Irrigated Alfalfa Management
for Mediterranean and Desert Zones

Buy Manual

Irrigating Alfalfa in Arid Regions

Blaine R. Hanson
Irrigation Specialist, Department of Land, Air, and Water Resources, University of California, Davis

Khaled M. Bali
Farm Advisor, University of California Cooperative Extension, Holtville, CA

Blake L. Sanden
Farm Advisor, University of California Cooperative Extension, Bakersfield, CA

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Chapter 7

Corresponding Author:
Blaine R. Hanson
(brhanson@ucdavis.edu)

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In Mediterranean and desert regions such as the U.S. Southwest, alfalfa must be irrigated to maximize farm profit. Although there is some dryland alfalfa, more than 90 percent of alfalfa grown in the 11 western U.S. states is irrigated. Good irrigation management is critical to successful alfalfa production, and it requires an understanding of the relationship between crop yield and water and the limitations of different irrigation systems. Properly managing an irrigation system requires knowledge of irrigation scheduling: determining *when* to irrigate, *how much* water to apply, and applying the water with *high irrigation efficiency*. This chapter focuses on methods for managing irrigation water to realize alfalfa yields that maximize farm income.

Evapotranspiration, Applied Water, and Yield

Evapotranspiration

In arid and semiarid environments, alfalfa yield and revenue are related to the amount of water used by the crop. The technical term for crop water use is crop evapotranspiration (ET), water that is evaporated into the atmosphere as a result of producing a crop. It consists of two components, transpiration and evaporation. Transpiration is water taken up by plants that evaporates directly from plant leaves, whereas evaporation is water evaporated directly from the soil. ET is affected by climate, plant type and stage of growth, health of the plant, salinity, and soil moisture content. Climate factors include solar radiation, air temperature, wind, and humidity, with solar radiation by far the most important factor because it provides most of the energy to evaporate water. ET will be small for a small plant canopy (e.g., just after harvest) and will consist mostly of evaporation because much of the soil is exposed to the sun's rays. As the canopy cover increases, ET becomes primarily transpiration because the mature plant canopy covers most of the soil, slowing evaporation. However, insufficient soil moisture will decrease ET and yield.

The ET of alfalfa depends on time of year and time after harvest (Fig. 7.1). Early in the year, ET is small due to the cool climatic conditions in the spring. ET then increases until midsummer, after which ET decreases with time. There can be considerable variability in ET from day to day due to climate variability, particularly temperature, wind, and solar radiation. Regardless of the time of year, ET decreases just after a harvest (see arrows in Fig. 7.1), then rapidly increases to a maximum level just before the next harvest.

ET can be measured as a depth of water, such as inches, feet, millimeters, or centimeters. Using the depth of water standardizes ET values, regardless of field size. The depth of water is the ratio of the volume of water applied to a field to the area of the field. Depth can be easily converted to volume. The volume of water is normally expressed as acre-inches, acre-feet, or hectare-meters, hectare-centimeters, liters, or megaliters. Thus, 1 inch (25.4 mm) of water is 1 acre-inch of water applied over 1 acre of land (0.405 ha), or 1 acre-inch per acre. One acre-inch of water equals 27,158 gallons (102.8 m^3); 1 acre-foot equals 325,900 gallons (1,234 m^3). Multiply by 12.33 to convert acre-foot (acre-ft) units into hectare-centimeters (ha-cm).

FIGURE 7.1

Daily evapotranspiration rates of a flood-irrigated alfalfa field, San Joaquin Valley of California. ET of alfalfa is affected by season, but also by harvest and regrowth (harvest dates shown).

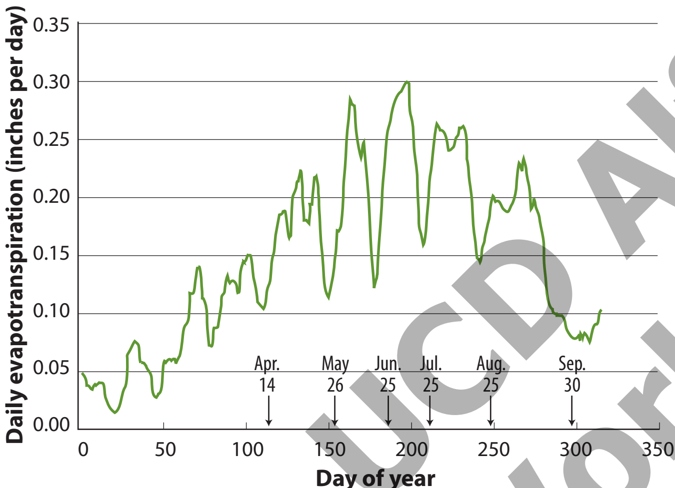
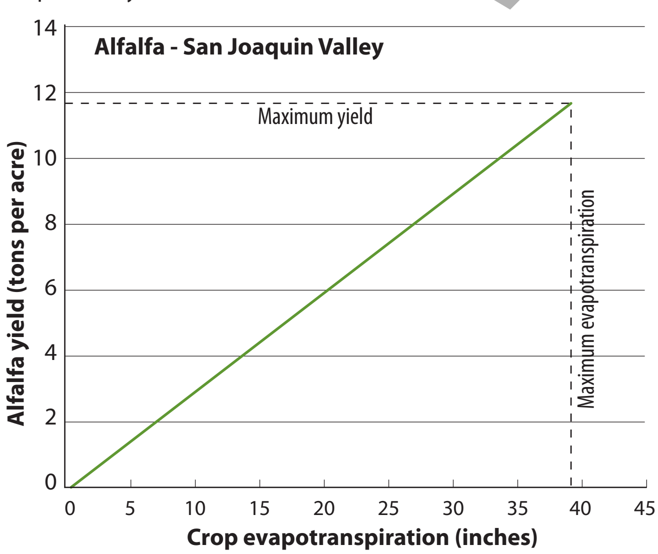


FIGURE 7.2

Effect of seasonal evapotranspiration on alfalfa yield for the San Joaquin Valley of California (Grimes et al. 1992).



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Effect of Evapotranspiration and Applied Water on Crop Yield

Seasonal alfalfa yield is directly related to seasonal ET (Fig. 7.2). Alfalfa yield increases as ET increases, with maximum yield occurring at maximum seasonal ET (determined by climatic conditions). Insufficient soil moisture, the result of insufficient applied water, is usually the reason that ET is less than maximum, which results in reduced yield.

The relationship between applied water and yield may differ from the ET-yield relationship. The effect of applied water on yield can differ throughout the year. Little yield response to applied water may occur for the first harvest simply because stored soil moisture from winter and spring precipitation may be sufficient for crop growth and to satisfy the ET of the crop (Fig. 7.3A). For later cuttings, stored moisture from winter/spring may be depleted; thus, yield increases as applied water increases (Fig. 7.3B,C). However, water applications that exceed the maximum ET or the water-holding capacity of the soil will have no effect on yield, as seen for water applications exceeding 5 inches (127 mm) for the second harvest (Fig. 7.3B).

Seasonal Alfalfa Evapotranspiration

The seasonal ET of alfalfa varies with location. The average historical seasonal ET for various locations in California is 48–49 inches (1219–1247 mm) for the Central Valley, 33 inches (840 mm) for the northeastern mountain areas, and 76 inches (1930 mm) for the southern desert areas (Hanson et al. 1999).

