1.5 Irrigation—Principles and Practices

Introduction: Irrigation

UNIT OVERVIEW

Effective irrigation practices can improve yields and quality, minimize water use, and protect natural resources. This unit introduces students to the basic concepts, tools, and skills used to deliver water efficiently and effectively on both a field and garden scale. Students will learn about the role of irrigation water in agriculture, the movement and cycling of water in agricultural systems, and the environmental factors that influence the type, frequency, and duration of irrigation. A lecture and demonstrations introduce the resources and essential skills needed to determine the proper timing and volume of irrigation, using both qualitative and quantitative methods. Through exercises and problem solving, students will practice calculating water budgets used to develop irrigation schedules and determine total water volume needs per unit of time. The latter calculations will help the student define needed irrigation delivery systems.

MODES OF INSTRUCTION

> LECTURE (1 LECTURE, 2 HOURS)

The class lecture outline introduces to the basic concepts and terms used in irrigation as well as two of the commonly used approaches to garden- and field-scale irrigation. Note: The instructor may want to present this lecture in two parts.

> DEMONSTRATION 1: FIELD-SCALE IRRIGATION (2 HOURS)

This field-scale demonstration illustrates how to gauge soil moisture by feel and how to establish, use, and maintain field-scale irrigation equipment.

> DEMONSTRATION 2: GARDEN-SCALE IRRIGATION (2 HOURS)

This garden-scale demonstration illustrates how to gauge soil moisture by feel and how to establish, use, and maintain garden-scale irrigation equipment.

> EXERCISES 1–3: FIELD- AND GARDEN-SCALE IRRIGATION SAMPLE CALCULATIONS (0.5 HOUR EACH)

Given evapotranspiration information and output data for drip and sprinkler irrigation systems, students will review how to calculate the needed frequency and duration of irrigation for a 1-acre field and a 100-square-foot garden bed.

> EXERCISE 4: CALCULATING A WATER BUDGET FOR A ONE-ACRE BLOCK OF VEGETABLES (0.5 HOUR)

Students will use their region's evapotranspiration information to calculate the needed frequency and duration of irrigation for a 1-acre field.

> EXERCISES 5–6: HOW MUCH WATER DO I NEED? HOW MANY ACRES CAN I IRRIGATE? SAMPLE CALCULATIONS (0.5 HOUR EACH)

Students will practice calculating total water volume needs per unit of time to determine the need for irrigation infrastructure.

> ASSESSMENT QUESTIONS (0.5 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

CONCEPTS

- The role of irrigation water in agricultural systems
- The movement and cycling of water in agricultural systems: E.g., transpiration, capillary action, evaporation, evapo-transpiration, evapotranspiration rate, percolation
- Water quantity measurements: E.g., acre/feet, acre/inch, and gallons/minute (GPM)
- Relevant measurements of soil moisture: Soil saturation, gravitational water, field capacity, permanent wilting point
- Environmental factors that influence the type, frequency, and duration of irrigation

SKILLS

- How to determine the timing and volume of irrigation using qualitative approaches: Gauging relative measures of field capacity using the feel method
- How to determine the timing and volume of irrigation using quantitative approaches: Water budgeting calculations using evapotranspiration rates and calibrated water delivery systems
- How to calculate total water volume needs per unit of time to determine the need for irrigation infrastructure
- How to access Web-based irrigation information

Lecture Outline: Irrigation

for the instructor

A. Pre-Assessment Questions

1. How do you determine when it is time to irrigate, and how frequently?
2. How do you determine how much water to apply?
3. What are some of the environmental factors that may influence the frequency or duration of irrigation?
4. What are some of the environmental factors that may influence the type of irrigation used?

B. The Role of Irrigation Water in Agricultural Systems

1. Sustains soil biological and chemical activity, extending mineralization and plant growth during dry periods
2. Creates soil solution for nutrient uptake and transfer
3. Provides necessary building blocks for the formation of carbohydrates
4. Provides physical support/structure for plant
5. Maintains optimal temperatures within the plant
6. Protects crops, e.g., during threats of freezing temperatures

C. Water Cycling in Agricultural Systems

1. Definition of terms
   a) Transpiration
   b) Capillary action
   c) Evaporation
   d) Evapotranspiration (ET)
   e) Evapotranspiration rate (ETo)
   f) Infiltration
   g) Percolation

