERCISE 3

The following sample calculation will show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the amount of water lost through evapotranspiration from a 100-square-foot garden bed.

A. CALCULATING THE NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ET) IN A 100-SQUARE-FOOT GARDEN BED

• Daily average summer evapotranspiration rate (ETo) in Santa Cruz = 0.15 inch/day

• Multiply this by 7 days/week = 1.05 inches/week

• 25-foot x 4-foot garden bed = 100 square feet

• 100 square feet x 144 (square inches/foot) = 14,400 square inches

• 100 square feet to 1 inch in depth = 14,400 cubic inches • 1,728 cubic inches/ cubic ft.

• 1 cubic foot = 7.48 gallons

• 14,400 cubic inches (100-square-foot garden bed) divided by 1,728 cubic inches = 8.33 cubic feet

• 8.33 cubic feet x 7.48 gallons/cubic foot = 62.31 gallons/week lost through Et

B. DRIP IRRIGATION OUTPUT CALCULATIONS

• Flow rate of high flow T-tape irrigation ribbon with 8-inch emitter spacing @ 10 psi = .74 gallons/minute/100 feet (assuming 100% efficiency)

• There are 133 emitters/100 ft. @ 8-inch spacing

• .74 divided by 133 = 0.00556 gallons/minute/emitter

• .00556 X 60 (inches/hour) = .334 gallons/hour/emitter

• A 25-foot row of T-tape = 300 inches

• 300 inches divided by 8-inches emitter spacing = 37.5 emitters/row

• 37.5 emitters/row x 4 rows t-tape/bed = 150 emitters/ bed

• 150 x .334 gallons/hour/emitter = 50.1 gallons/hour

C. CALCULATING IRRIGATION REQUIREMENTS

• 62.31 gallons of water are lost from a single 100-square-foot garden bed through evapotranspiration each week. Four lines of high flow T-tape deliver 50.1 gallons/hour @ 10 psi. To calculate the amount of irrigation time required to replace the amount of water lost through ET, complete the following:

• 62. 31 gallons/week (ET) divided by 50.1 gallons/hour (output) = 1.25 hours (or 75 minutes) of irrigation time @ 10 psi. This application of water should be divided between two to three equally long irrigation sets each week, 40 or 25 minutes in length respectively.

• 20% more time should be added to compensate for evaporative losses, leakage, etc. These respective times should be increased to two 45-minute sets or three 30- minute sets/week.

Hands-On Exercise 4: Calculating a Water Budget for a One-Acre Block of Vegetables (using sprinkler irrigation)

In the following exercise you will calculate the amount of irrigation time and frequency of irrigations required to replace the amount of water lost through evapotranspiration in your area from a one-acre block of vegetables using sprinkler irrigation.

A. NUMBER OF GALLONS LOST THROUGH EVAPOTRANSPIRATION (ETo) IN A ONE-ACRE FIELD:

• Step 1: Daily average summer evapotranspiration rate (ETo) for an actively growing crop in full canopy in your area = _______ inches/day

• Step 2: Multiply this by 7 days/week = _______ inches/week

Given: There are 27,158 gallons of water in an acre inch (the amount of water needed to cover an acre to a 1-inch depth)

Given: An acre = 43,560 square feet (roughly 208 feet x 208 feet)

• Step 3: Multiplying _______ inches/week (ETo) x _______ 27,158 gallons/acre inch = _______ gallons/acre of water lost each week through evapotranspiration in an actively growing crop in full canopy in your area.

B. SPRINKLER IRRIGATION OUTPUT CALCULATIONS

• Step 4: Flow rate in gallons per minute (gpm) from an individual sprinkler head

• Step 5: Given: There are roughly 109 sprinkler heads per acre using 20 foot pipes set

20 feet apart. (20 feet x 20 feet = 400 square feet. 43,560 square feet/acre divided by

400 = 109)

• Step 6: 109 sprinkler heads x _______ gallons/ _______ minute each = _______ gallons per minute

• Step 7: _______ gallons/minute x 60 minutes/ _______ hour = ______ gallons/hour/acre total

C. CALCULATING IRRIGATION REQUIREMENTS

• To calculate the amount of irrigation time required (in hours/week) to replace the amount of water lost through evapotranspiration each week, complete the following calculations:

• Divide the total in Step 3 _______ gallons/acre ET by the total in Step 7 _______ gallons/hour/acre from the irrigation system = _______ hours of irrigation time required each week. This total time should be divided in to 2-3 irrigation sets for mixed vegetable operations.

* Note: It is also important to factor in an additional 10-20% for evaporative losses due to extreme heat and wind conditions. It is further advisable to use several rain gauges to check the actual amount applied and to assess uniformity of application.

Hands-On Exercises 5 and 6 (Sample Calculations): How Much Water Do I Need? How Many Acres Can I Irrigate?