Irrigation Scheduling

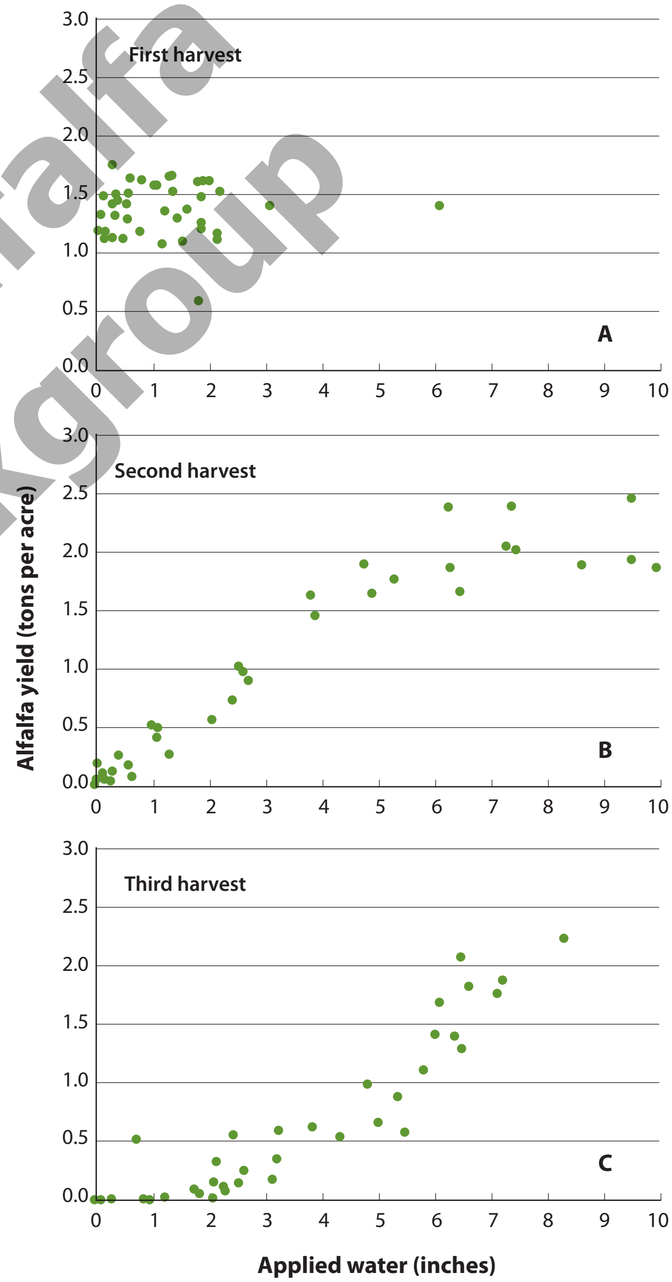
Irrigation scheduling involves determining “When should irrigation occur?” and “How much water should be applied?” The answers to these questions are critical for properly managing irrigation water for alfalfa production.

When Should Irrigation Occur?

Irrigate before the yield is reduced by insufficient soil moisture. This requires irrigating frequently enough to prevent excessive soil moisture depletion. A standard approach to irrigation scheduling (called the water balance or checkbook method) is to determine how much soil moisture can be depleted between irrigations without reducing crop yield, then irrigate when total alfalfa ET between irrigations equals that depletion. An allowable soil moisture depletion commonly used for alfalfa is 50 percent, meaning 50 percent of the available soil moisture can be depleted between irrigations without reducing yield. The interval between irrigations is the number of days required for the total ET to equal that depletion.

FIGURE 7.3

Effect of applied water on alfalfa yield for the first, second, and third harvests. To convert inches to mm, multiply × 25.4.



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How Much Water Has Been Depleted?

Soil moisture is normally described as inches of water per foot of soil or millimeters of water per meter of soil. The available soil moisture is the total amount of moisture that can be extracted from the soil by a plant root system and depends on soil type and structure and rooting depth. The upper limit for the available soil moisture is the field capacity. This is the maximum soil moisture storage capacity of the soil and is defined as the soil moisture content at which deep percolation ceases after irrigation. The lower limit of available soil moisture is the permanent wilting point (soil moisture content at which permanent plant wilt occurs). Table 7.1 lists available soil moisture for different soil types.

Allowing a plant to use all of the available soil moisture will cause permanent wilting, so only 50 percent of the available soil moisture should be used before irrigation to avoid alfalfa crop stress due to insufficient soil moisture. At the time of 50 percent depletion, calculations of the amount of water that has been used must be made. This amount is the allowable depletion, defined as the amount of soil moisture that can be used without decreasing yield. The total amount of available soil moisture also depends on root depth. The total available soil moisture is determined by multiplying the values in Table 7.1 by the root depth. Thus, for example, from Table 7.1, on a sandy clay soil with a rooting depth of 4 feet, the available soil moisture would be 1.6 inches/foot × 4 feet = 6.4 inches (16.4 cm) available water, and the allowable depletion would be 3.2 inches (8.2 cm) of water in that rooting depth.

TABLE 7.1

Available soil moisture for various soil textures. Fine-textured soils (clays, silty soils) hold substantially more water than sandy soils.

Soil Texture	Available Soil Moisture (in/ft*)
Sand	0.7
Loamy sand	1.1
Sandy loam	1.4
Loam	1.8
Silt loam	1.8
Sandy clay loam	1.3
Sandy clay	1.6
Clay loam	1.7
Silty clay loam	1.9
Silty clay	2.4
Clay	2.2

*To convert inches to millimeters, multiply by 25.4. To convert feet to meters, multiply by 0.304.

Estimating Crop Water Use (ET)

It is important to estimate how much water has been used within a defined period of time (the crop ET) to determine irrigation scheduling (amount and timing). Alfalfa ET can be estimated using Equation 1:

$$ET = K_c \times ET_o \quad \text{[Eq. 1]}$$

where *ET* is crop evapotranspiration, K_c is a crop coefficient, and ET_o is the evapotranspiration of a reference crop, defined as the ET of a well-watered grass. ET_o in California varies from region to region, and is available from the California Irrigation Management Information System (CIMIS) (www.cimis.water.ca.gov).

Although the CIMIS program provides ET_o values on an actual time basis, historical or long-term averages of ET_o can be used for the Central Valley of California with minimal error in ET estimates. Historical values are more convenient to use and allow one to develop an irrigation schedule at the start of irrigation in spring for the entire growing season. Table 7.2 lists historical daily values of ET_o for selected locations in California.

The K_c depends on the alfalfa stage of growth. The K_c is smallest just after a harvest, about 0.4 to 0.5, and reaches a maximum just prior to harvest, about 1.1 to 1.2. However, it is more practical to use average alfalfa K_c values over the season for irrigation scheduling (Table 7.3) because of the difficulty in adjusting the actual coefficient for alfalfa growth due to rapidly changing K_c as the alfalfa grows between harvests. Table 7.3 also contains K_c values for grass hay, clover, and pasture.

Determining the historical alfalfa ET is simplified by using the values listed in Table 7.4 for different areas of California. These values were determined using Equation 1, the ET_o

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values in Table 7.2, and the alfalfa crop coefficients in Table 7.3. For irrigators of grass hay, clover, and pasture, ET will need to be calculated using the procedure described in the following section.