D. Units of Water Measurement

1. Definition of terms
   a) Acre inch
   b) Acre foot
   c) Gallons per minute (GPM)

E. Soil Moisture, Plant Stress, and Crop Productivity

1. Reduction of yield due to water stress
   a) Water-stress-sensitive stages of crop development (prioritized)
      - Flowering
      - Yield formation/fruit set
      - Early vegetative growth/seedling stage
      - Fruit ripening
2. Water stress and an increased susceptibility to pests and pathogens
3. Permanent wilting point and crop loss

F. Determining When to Irrigate and How Much Water to Apply

1. Water budgeting (quantitative) approach
   a) When evapotranspiration exceeds precipitation, irrigation is required
   b) Resources for determining regional average evapotranspiration rates: California Irrigation Management Information Systems (CIMIS) data (see Resources section)
   c) Techniques for determining site-specific evapotranspiration
      i. Evaporation pans
   d) Calculations used to determine quantities of water delivered through calibrated irrigation systems (see Hands-on Exercises 1–3)
   e) Irrigation scheduling in different systems based on water budgeting approach
      i. Annual crops
      ii. Perennial crops
      iii. Orchard systems
      iv. Disadvantages of water budgeting approach
      v. Advantages of water budgeting approach
2. Monitoring soil moisture by feel: a qualitative approach (see appendix 1)
   a) Definition of terms
      i. Soil saturation
      ii. Gravitational water
      iii. 100% of field capacity
      iv. 50% of field capacity as critical soil moisture level
      v. 25% of field capacity
      vi. Permanent wilting point
      vii. Soil water potential
   b) Exceptions to and variations on the above general rule (see appendix 2)
      i. Vegetables
      ii. Perennials
      iii. Orchards
   c) Tools for determining soil moisture
      i. Soil auger
3. Automated tools for determining soil moisture in root zone of crop
   a) Tensiometers
   b) Gypsum blocks
   c) Advantages and disadvantages of method

G. Environmental Factors Influencing Frequency and Volume of Irrigation

1. Climate
   a) Air temperature
   b) Precipitation
   c) Humidity
   d) Wind
2. Soils
   a) Sandy soils
   b) Silty soils
   c) Clay soils
   d) Loam soils
   e) Well-improved agricultural soils

3. Stage of development and crop natural history
   a) "Water-loving" crops (e.g., celery)
   b) Drought tolerant crops (e.g., tomato varieties, winter squash varieties, Amaranth, etc.)
   c) Maturation period (e.g., onions and garlic)

H. Environmental Factors Influencing the Type of Irrigation Used

1. Climate and incidence of disease
   a. Drip-irrigated crops
   b. Overhead-irrigated crops

I. Irrigation Delivery Systems

1. Sprinklers
   a) Micro-sprinklers
      i. Cost
      ii. Efficiency
      iii. Application uniformity
      iv. Design considerations and infrastructure requirements
   b) Hand-moved aluminum pipe with impact heads
      i. Cost
      ii. Efficiency
      iii. Application uniformity
      iv. Design considerations and infrastructure requirements
2. Drip irrigation
   a) In-line emitters
   b) T-tape
   c) Header design
   d) Management
      i. Filtration
      ii. Pressure regulation
      iii. Flushing
      iv. Fertigation

Detailed Lecture Outline: Irrigation

for the student

A. Pre-Assessment Questions:

1. How do you determine when it is time to irrigate?
2. How do you determine how much water to apply?
3. What are some of the environmental factors that may influence the frequency or duration of irrigation?
4. What are some of the environmental factors that may influence the type of irrigation used?

B. The Role of Irrigation Water in Agriculture Systems

1. 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
2. Promotes soil solution and nutrient uptake

   Irrigation water becomes the medium into which soil nutrients are dissolved (soil solution) and through which nutrients are made available for plant uptake
3. 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 their constituent atoms rearranged to form new molecules: Carbohydrates and oxygen
4. 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
5. 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
6. Crop protection

   Irrigation water is commonly used to lower the freezing temperature in orchard systems during threats of damaging frost

C. Water Cycling in Agricultural Systems

1. Definition of terms
   a) Transpiration: The loss of water through the stomata of plants as it changes from a liquid to a gas form
   b) 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.
   c) Evaporation: The loss of water from the soil to the atmosphere as it changes from a liquid to a gas form and is no longer available to crop plants
   d) Evapotranspiration (ET): The combination of water being lost from a soil through the combined processes of evaporation and transpiration
   e) Evapotranspiration rate (ETo): The volume of water lost through evapo-transpiration in a given time period
   f) Percolation: The gravitational process of water moving downward and through the soil horizons