In the following exercises you will calculate the total rate and volume of irrigation water that must be delivered to support two hypothetical farming operations. This information will help you determine the irrigation system needed to support the delivery of this volume of water.

EXERCISE 5: HOW MUCH WATER DO I NEED?

I have 10 acres that I want to farm. The climate is Mediterranean with a fairly dry summer season. There is no well or pump on the property. The property is situated over an aquifer that has an adequate water supply. I have adequate capital to invest in a well and pump to supply irrigation water for my farm. I need to decide how much water I need (flow rate in gallons per minute) to irrigate the entire 10 acres, so that I can have the proper-sized well and pump installed.

GIVEN

• At any time during the summer the entire 10 acres may be in production

• The daily average evapotranspiration rate (ETo) during the summer months is about

0.30 inch per day

- There are 27,158 gallons of water in an acre inch
- You only plan to run the pump 12 hours per day
- There are 10,080 minutes per week (60 minutes/hour x 24 hours/day x 7 days/week)
- There are 5,040 minutes per week at 12 hours per day (10,080 divided by 2)

SOLUTION

1. Multiply 0.30 inches (ETo) by 7 (days per week) to get 2.1 inches per week

2. Assume that your application will be 75% efficient and multiply 2.1 (inches per week) by 1.25 to get 2.625 inches per week (application rate to supply actively growing crops with adequate moisture for maximum yield during summer months)

3. Multiply 2.625 inches per week by 27,158 (gallons per acre inch) to get 71,290 gallons per acre per week

4. Multiply 71,290 (gallons per week) by 10 (acres) to get 712,900 gallons per week

5. Divide 712,900 (gallons per week) by 5,040 (minutes per week at 12 hours per day) to get 141.44 gallons per minute

Your pump and well will have to deliver 141.44 gallons of water per minute to keep your

10-acre farm productive during the summer months. If you were willing to irrigate 24 hours per day you would only need an output of 70 GPM (gallons per minute).

EXERCISE 6: HOW MANY ACRES CAN I IRRIGATE?

Someone has just offered you 10 acres of farmland in Punaluu. There is a pump and well on the property capable of delivering 15 GPM. There are no other sources of water in the area. Your daily average Eto in the summer is 0.20 inch. How many acres of irrigated vegetables can you plant during the summer months without running short of water?

GIVEN

- The daily average ETo during the summer months is about 0.20 inch per day
- There are 27,158 gallons of water in an acre inch
- The pump flow rate is 15 gallons per minute
- You are only able to run the irrigation 12 hours per day during peak use

SOLUTION

1. Multiply 15 gallons per minute (GPM) by 60 (min per hr) to get 900 gallons per hour

2. Multiply 900 gallons per hour by 84 (hours per week @ 12 hours per day) to get

75,600 gallons per week maximum pump output

3. If your average ETo during the summer months is .20 inches per day for an actively growing crop in full canopy, then multiply .20 (daily ETo) by 7 (days per week) to get inches per week

4. Multiply 1.4 (inches per week ETo) by 27,158 (gallons per acre inch) to get 38,021 gallons per acre per week to keep your full canopy crops supplied with adequate water during the summer months

5. Assuming your application efficiency is 75%, multiply 38,021 by 1.25 to get 47,526 gallons per week

6. Divide 75,600 (maximum pump output per week) by 47,526 (weekly crop need per acre) to get 1.6 acres

Your 15 GPM well is capable of irrigating 1.6 acres of actively growing crop in full canopy during the summer months assuming 75% application efficiency and with application happening 12 hours per day. If you are willing to irrigate 24 hours per day then you can irrigate 3.2 acres.

If you increase your efficiency by only using overhead during the night, and utilize drip tape, you could increase your crop area slightly. If you plant crops with a low moisture requirement and if your soil and climate are conducive to dry farming (deep clay soil, mild summer temperatures, and at least 30 inches of precipitation annually during the winter) you might be able to farm the entire 10 acres.

Cite:

(CASFS. UC Santa Cruz, 1156 High St., Santa Cruz, CA 95064. Phone: 831-459-3240 Email: casfs@ucsc.edu) for providing this information.

Georgia Organics

Georgia Organics, 200-A Ottley Drive, Atlanta, GA 30324

http://georgiaorganics.org/for-farmers/fundamentals-of-organic-farming-and-gardening-an-instructors-

guide-revised-for-2009/table-of-contents/

CTAHR

College of Tropical Agriculture and Human Resources

http://www.ctahr.hawaii.edu/site/default.aspx

Resources:

Water Conservation

https://afsic.nal.usda.gov/soil-and-water-management/water-conservation

Irrigation Scheduling

http://wwwcimis.water.ca.gov/cimis/infoIrrSchedule.jsp