Irrigation Scheduling—Determining Timing and Quantity

The procedure for determining when to irrigate based on an allowable depletion is as follows:

Step 1: Determine the total allowable soil moisture depletion by multiplying the available soil moisture in Table 7.1 by the root depth, then multiplying by 0.5 (which is the allowable depletion expressed as a decimal fraction).

Step 2: Determine the daily ET_o for a given time period and location (Table 7.2).

Step 3: Determine the K_c (Table 7.3).

TABLE 7.2

Historical reference crop evapotranspiration (inches* per day) for various alfalfa-growing regions in California

		Low Desert	San Joaquin Valley			Sacramento Valley			Intermountain
		Brawley	Shafter	Five Points	Parlier	Davis	Nicolaus	Durham	McArthur
		(Inches/day)							
Jan	1–15	0.07	0.03	0.04	0.03	0.03	0.03	0.03	0.02
	16–31	0.09	0.05	0.05	0.04	0.05	0.04	0.05	0.03
Feb	1–15	0.10	0.07	0.06	0.06	0.06	0.06	0.06	0.04
	16–29	0.13	0.09	0.09	0.08	0.09	0.09	0.09	0.07
Mar	1–15	0.16	0.11	0.11	0.10	0.09	0.09	0.09	0.08
	16–31	0.19	0.14	0.15	0.13	0.14	0.12	0.12	0.11
Apr	1–15	0.22	0.19	0.20	0.17	0.18	0.15	0.16	0.14
	16–30	0.25	0.20	0.22	0.19	0.20	0.18	0.17	0.14
May	1–15	0.28	0.24	0.26	0.22	0.23	0.21	0.21	0.18
	16–31	0.29	0.26	0.27	0.24	0.24	0.21	0.22	0.19
Jun	1–15	0.31	0.27	0.29	0.26	0.28	0.24	0.25	0.22
	16–30	0.32	0.28	0.30	0.27	0.29	0.26	0.26	0.25
Jul	1–15	0.31	0.28	0.30	0.27	0.29	0.26	0.27	0.27
	16–31	0.29	0.26	0.28	0.25	0.27	0.25	0.25	0.25
Aug	1–15	0.29	0.25	0.28	0.24	0.26	0.24	0.24	0.25
	16–31	0.28	0.23	0.25	0.22	0.24	0.21	0.21	0.22
Sep	1–15	0.26	0.21	0.23	0.19	0.21	0.19	0.19	0.18
	16–30	0.22	0.18	0.20	0.15	0.18	0.16	0.16	0.14
Oct	1–15	0.19	0.16	0.17	0.13	0.16	0.13	0.14	0.12
	16–31	0.15	0.12	0.13	0.09	0.12	0.09	0.10	0.08
Nov	1–15	0.12	0.08	0.10	0.07	0.09	0.07	0.07	0.05
	16–30	0.10	0.06	0.07	0.04	0.06	0.05	0.05	0.03
Dec	1–15	0.07	0.05	0.05	0.03	0.05	0.03	0.04	0.02
	16–31	0.07	0.03	0.03	0.02	0.04	0.04	0.03	0.02

*To convert inches to millimeters, multiply by 25.4.

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Step 4: Calculate the daily ET using Equation 1, or use the values in Table 7.4 for alfalfa.

Step 5: Determine the interval between irrigations by dividing the total allowable soil moisture depletion by the daily crop ET.

Scheduling Example

Determine the interval between irrigations for alfalfa from June 16 through June 30 for a field in the Fresno area. The soil type is silt loam, and root depth is 5 feet (1.52 m).

Step 1: The available soil moisture for silt loam is 1.8 inches (46 mm) per foot (0.305 m) (Table 7.1). The total allowable soil moisture depletion is 1.8 inches (46 mm) per foot × 5 feet (1.52 m) (rooting depth) × 0.5 = 4.5 inches (114 mm). The allowable depletion is 50 percent of the total available soil moisture, or 0.5 expressed as a decimal fraction.

Step 2: The ET_o for June 16–30 is 0.27 inches (6.8 mm) per day (Table 7.2, Parlier location).

Step 3: The K_c is 0.95 for a dry location with moderate wind (Table 7.3).

Step 4: The ET is 0.95 × 0.27 inches (6.9 mm) per day = 0.26 inches (6.6 mm) per day. The daily ET of 0.26 inches (6.6 mm) per day can also be found in Table 7.4, thus eliminating Steps 2 and 3 for alfalfa.

Step 5: The desired interval between irrigations can be calculated as: 4.5 inches ÷ 0.26 inches per day (114 mm ÷ 6.6 mm per day) = 17 days.

This method is inappropriate for shallow groundwater conditions. This method assumes that the soil moisture depletion between irrigations equals the ET. Under shallow groundwater conditions, this assumption is invalid because some of the crop's water can come from the groundwater; thus, the soil moisture depletion between irrigations will be smaller than the ET.

This procedure also assumes that infiltration of the furrow or border (flood) irrigation water is sufficient to replace all ET that was depleted since the last irrigation. This is not always the case. Many semiarid soil types "seal up" over the season, which limits the recharge of soil moisture. This is particularly a problem where sandy loam soils are irrigated with very low-salt water. With cracking clay loam soils, infiltration is primarily controlled by water flow into the cracks. Once the cracks seal shut, little infiltration may occur.

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Influence of Cutting Schedule

Scheduling irrigations of alfalfa is complicated by the harvest schedule, which occurs about every 28 to 30 days in most areas. The first irrigation after harvest cannot occur until the alfalfa bales are removed. The final irrigation between harvests will need to occur at a time that provides sufficient soil drying before the harvest. Thus, irrigation scheduling of alfalfa is often controlled by the harvest schedule, not by allowable soil moisture depletion.

Growers are limited to the choice of irrigating once, twice, or sometimes three times between harvests, depending upon soil type and time of year. One irrigation between harvests may result in excessive soil moisture depletion between harvests, whereas with two

TABLE 7.3

Average crop coefficients for forage crops. *Source:* Doorenbos and Pruitt, 1977

Climatic Condition		Crop Coefficients (Kc)			
		Alfalfa	Grass Hay	Clover	Pasture
Humid, with light to moderate wind	average	0.85	0.80	1.00	0.95
	peak	1.05	1.05	1.05	1.05
	low	0.50	0.60	0.55	0.55
Dry with light to moderate wind	average	0.95	0.90	1.05	1.00
	peak	1.15	1.10	1.15	1.10
	low	0.40	0.55	0.55	0.50
Strong wind	average	1.05	1.00	1.10	1.05
	peak	1.25	1.15	1.20	1.15
	low	0.30	0.50	0.55	0.50

or three irrigations between harvests, irrigations will occur before the allowable depletion occurs. For these situations, efficient irrigation requires relatively small applications of water.

The constraints resulting from soil problems and harvest schedules may mean that irrigation should occur before the allowable depletion occurs, the determination of which was discussed earlier. Thus, a management allowable depletion (MAD) should be used, which takes these constraints into account. Usually, the MAD will be smaller than the calculated allowable depletion based on a 50 percent allowable depletion. The MAD will need to be determined from field experience and soil moisture measurements. Smaller water applications may be required to achieve MAD.