D. Units of Water Measurement

1. Definition of terms
   a) 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.
   b) Acre foot: The equivalent volume of water application that would cover one acre of land one foot deep in water
   c) Gallons per minute (GPM): The number of gallons being delivered through an irrigation system in one minute

E. Soil Moisture, Plant Stress, and Crop Productivity

1. Reduction of yield due to water stress
   a) Water-stress-sensitive stages of crop development (prioritized)
      i. Flowering
      ii. Yield formation/fruit set
      iii. Early vegetative growth/seedling stage
      iv. Fruit ripening
2. Increased susceptibility to pests and pathogens with water stress

   Crops repeatedly subjected to water stress will be less resistant and resilient to both pest and pathogens
3. Permanent wilting point

   Crop plants reaching permanent wilting point often die, do not grow well thereafter, or are non-productive

F. Determining When to Irrigate and How Much Water to Apply

1. Water budgeting approach
   a) When seasonal ET > precipitation, irrigation is required
   b) Resources for determining regional average ET (e.g., CIMIS; see Resources section)
   c) Determining site specific ETo

      The evapotranspiration rate for your garden or farm may be determined by averaging the time period required for the evaporation of 1 inch of water from a given vessel
   d) Replacing ET with calibrated irrigation systems (see Hands-on Exercises)

      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
   e) Irrigation scheduling in different systems based on water budgeting approach (see Hands-on Exercises)

      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.
      i. Annual crops

ii. Perennial crops
iii. Orchard systems
f) Disadvantages: Root restriction and drought susceptibility
g) Advantages of water budgeting approach: Efficiency in time and water resources

2. Measuring soil moisture by feel approach (see appendix 1)
   a) Definition of terms
      i. Soil saturation: When all the pores of a given soil are filled with water
      ii. 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.
      iii. 100% of field capacity: The point reached when no additional gravitational water drains from a previously saturated soil
      iv. 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 in the root zone of the crop is the soil moisture level at which most crops should be irrigated.
      v. 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
      vi. Plant available water: The water content held in the soil between field capacity and permanent wilting point that is available for uptake by plants
      vii. 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.
   b) Exceptions to the above general rule (see appendix 2)
      i. Vegetable crops
      ii. Perennial crops
      iii. Orchard systems
   c) Hand tools for determining soil moisture in root zone of crop
      i. Soil auger
   d) Advantages and disadvantages of measuring soil moisture by feel approach: Additional labor time and inefficiencies of water use
3. Automated tools for determining soil moisture in root zone of crop
   a) Tensiometers
   b) Gypsum blocks

G. Environmental Factors Influencing Frequency and Volume of Irrigation

1. Climate
   a) Air temperature: Increased air temperatures will increase the rate of ET
   b) 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.
   c) Humidity: Increased humidity will decrease the rate of ET
   d) Wind: High wind speeds increase ETo
2. Soils
   a) Sandy soils drain rapidly and do not hold water well
   b) Silty soils drain slowly and hold water well
   c) Clay soils drain very slowly and hold water tightly
   d) Loam soils both drain well and hold water well
   e) Well-improved agricultural soils maintain good drainage and moisture retention properties

3. Stage of development and crop natural history
   a) "Water-loving" crops (e.g., celery) demand less fluctuation in soil moisture levels
   b) Drought-tolerant crops (e.g., tomato varieties, winter squash varieties, Amaranth, etc.) may require little or no irrigation
   c) Maturation period: Prior to harvest, many crops (e.g., onions and garlic) require a gradual reduction in irrigation to encourage maturation.

H. Environmental Factors Influencing the Type of Irrigation Used

1. Climate and incidence of plant pathogens

   Overhead irrigation may encourage the growth and spread of certain plant pathogens on crops in certain climates (e.g., *Phytopthora* spp. on melons, cucumber, onions, peppers, and tomatoes along coastal California).

I. Irrigation Delivery Systems

1. Sprinklers
   a) Micro-sprinklers
      i. Cost
      ii. Efficiency
      iii. Application uniformity
      iv. Design considerations and infrastructure requirements
   b) Hand-moved aluminum pipe with impact heads
      i. Cost
      ii. Efficiency
      iii. Application uniformity
      iv. Design considerations and infrastructure requirements
2. Drip irrigation
   a) In-line emitters
   b) T-tape
   c) Header design
   d) Management
      i. Filtration
      ii. Pressure regulation
      iii. Flushing
      iv. Fertigation

Demonstration 1: Field-Scale Irrigation

for the instructor

OVERVIEW

This demonstration offers students an in-field look at the tools and techniques used to deliver irrigation water efficiently from the mainline irrigation infrastructure through the specific irrigation delivery system used on your farm. The instructor should begin with an explanation of the irrigation infrastructure used to deliver water to and through the farm, then explain how to set up, adjust, and maintain the specific irrigation system(s) currently in use.

PREPARATION AND MATERIALS

- Map of farm irrigation system

Irrigation equipment:

- Established set of aluminum pipe with sprinklers
- Component pieces of sprinklers
- Established set of drip irrigation
- Component pieces of drip irrigation equipment
- Tools for setting up and adjusting irrigation equipment
- Irrigation schedules (see appendix 3)

PREPARATION TIME

1.5 hours

DEMONSTRATION TIME

2 hours

DEMONSTRATION OUTLINE

A. Irrigation Infrastructure

1. Explain the layout and identify major components of the farm irrigation water delivery system from source to crop

B. Measuring Flow Rate

1. Demonstrate how to determine flow rate using a garden hose and a 5-gallon bucket

C. Sprinkler Irrigation Systems

1. Demonstrate a typical field layout and a typical orchard layout of a hand-moved aluminum sprinkler system. Include the following demonstrations:
   a) The proper technique for moving and laying out sprinkler pipes
   b) Flushing the system clean
   c) Sprinkler head adjustment
   d) Layout design and pipe hook-up
2. Demonstrate and explain the importance of proper head adjustment and timing as it relates to application uniformity
3. Demonstrate and explain how to determine optimum operating pressure
4. Students are given the opportunity to unhook, move, and hook up a sprinkler set. The sprinkler set is then turned on and adjusted.

D. Drip Irrigation Systems

1. Demonstrate and explain several examples of drip irrigation header set-ups
2. Demonstrate and explain how to turn on a drip system and set pressure and check for leaks
3. Demonstrate the following:
   a) How a gate-valve and ball-valve work
   b) How to set up a drip irrigation header
      i. How to properly punch holes in the 2" oval tube
      ii. How to install the barbed connectors into the oval tube
      iii. How to connect the T-tape to the various types of connectors
      iv. How to splice T-tape for repairs
      v. How to cap ends of T-tape
      vi. How to determine proper system pressure
      vii. How to properly roll out and roll up T-tape for placement and storage

4) Have students cut and splice T-tape

E. Review and Discuss Irrigation Scheduling

1. Review the calculations in Hands-on Exercises 1–3 to determine the volume of water and the frequency of irrigation necessary to replace the water lost through regional evapotranspiration
2. Assign Exercise 4: Calculating irrigation requirements using regional evapotranspiration data
3. Describe and demonstrate the use of an irrigation schedule for tracking and planning irrigation (see appendix 3)

F. Review and Discuss Exercises 5 and 6

1. Exercise 5: How much water is needed to irrigate a given area of land?
2. Exercise 6: How much area can one irrigate with a given flow rate?

Demonstration 2: Garden-Scale Irrigation

for the instructor

OVERVIEW

Students must be able to accurately gauge soil moisture and use scale-appropriate irrigation tools and techniques in order to irrigate garden crops efficiently and effectively. The following demonstration provides an overview of the basic skills, concepts, and tools used in garden-scale irrigation. During this demonstration, the instructor should discuss the different approaches to irrigation (qualitative and quantitative) as well as demonstrate the tools and techniques used to monitor soil moisture and schedule irrigation.