Managing Flood Irrigation

Flood or border irrigation systems are difficult to manage efficiently, since large quantities of water are required to move water down the checks, and it takes considerable time for water to advance or flow across the field. Additionally, a large quantity of water may pond on the soil surface during the irrigation event, especially at the tail ends of fields (discussed later). As a result, small water applications may not be feasible unless very

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TABLE 7.4

Historical evapotranspiration of alfalfa (inches* per day) for various locations in California

		Shafter	Five Points	Parlier	Davis	Nicolaus	Durham	McArthur	Brawley
Jan	1–15	0.03	0.04	0.03	0.03	0.03	0.03	0.02	0.07
	16–31	0.05	0.05	0.04	0.05	0.04	0.05	0.03	0.09
Feb	1–15	0.07	0.06	0.06	0.06	0.06	0.06	0.04	0.11
	16–29	0.09	0.09	0.08	0.09	0.09	0.09	0.07	0.14
Mar	1–15	0.12	0.12	0.10	0.09	0.09	0.09	0.08	0.17
	16–31	0.15	0.16	0.12	0.13	0.11	0.11	0.10	0.20
Apr	1–15	0.20	0.21	0.16	0.17	0.14	0.15	0.13	0.23
	16–30	0.21	0.23	0.18	0.19	0.17	0.16	0.13	0.26
May	1–15	0.25	0.27	0.21	0.22	0.20	0.20	0.17	0.29
	16–31	0.27	0.28	0.23	0.23	0.20	0.21	0.18	0.30
Jun	1–15	0.28	0.30	0.25	0.27	0.23	0.24	0.21	0.33
	16–30	0.29	0.32	0.26	0.28	0.25	0.25	0.24	0.34
Jul	1–15	0.29	0.32	0.26	0.28	0.25	0.26	0.26	0.33
	16–31	0.27	0.29	0.24	0.26	0.24	0.24	0.24	0.30
Aug	1–15	0.26	0.29	0.23	0.25	0.23	0.23	0.24	0.30
	16–31	0.24	0.26	0.21	0.23	0.20	0.20	0.21	0.29
Sep	1–15	0.22	0.24	0.18	0.20	0.18	0.18	0.17	0.27
	16–30	0.19	0.21	0.14	0.17	0.15	0.15	0.13	0.23
Oct	1–15	0.17	0.18	0.12	0.15	0.12	0.13	0.11	0.20
	16–31	0.13	0.14	0.09	0.11	0.09	0.10	0.08	0.16
Nov	1–15	0.08	0.11	0.07	0.09	0.07	0.07	0.05	0.13
	16–30	0.06	0.07	0.04	0.06	0.05	0.05	0.03	0.11
Dec	1–15	0.05	0.05	0.03	0.05	0.03	0.04	0.02	0.07
	16–31	0.03	0.03	0.02	0.04	0.04	0.03	0.02	0.07

*To convert inches to millimeters, multiply by 25.4.

short check lengths are used. Multiple irrigations between harvests will probably result in infiltrated amounts exceeding the soil moisture depletion for the field lengths normally used for flood irrigation. These amounts may move beyond the root zone, depending on soil type.

A trial-and-error approach will be needed to determine the irrigation set time for flood irrigation. The irrigation set time should equal the time for the water to flow to about 70 to 90 percent of the check length, depending on site-specific conditions. These conditions include infiltration rate, surface roughness, field length, check width, inflow rate, and slope. At that time, the water should be stopped or cut off. However, if the set time is too short, water may not reach the end of the field. If the set time is too long, runoff and infiltration may be excessive.

Managing Sprinkler Irrigation

Small applications of water are possible with sprinkler irrigation. Managing the irrigation water will consist of matching the ET between irrigations with the amount of water applied with the sprinkler irrigation system. The amount of water to be applied by sprinkler irrigation can be determined with the following steps:

Step 1: Determine the daily ET_o (Table 7.2).

Step 2: Determine the K_c (Table 7.3).

Step 3: Determine the daily alfalfa ET using Equation 1 or using Table 7.4. Use of Table 7.4 eliminates Steps 1 and 2.

Step 4: Determine the total ET between irrigations by multiplying the daily ET (Step 3) by the days since the last irrigation.

Step 5: Determine the amount to be applied by dividing the total ET by the irrigation efficiency, expressed as a decimal fraction. Irrigation efficiency values of 0.7 to 0.75 are recommended for hand-move and wheel-line sprinklers, and 0.85 for center-pivot sprinkler machines.

Sprinkler Timing

The amount of water applied should equal the alfalfa ET or soil moisture depletion between irrigations and an additional amount to account for the irrigation efficiency. The irrigation set time needed for sprinkler irrigation can be determined using either of the two following methods:

- Calculate the required irrigation set time using Equation 2 (below). The flow rate into the field is required for this approach.

  $$T = 449 \times A \times D \div Q \quad \text{[Eq. 2]}$$

  where T is the irrigation time per set (hours per set), A is the acres (ha) irrigated per set, D is the desired inches (mm) of water to be applied, and Q is the field flow rate in gallons (l) per minute, or cubic meters per hour. D is equal to the ET divided by the irrigation efficiency (IE). Use an IE value of 0.75 for wheel-line and hand-move sprinkler systems and 0.85 for center pivot systems. This method is appropriate for all sprinkler systems. The constant 449 is the conversion factor for English units; use 165 for metric units.

- Determine the application rate (AR) of the sprinkler. This method is appropriate for wheel-line and hand-move sprinkler systems. The irrigation set time is calculated from Equation 3:

  $$T = D \div AR \quad \text{[Eq. 3]}$$

  where T equals the irrigation set time (hours) and AR is the application rate (inches [mm] per hour). The application rate depends on the discharge rate of an individual sprinkler and the overlapped sprinkler spacing, and can be determined from Equation 4:

  $$AR = (96.3 \times q) \div (S_l \times S_m) \quad \text{[Eq. 4]}$$

  where q is the individual sprinkler discharge rate in gallons (or liters) per minute, S_l is the sprinkler spacing along the lateral line in feet (m), and S_m is the lateral spacing along the main line in feet (m). The constant 96.3 is used for English units; use 59.8 for metric units. The sprinkler discharge rate can be measured by inserting a garden hose over the nozzle and measur-

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ing the time to fill a container of a known volume with water. This measurement may be needed for older sprinkler systems that may have worn nozzles. The sprinkler discharge rate can also be estimated from Table 7.5 by measuring the nozzle pressure with a pitot gauge (available from irrigation supply stores) and the nozzle size.

Since so many variables are involved (soil peculiarities, temporary weather patterns, crop growth differences, etc.), ET-based irrigation management methods should be used in combination with soil monitoring to reflect real-world conditions.

Soil Moisture Monitoring

Soil moisture monitoring should be used in combination with the water balance or ET method, as a method of "ground truthing" the effectiveness of an irrigation strategy. Soil moisture monitoring can provide the following information to help evaluate the irrigation water management of alfalfa:

- Did sufficient water infiltrate the soil to an adequate depth?
- Has too much water been applied?
- What is the water uptake pattern of the roots?
- When should irrigation occur?
- How long does it take for water to infiltrate the soil?

Knowledge of soil wetting and drying patterns can assist managers to determine whether the ET approach should be modified for individual field conditions.

Many soil moisture sensors are available for measuring either soil moisture or soil-moisture tension. Soil-moisture tension is the tenacity with which water is retained by the soil: the higher the tension, the drier the soil. The sensors should be installed at about one-fourth to one-third of the root zone depth for irrigation scheduling purposes and at the bottom of the root zone to ensure adequacy of irrigation.