PREPARATION AND MATERIALS

- Oscillators
- Fan
- Drip irrigation system
- Rose
- Micro-sprinklers
- Rain gauge
- Ross
- Soil moisture chart (see appendix 1)
- Blank irrigation schedule (see appendix 4)
- Soil samples or pre-irrigated soils at varying percentages of field capacity

PREPARATION TIME

1.5 hours

DEMONSTRATION TIME

2 hours

DEMONSTRATION OUTLINE

A. Irrigation Management by Percent Field Capacity

1. Review terms
   a) Soil saturation
   b) Gravitational water
   c) 100% of field capacity
   d) 50% of field capacity
      i. Review 50% of field capacity as critical moisture level for most cultivated annual crops
   e) 25% of field capacity
   f) Permanent wilting point
2. Review exceptions to the to the 50% field capacity general rule (see appendix 2)
3. Review the stages of crop development at which plants are most sensitive to drought/water stress
   a) Flowering
   b) Yield formation/fruit set
   c) Early vegetative growth/seedling stage
   d) Fruit ripening
4. Have students gauge soil moisture (in percent field capacity) by feel and appearance using appendix 1, Estimating Soil Moisture by Feel
5. Review how to develop an irrigation schedule based on an estimated frequency of dry down to 50% of field capacity (see appendices 3 and 4)
6. Discuss and demonstrate how to properly maintain seedbed soil moisture for small- and large-seeded direct-sown crops
7. Discuss and demonstrate how to assemble, use, and repair garden-scale irrigation equipment (t-tape, oscillators, micro sprinklers, etc.) in delivering water effectively and efficiently
8. Discuss and demonstrate how to assemble and repair the PVC portions of a garden-scale irrigation system

B. Irrigation Management Using the Water Budgeting Approach

1. Determining ETo
   a) The use of California Irrigation Management Information Systems (CIMIS) data to determine average weekly ETo (see Resources section)
   b) The use of evaporation pans to determine site-specific averages for weekly ETo
2. Review and discuss the calculations used in developing a weekly irrigation schedule to replace water lost through ETo for drip-irrigated crops. Assign and review the Garden Irrigation Exercise (see next section).
3. Discuss and demonstrate the use of rain gauges in monitoring the volumes of water delivered to replace water losses through ETo in overhead-irrigated crops

Hands-On Exercises 1– 3 (Sample Calculations): Replacing Water Lost through Evapotranspiration (ET) Using the Water Budgeting Approach

for the student

EXERCISE 1

The following sample calculation willl show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the 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 Santa Cruz = 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 Santa Cruz, California

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 willl show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the 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 Santa Cruz = .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 Santa Cruz, California.

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.

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 willl show you how to calculate the amount of irrigation time and frequency of irrigations required to replace the 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)

for the student

In the following exercise you will calculate the amount of irrigation time and frequency of irrigations required to replace the 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 evapo-transpiration 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?

for the student

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 the Pajaro Valley on the central coast of California. 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 1.4 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.

Assessment Questions

1) Describe four functions of water in an agricultural system.

2) What is soil saturation?

3) What is field capacity?

4) What is the level of soil moisture at which most crop plants require additional water?

5) Describe two ways that agriculturists determine the need for irrigation.

6) Number the following stages of crop development in terms of their sensitivity to drought/water stress (1 being most sensitive and 4 being least sensitive):

   _____ Flowering
   _____ Yield formation/fruit set
   _____ Early vegetative growth
   _____ Fruit ripening

Assessment Questions Key

1) Describe four functions of water in an agroecosystem.
   - *plant support/turgidity*
   - *nutrient transport (soil solution)*
   - *plant cooling through transpiration*
   - *plant nutrient (photosynthesis)*
   - *soil moisture for soil organisms*

2) What is soil saturation?

   When water is filling all the available pore spaces in a given soil

3) What is field capacity?

   A soil is at field capacity when the free water/ gravitational water drains from a saturated soil

4) What is the level of soil moisture at which most crop plants require additional water?

   50% of field capacity

5) Describe two ways that agriculturists determine the need for irrigation.
   - *Qualitative: Measuring for relative percentages of field capacity in the root zone of the crop*
   - *Quantitative: Determining the evapotransporation rate of a given site and systematically replacing the amount of water lost each week through calibrated water delivery systems*

6) Number the following stages of crop developmental in terms of their sensitivity to drought/water stress (1 being most sensitive and 4 being least sensitive):

   1. Flowering

   2. Yield formation/fruit set

   3. Early vegetative growth

   4. Fruit ripening

Resources

PRINT RESOURCES

Cleveland, David A. and Daniela Soleri. *1991. Food from Dryland Gardens: An Ecological and Social Approach to Small-Scale Household Food Production*. Tucson, AZ: Center for People, Food and the Environment.