Although many sensors are available, only a few are practical for monitoring soil moisture in alfalfa fields. One type of sensor that is well-suited for alfalfa fields is the Watermark electrical resistance block (Irrometer, Inc., Riverside, CA) (Fig. 7.4). This instrument is inexpensive, easy to install and read, requires no maintenance, and is not susceptible to damage from harvesting equipment. It provides readings in centibars of soil-moisture tension, which can be compared with appropriate guidelines (Table 7.6) to determine when to irrigate. Sidebar 1 describes a procedure for installing and using this instrument, which is also covered in detail in Orloff et al. 2001. This

TABLE 7.5

Application rates for various pressures and nozzle sizes for a 40 × 60 foot (12 × 18 m) spacing

Pressure (psi)	Nozzle Size (inches*) 5/32	11/64	3/16	13/64
	inches per hour			
30	0.15	0.18	0.22	0.26
35	0.16	0.20	0.24	0.28
40	0.18	0.21	0.25	0.30
45	0.19	0.22	0.26	0.33
50	0.20	0.24	0.28	0.34
55	0.21	0.25	0.29	0.36
60	0.22	0.26	0.31	0.37

*To convert inches to millimeters, multiply by 25.4.

FIGURE 7.4

One type of sensor that is well-suited for alfalfa fields is the Watermark electrical resistance block.

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publication and a downloadable Excel spreadsheet are available at http://alfalfa,ucdavis.edu.

The use of these electrical resistance blocks is illustrated by soil-moisture tension readings made in 2003 and 2004 in the same flood-irrigated field (Figs. 7.6–7.7). Soil type was clay loam. In 2003, one irrigation occurred between harvests. Soil-moisture tensions at about 1 foot (30 cm) deep just before harvests in June and July ranged from approximately 100 centibars to more than 200 centibars, suggesting soil moisture depletions between harvests exceeded the allowable depletion, particularly in July, and that more frequent irrigation was needed (Fig. 7.6). In 2004, two irrigations occurred between harvests to

Sidebar 1:

Installing Watermark Electrical Resistance Blocks

Step 1: Soak blocks in water for a few minutes to saturate them.

Step 2: Check the block readings before installing to ensure that they are working.

Step 3: Make a small-diameter hole with a soil probe or a small-diameter auger to a depth slightly deeper than that desired.

Step 4: Make a slurry of water mixed with a small amount of soil, and, if possible, gypsum, and pour down the hole to provide good contact between soil and block. This contact is vital because water must flow in and out of the block for the block to respond to changes in soil-moisture tension.

Step 5: Push the block into the slurry in the bottom of the hole with a length of PVC pipe (1/2 in. [12.7 mm], Schedule 80). Cut a notch in the bottom of the pipe for the wire lead of the block to prevent the wire from being damaged during installation.

Step 6: Remove the pipe and backfill the hole with soil removed from the hole. Do not damage the wire leads during the backfilling. As the hole is filled, pack the backfilled soil in the hole with the PVC pipe. Be sure to identify each block with a tag or knots in the wire to indicate its depth of installation.

Step 7: Allow the blocks to equilibrate with the soil moisture for about 24 hours before making readings of soil-moisture tension.

Step 8: Compare the block readings with the threshold values in Table 7.6 to determine when to irrigate.

At a minimum, install one block at approximately one-fourth to one-third of the root zone to schedule irrigations, and a block at the bottom of the root zone to monitor depth of wetting. Blocks installed at different depths, however, provide better information on depth of wetting and soil-moisture uptake patterns. One approach is to install blocks at depths of 12, 24, and 48 inches (0.3, 0.6, and 1.2 m). Little change in block readings at the lower depths or increasing values of tension during the irrigation season indicate insufficient water applications.

Install at least two sites of blocks for every 40 acres (16 ha). This might consist of one site about 200 feet (61 m) from the head end of the field and a second site 200 to 300 feet (61–91 m) from the tail

TABLE 7.6

Threshold values of soil-moisture tension at which irrigation should occur for alfalfa for different soil types (Orloff et al. 2001). Values are based on a 50 percent depletion of available soil moisture for different soil types.

Soil Type	Threshold Soil-Moisture Tension (centibars)
Sand or loamy sand	40–50
Sandy loam	50–70
Loam	60–90
Clay loam or clay	90–120

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Installing Watermark Sensors (continued)

end of the same check. More sites may be needed, depending on soil texture variability and cropping patterns in a field. Separate stations for problem areas or for areas having different soil conditions or crops are recommended.

Periodic measurements of soil moisture normally are made once or twice per week. However, research has shown that continuous measurements of soil moisture better describe the trends in soil moisture over time. Continuous measurements require that the sensors be connected to a data logger. The data logger can be installed in the field near the sensors (which makes it susceptible to damage from harvesting equipment) or on the side of the field, which requires wires to connect the logger to the sensors (Fig. 7.5). A procedure for installing a wire is to shank a four- to seven-lead sprinkler or phone wire under the field surface with a fertilizer knife out to the end of the field and attaching a data logger. This cable is then attached to the buried blocks (use waterproof connectors), leaving no wires or equipment in the field that interfere with equipment and can be hard to find. If a data logger is not used, it still may be desirable to install a buried wire for the hand-read meter.

In very sandy soils, electrical resistance blocks and tensiometers may not work very well. This is because in unsaturated sandy soils, water flow through the soil is extremely slow; thus water flow into and out of the block also will be very slow and will not reflect the actual changes in soil-moisture tension.

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FIGURE 7.5

A recommended installation layout for soil moisture sensors in an alfalfa field.

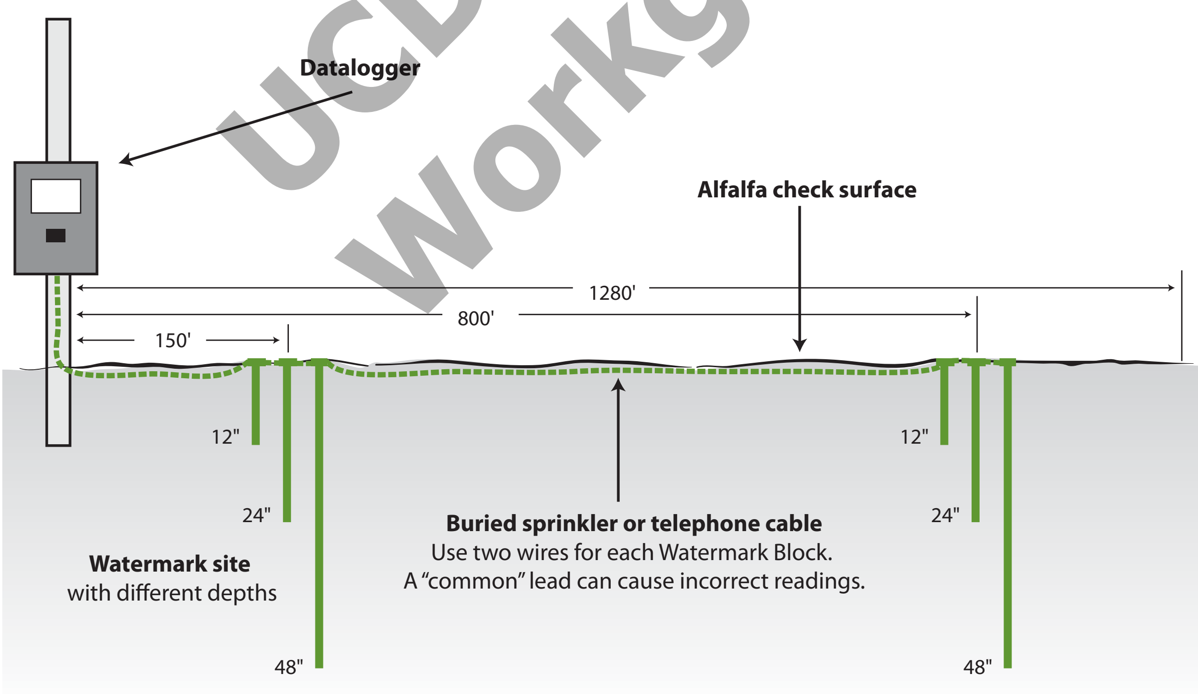


FIGURE 7.6

Soil-moisture tension for a flood-irrigated field irrigated once per harvest.