An overview of small-scale and community-based food production techniques intended for use by development educators and rural organizers in less developed nations. Encourages the development of gardens that serve local needs, that are based on local knowledge, and that conserve natural resources and the biodiversity of traditional crops. Includes an excellent section on the principles and practices of low-technology garden-scale irrigation.

Hansen, Blaine, Larry Schwankl, and Allan Fulton. *1999. Scheduling Irrigations: When and How Much Water to Apply*. Publication 3396. UC Irrigation Program, UC Davis. Oakland, CA: University of California Division of Agriculture and Natural Resources.

A technical reference for irrigation tools and techniques used in production agriculture. Includes many common calculations used to determine when to irrigate and how much water to apply.

Hansen, Blaine, Larry Schwankl, and Terry Prichard. 1999. *Micro-irrigation of Trees and Vines*. Publication 94-01. UC Irrigation Program, UC Davis. Oakland, CA: Division of Agriculture and Natural Resources.

Offers an overview of the rationale for micro-irrigation and how to assemble, operate, and maintain such a system.

WEB RESOURCES

California Irrigation Management Information Systems

www.cimis.water.ca.gov

California weather information site designed to help growers, turf managers, and others properly time irrigation applications.

California Agriculture Teachers Association (CATA) Sustainable Agriculture Curriculum and PowerPoint Resources

www.ccagcans.com/cansdefault.html
(see "Course Curriculum")

The CATA Sustainable Agriculture Curriculum and PowerPoint site contains 5 courses (including course descriptions, outlines, and resource listings) and over 40 PowerPoint titles. Developed by leading agricultural professionals, these resources address various aspects of sustainable food systems and organic agricultural production practices.

Exploring Sustainability in Agriculture: An Online Sustainable Agriculture Instructional Resource, Center for Agroecology and Sustainable Food Systems

zzyx.ucsc.edu/casfs/instruction/esa/index.html

This online resource from the Center for Agroecology and Sustainable Food Systems includes a catalogue description and outline for a comprehensive course on sustainable agriculture, appropriate for the community college, state college, or university level. The outline and annotated resources address topics in social and environmental sciences; plant, soil, crop, and animal sciences; pest management; natural resource management; the adoption of sustainable agriculture; and the growth and development of sustainable agriculture and the organic food industry.

UC Davis Small Farm Center, Family Farm Series Publications: Vegetable Crop Production—Tips on Irrigating Vegetables

www.sfc.ucdavis.edu/Pubs/Family_Farm_Series/Veg/vegcrop.html

Information on pre-irrigation, timing, irrigation system options, and other useful tips for irrigating vegetable row crops.

UC Division of Agriculture and Natural Resources: Irrigation

www.anrcatalog.ucdavis.edu

Publications and instructional materials on irrigation.

Appendix 1: Estimating Soil Moisture By Feel

SOIL MOISTURE LEVEL (% OF FIELD CAPACITY)	COARSE (SAND)	LIGHT (LOAMY SAND, SANDY LOAM)	MEDIUM (FINE, SANDY LOAM, SILT LOAM)	HEAVY (CLAY LOAM, CLAY)
0 –25% No available soil moisture. Plants wilt. Irrigation required. (1st range)	Dry, loose, single grained, flows through fingers. No stain or smear on fingers.	Dry, loose, clods easily crushed and will flow through fingers. No stain or smear on fingers.	Crumbly, dry, powdery, will barely maintain shape. Clods, breaks down easily. May leave slight smear or stain when worked with hands or fingers.	Hard, firm baked, cracked. Usually too stiff or tough to work or ribbon[1] by squeezing between thumb or forefinger. May leave slight smear or stain.
25 –50% Moisture is available, but level is low. Irrigation needed. (2nd range)	Appears dry; will not retain shape when squeezed in hand.	Appears dry; may tend to make a cast[2] when squeezed in hand, but seldom will hold together.	May form a weak ball[2] under pressure but will still be crumbly. Color is pale with no obvious moisture.	Pliable, forms a ball; will ribbon but usually breaks or is crumbly. May leave slight stain or smear.
50 –75% Moisture is available. Level is high. Irrigation not yet needed. (3rd range)	Color is darkened with obvious moisture. Soil may stick together in very weak cast or ball.	Color is darkened with obvious moisture. Soil forms weak ball or cast under pressure. Slight finger stain, but no ribbon when squeezed between thumb and forefinger.	Color is darkened from obvious moisture. Forms a ball. Works easily, clods are soft with mellow feel. Will stain finger and have slick feel when squeezed.	Color is darkened with obvious moisture. Forms good ball. Ribbons easily, has slick feel. Leaves stain on fingers.
75% to field capacity (100%) Soil moisture level following an irrigation. (4th range)	Appears and feels moist. Color is darkened. May form weak cast or ball. Will leave wet outline or slight smear on hand.	Appears and feels moist. Color is darkened. Forms cast or ball. Will not ribbon, but will show smear or stain and leave wet outline on hand.	Appears and feels moist. Color is darkened. Has a smooth, mellow feel. Forms ball and will ribbon when squeezed. Stains and smears. Leaves wet outline on hand.	Color is darkened. Appears moist; may feel sticky. Ribbons out easily, smears and stains hand, leaves wet outline. Forms good ball.