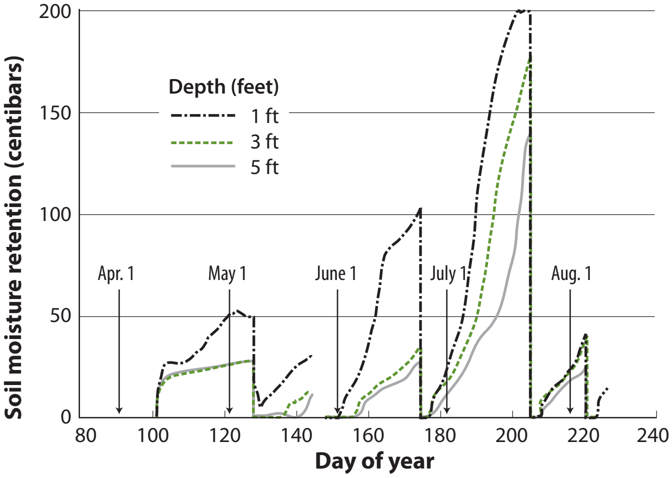


FIGURE 7.7

Soil-moisture tension for a flood-irrigated field irrigated two times between harvests.

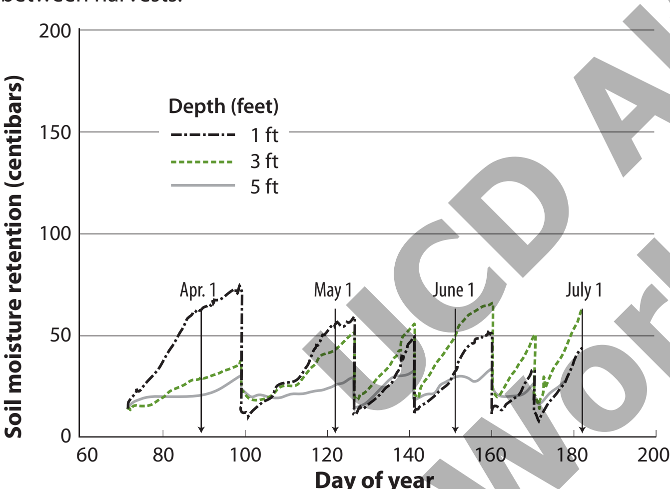
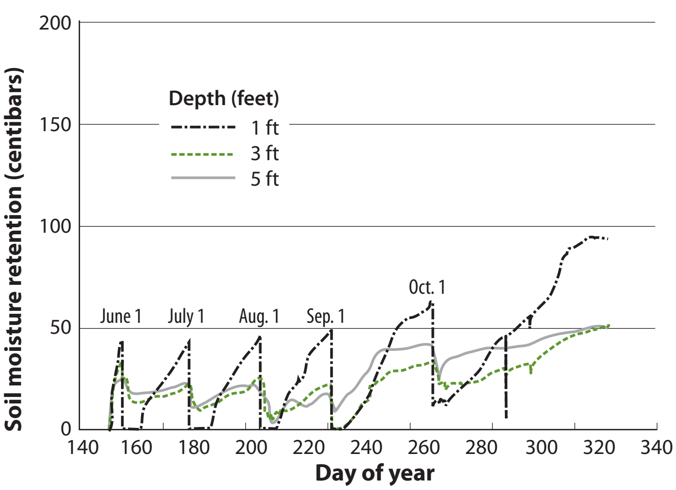


FIGURE 7.8

Soil-moisture tension for a sprinkler-irrigated field irrigated too frequently.



reduce or eliminate crop stress due to insufficient soil moisture. Soil-moisture tensions just before harvest ranged from 50 to 70 centibars at 1 foot (30 cm) deep (Fig. 7.7). However, these soil-moisture tension values indicate that these irrigations probably occurred at soil moisture depletions smaller than the allowable depletion, a situation that is unavoidable because of the harvest schedule.

Watermark blocks have also been used to evaluate the irrigation water management of sprinkler irrigation systems. In one case, relatively small soil-moisture tension values occurred at all depths throughout the irrigation season with values at the 1-foot (30 cm) depth never exceeding 50 centibars until near the end of the irrigation season (Fig. 7.8). At the deeper depths, tension values were less than 30 centibars. These data suggest that a longer interval between irrigations should be used. Contributions by shallow groundwater to the ET may be responsible for this result.

Soil moisture sensors can also be used to determine if the infiltration time is sufficient. Data from Watermark block measurements (not shown) showed that only about 2 to 3 hours were needed to infiltrate water to about 5 feet (1.5 m) deep in cracked soils. This indicates that in these cracked soils, only 2 to 3 hours of ponding are needed along the lower part of the field to infiltrate water. Note: ponding during flood irrigation events should be limited during times of high temperatures, due to the risk of scald.

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Uniformity and Efficiency of Irrigation Systems

Uniformity and efficiency describe the performance of irrigation systems. Uniformity refers to the evenness at which water is applied or infiltrated throughout the field and depends on system design and maintenance. Efficiency refers to the ability of an irrigation system to match the water needed for crop production with applied irrigation water and depends on system design, maintenance, and management. Higher irrigation uniformity results in a greater potential irrigation efficiency of a properly managed irrigation system.

If all parts of a field received exactly the same amount of water, the uniformity would be 100 percent. However, regardless of the irrigation method, some areas of a field will receive more or less water than other areas, providing uniformities of less than 100 percent. If the least-watered areas of the field receive an amount equal to the soil moisture depletion, excess amounts of water will be applied to other areas, resulting in water percolating below the root zone, commonly called deep percolation. This water is not effectively used by crops, is considered lost water, and lowers irrigation efficiency. Lower distribution uniformities result in greater differences in applied or infiltrated water throughout the field and more drainage below the root zone.

An index commonly used to assess the uniformity of infiltrated water is the distribution uniformity (DU), calculated as follows:

$$DU = \frac{100\,\overline{X}_{LQ}}{\overline{X}},$$

where $\overline{X}$ is the average amount of infiltrated or applied water for the entire field, and $\overline{X}_{LQ}$ is the average of the lowest one-fourth of the measurements of applied or infiltrated water, commonly called the low quarter (usually the lower end of the field for flood irrigation). $\overline{X}_{LQ}$ is referred to as the minimum amount of infiltrated or applied water.

Irrigation efficiency is the ratio of the amount of water beneficially used for crop production to the amount of water applied to the field. Evapotranspiration (ET) is the largest single beneficial use of irrigation water in crop production. Leaching for salinity control is also a beneficial use.

Losses affecting the irrigation efficiency are percolation below the root zone, surface runoff, and evaporation from sprinklers before water reaches the soil. Percolation occurs when the amount of infiltrated water exceeds the soil moisture storage capacity of the soil. Surface runoff occurs when the application rate of the irrigation water exceeds the infiltration rate and is difficult to avoid for flood irrigation systems. This loss can be eliminated by recovering the surface runoff and using it elsewhere or recirculating the runoff back to the "head" of the field during irrigation. Evaporative losses from sprinklers can be important and are dependent on nozzle and sprinkler characteristics and climate, but generally do not exceed 10 percent of the applied water.

The DU of a properly irrigated field is approximately equal to its potential irrigation efficiency, assuming surface runoff is beneficially used. Table 7.7 lists potential practical irrigation efficiencies developed from irrigation system evaluation data.

Flood or Border Irrigation Systems

Border or check flood irrigation systems, which cause a sheet of water to flow across the field, are the dominant systems used for alfalfa in California. The advantages of this method are that it is almost completely gravity powered, and it is inexpensive, both in terms of system costs and energy costs. Disadvantages are that its performance depends strongly on soil properties, such as the infiltration rate, slope, surface roughness, and border design. It is the most difficult irrigation method to manage efficiently because of these factors; thus, a trial-and-error approach is normally used to manage these systems.

Border or check flood irrigation systems used in California usually have slopes from 0.1 percent to 0.2 percent and use small "border checks" (or small levees) about 6 inches (15 cm) high to confine water to a check width of 10 to 100 feet (3.05–30.5 m) wide so that water moves down the field. Laser-monitored earth-scraping equipment is normally used for

TABLE 7.7

Practical potential irrigation efficiencies (Hanson 1995)

Irrigation Method	Irrigation Efficiency (%)
Sprinkler	
Continuous-move	80–90
Periodic-move	70–80
Portable solid-set	70–80
Microirrigation	80–90
Furrow	70–85
Border check	70–85

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field leveling and smoothing, a critical aspect of its success. Field length in the direction of flow varies, but a 1,200- to 1,300-foot (366–400 m) check length is common. Sometimes flood systems are combined with "corrugated" or "bedded" systems that facilitate water movement and drainage on finer-textured soil.

Design variables for flood irrigation include slope, border length, border inflow rate, surface roughness, and infiltration rate. Recommended field lengths and flow rates for various soil types are shown in Table 7.8.

A description of the behavior of flood irrigation is as follows:

- At the start of the irrigation, the water starts flowing or advancing down the check.
- At the same time, water ponds on the soil surface. During the irrigation, the amount of ponded or stored water is substantial and may be 3 to 4 inches (76–102 mm) deep. (Note: In contrast, stored water during furrow irrigation is insignificant relative to the amount applied.)
- The ponded water infiltrates the soil as water flows across the field.
- At cutoff, the irrigation water is stopped. The ponded water, however, continues to flow down the field and infiltrate into the soil after cutoff. It may supply all of the soil moisture replenishment along the lower part of the field. (Note: In contrast, infiltration after cutoff is insignificant for furrow irrigation.)
- The stored water also causes surface runoff at the end of the field. The longer the irrigation set time, the more the potential runoff from the stored water.

The flow of water across the field is characterized by the advance curve, which shows the time at which water arrives at any given distance along the field length (Fig. 7.9). The recession curve shows the time at which water no longer ponds on the soil surface at any given distance along the field length (Fig. 7.9). The difference between advance time and recession time at any distance along the check length is the time during which water infiltrates the soil or the infiltration time. These infiltration times vary along the field length, resulting in more water infiltrating in some parts of the field compared to other areas, lowering DU.

Improving Flood Irrigation Systems

Flood irrigation system efficiency can be improved by reducing deep percolation below the root zone and reducing surface runoff. However, measures that reduce deep percolation can increase surface runoff and vice versa.

TABLE 7.8

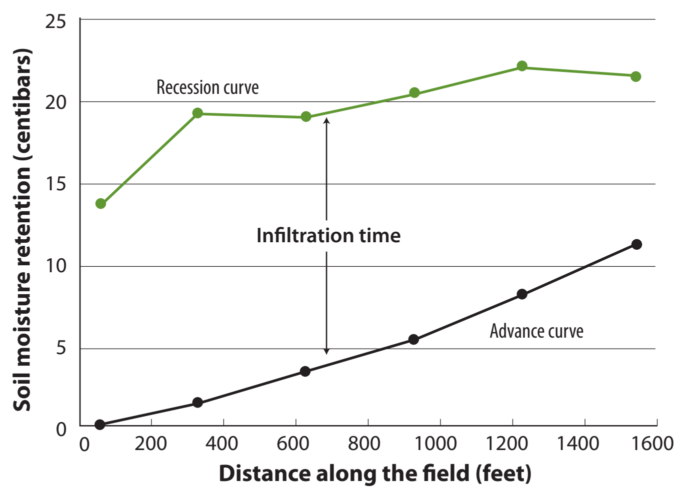
Recommended unit flow rates and border lengths for field slopes of 0.1 to 0.2 percent

Soil Type	Check Length (feet[1])	Unit Flow Rate (gpm/foot* of width)
Clay	1,300	7 to 10
Clay loam	1,300	10 to 15
Loam	1,300	25 to 35
Loam	600	15 to 20
Sandy loam	600	25 to 30
Sandy	600	30 to 40

*Multiply units per foot by 0.304 to determine check length in meters. Multiply gallons per minute (gpm) by 0.227 to obtain cubic meters per hour (cu m/hr).

FIGURE 7.9

Advance and recession curves for a flood-irrigated field.



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Some measures commonly recommended include:

Increase the check flow rate. This commonly-recommended measure reduces the advance time to the end of the field, thus decreasing variability in infiltration times along the field length. Yet, field evaluations showed only a minor improvement in the performance of flood irrigation under higher flow rates compared with lower flow rates (Howe and Heerman 1970; Schwankl 1990; B. Hanson, unpubl. data). The higher flow rates can potentially increase surface runoff.

Reduce the field length. This is the most effective measure for improving uniformity and for reducing percolation below the root zone. Studies have shown that shortening the field length by half can reduce percolation by at least 50 percent. The distribution DU of infiltrated water will be increased by 10 to 15 percentage points compared with the normal field length. Using the original flow rate into the check, the new advance time to the end of the shortened field generally will be 30–40 percent of the advance time to the end of the original field length. Thus, the irrigation set time must be reduced to account for the new advance time. Failure to reduce the set time will greatly increase both deep percolation and surface runoff. A major problem with this measure is the potential for increased surface runoff, which could be two to four times more runoff for the reduced length compared with the original field length (Hanson 1989).