[1] Ribbon is formed by squeezing and working soil between thumb and forefinger.

[2] Cast or ball is formed by squeezing soil in hand.

Appendix 2: General Irrigation Rules

- During the flowering and fruit set stages of crop development, plants are most sensitive to drought/water stress.
- Most crops require irrigation when the soil moisture in the root zone of the plant has decreased to ~50% of field capacity. Use appendix 1, Estimating Soil Moisture By Feel, to help you determine the moisture content of the soil.
- Seed beds containing small-seeded, directly sown crops require light and frequent water applications. Apply water each time 50% of the surface soil has dried down, showing discoloration (see appendix 4, Unit 1.4).
- Seed beds containing large-seeded, directly sown crops require less frequent water applications. Apply water each time the soil at the depth of the seed has dried to 50% of field capacity. Use appendix 1 to help you determine the moisture content of the soil.

ADDENDA TO THE GENERAL RULES

1. Potatoes: Phase 1 and phase 4 (the planting and maturation stages) require the full soil moisture fluctuation between 50% and 100% of field capacity. Phase 2 and phase 3 (tuber initiation and enlargement) demand less of a fluctuation, responding favorably to a moisture swing between 75% and 100% of field capacity.
2. Other Solanaceae family crops (e.g., tomatoes, peppers, eggplant) respond favorably to a full swing between 50% and 100% of field capacity.
3. Cut flowers: Irrigation 24 hours prior to harvest will help assure full turgor pressure at harvest time and increase the vase life of the stems or bouquets.
4. Leafy greens: 50% of field capacity minimum.
5. Alliums: 50% of field capacity minimum.
6. Established fresh beans and peas: 50% of field capacity minimum.
7. Celery responds favorably to a moisture swing between 75%–100% of field capacity.

Appendix 3: Field Irrigation Schedule

FIELD

CROPS/FIELD	DATE	TIME	AMOUNT (INCHES)	IRRIGATION METHOD	COMMENTS

Appendix 4: Garden Irrigation Schedule

CROP/BED	DATE	TIME	AMOUNT (INCHES OR TIME)	IRRIGATION METHOD	COMMENTS

Appendix 5: Amount of Water Needed to Pre-Irrigate a Dry Soil to Different Depths (Approximate)[1]

SOIL TYPE[2]	INCHES WATER PER FOOT SOIL DEPTH	INCHES WATER TO REACH 6 FEET DEEP
Clay	1.4–1.8	8.6–10.8
Silty clay	1.6–1.9	9.6–11.4
Sandy clay	1.6–1.9	9.6–11.4
Silty clay loam	2.2–2.3	13.0–13.7
Clay loam	2.0–2.2	12.2–13.0
Sandy clay loam	2.0–2.2	12.2–13.0
Silt-loam	1.8–2.0	10.8–12.2
Loam	1.7–1.9	10.1–11.4
Very fine sandy loam	1.7–1.9	10.1–11.4
Sandy loam	1.1–1.3	6.5–7.9
Loamy very fine sand	1.1–1.3	6.5–7.9
Loamy fine sand	1.0–1.2	5.8–7.2
Loamy sand	0.7–1.0	4.3–5.8
Very fine sand	0.7–1.0	4.3–5.8
Fine sand	0.7–1.0	4.3–5.8
Sand	0.7–1.0	4.3–5.8
Coarse sand and gravel	0.4–0.7	2.2–4.3

[1]Based on available water holding capacity; plants have dried soil to permanent wilting point, 15 ATM.

[2]Assumes the soil is uniform throughout irrigation depth.