Select an appropriate cutoff time. The amount of surface runoff or tailwater can be greatly reduced by decreasing the cutoff time of the irrigation water. This is the most effective measure for reducing surface runoff. The cutoff time for a given field may need to be determined on a trial-and-error basis. The cutoff time should occur before the water reaches the end of the field, except for sandy soils with high infiltration rates. However, the cutoff time should allow sufficient water to infiltrate the end of the field. Research in the Imperial Valley showed runoff to be about 2 percent of the infiltrated volume, for a cutoff time equal to the time for water to travel or advance to about 70 percent of the field length in cracked clay soil (Grismer and Bali 2001; Bali et al. 2001). A procedure for estimating the cutoff time for cracked clay soil is shown in Sidebar 2.

The effect of reducing the cutoff time on surface runoff is shown in Table 7.9, using data from evaluations of flood irrigation systems. The advance time to the end of this field was 670 minutes. A cutoff time of 800 minutes (grower's cutoff time) resulted in substantial surface runoff. Reducing the cutoff time to 600 minutes decreased the surface runoff by 82 percent, yet the infiltration time at the end of the field was adequate. However, a cutoff time of 500 minutes resulted in incomplete advance to the end of the field; thus, no infiltration occurred at the end of the field. The effect of the decreasing cutoff times on the uniformity of infiltrated water was slight until cutoff times were much less than the advance time.

TABLE 7.9

Effect of cutoff time on applied water, surface runoff, and distribution uniformity (DU)

Cutoff Time (minutes)	Applied Water (inches*)	Surface Runoff (inches*)	DU (%)
800	12.8	2.8	89
700	12.1	1.6	87
600	11.2	0.5	82
550	10.7	0.06	78
500	9.8	0	62

*To convert inches to millimeters, multiply by 25.4.

Recover surface runoff. Recirculation systems (commonly called tailwater-return systems), or storage-reuse systems, can dramatically improve efficiency of flood irrigation systems. Recirculation systems involve collecting the surface runoff in a small reservoir at the lower end of the field and then recirculating the water back to the "head" of the field during irrigation, using a low lift pump and a buried or portable pipeline. The recirculated water should be used

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Sidebar 2:

Management of Flood-Irrigation in Heavy Soils

Selecting an appropriate cutoff time can prevent excessive surface runoff. A relatively simple technique that predicts the cutoff time necessary to minimize runoff and to improve water use efficiency has been developed for heavy, cracked clay soil (Grismer and Tod 1994). In these soils, water flow into the cracks accounts for most of the infiltration. Little infiltration occurs after the cracks swell shut. Although the method is applicable for all soils, it works best with heavy clay soils. The main objective is to fill the soil cracks with water with little or no runoff. Based on experience in heavy clay soils in the Imperial Valley, the cutoff distance for most 0.25-mile (0.4-km) run borders is from 850 to 1,050 feet (259–320 m) for a wide range of flow rates and field conditions.

The following information is needed to estimate the cutoff time necessary to minimize or eliminate runoff:

- Border or check width and length (feet [meters]).
- Average check flow rate in cubic feet per second (cfs)[1].
- The times for the advancing water to reach 300 feet and 400 feet (91 m and 122 m) down the field.

This method requires the following setup in the field:

- Measure the flow rate.
- Place one stake at 300 ft (91 m) from the water inlet.
- Place a second stake at 400 ft (122 m) from the inlet.

The procedure for estimating the cutoff distance is:

Step 1: Determine the flow rate into a check.

Step 2. Determine the time difference of the water advance between the first and second stakes by subtracting the 400-foot (122-m) time (second stake) from the 300-foot (91-m) time (first stake).

Step 3: Use Table 7.10 to determine the cutoff distance for the check flow rate and the time difference.

Example

Determine the cutoff distance for a 1,200-foot-(366-m) long field with 65-foot (20-m) check widths. Four checks or borders are irrigated during each set using a flow rate of 9 cfs[1].

Step 1: The average flow rate per check is 9 cfs[1] ÷ 4 = 2.25 cfs/border.

Step 2: The time required for water to advance from the first stake to the second stake = 26 minutes.

Step 3: From Table 7.10, the cutoff distance for 2.2 cfs[1] and a time of 26 minutes is about 970 feet (296 m) down the field length.

[1]Note: 1 cfs = 449 gallons (2,041 l) per minute.

TABLE 7.10

Irrigation cutoff distance for border-irrigated alfalfa field

(Border width 65 ft [20 m], border length 1,200 ft [366 m], slope 0.1%)

Time (min)/100 ft [30 m] of advance	Flow rate (cfs)[1]				
	2.0	2.2	2.4	2.6	2.8
	Estimated cutoff distance (ft)[2]				
16				845	855
18	850	865	875	885	895
20	890	890	910	920	925
22	915	925	935	945	950
24	940	950	955	965	970
26	960	970	975	985	990
28	975	985	990	1,000	1,005
30	990	1,000	1,005	1,010	
32	1,000	1,010	1,020		

[1]1 cubic foot per second (cfs) = 449 gallons per minute

[2]To convert feet to meters, multiply by 0.304.

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to irrigate an additional area of the field. Simply recirculating the runoff back to the same irrigation set that generated the runoff results only in temporarily storing the water on the field and will increase the amount of runoff.

Similarly, a storage/reuse system involves storing all of the surface runoff from a field, then using that water to irrigate another field at the appropriate time. This approach requires a farm with multiple adjacent fields, a relatively large reservoir, and distribution systems to convey surface runoff to the storage reservoir and to convey the stored water to the desired fields.

Care should be taken that water quality is not degraded from storage-reuse systems. Pesticides have been found to infiltrate groundwater on some soil types, primarily from catchment basins, originating from field runoff. In these cases, steps to seal basins from subsurface infiltration may be effective at preventing contamination.

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Sprinkler Irrigation Systems

Sprinkler irrigation systems used for alfalfa production are wheel-line or side-roll systems, hand-move systems, and center-pivot and linear-move sprinkler machines. Wheel-line and hand-move sprinklers are classified as periodic-move systems, whereas center-pivots and linear-moves are classified as continuous-move systems.

Wheel-line/Hand-move Sprinkler Systems

Wheel-line sprinkler systems consist of aluminum lateral pipes rigidly coupled together and mounted on large aluminum wheels. The lateral pipe is the axle of the system, with the wheel spacing equal to the sprinkler spacing and the sprinklers located midway between wheels. The sprinkler lateral is moved with an engine mounted at the center of the line that twists the pipe and causes the lateral to roll sideways, hence the common name of side-roll sprinklers. Wheel-line systems are best suited for fields that are rectangular with relatively uniform topography. Frequently, one wheel-line lateral is used for each 40 acres (15 ha). A common sprinkler spacing for both wheel-lines and hand-moves is 40 × 60 feet (12 × 18 m).

The move distance depends on the wheel diameter and the number of wheel revolutions. Normally, lateral moves of 60 feet (18 m) are common; these require four revolutions of a 4.8-foot (1.5-m) diameter wheel (circumference equals 15 feet [4.6 m]). Before moving the lateral, the pipe must be drained using quick drains installed at each sprinkler location.

Wheel-line and hand-move laterals frequently are about 1,300 feet (396 m) long. A 4-inch (102-mm) diameter pipe is commonly used; however, 5-inch (127-mm) pipe is also used, which results in less pressure loss along the lateral length. A sprinkler spacing of 40 feet (12 m) is normally used along the lateral, whereas a 60-foot (18-cm) lateral spacing along the mainline is frequently used. However, sometimes a 30-foot (9-m) sprinkler spacing and a 50-foot (15-m) lateral spacing are used.

Sprinkler nozzles normally used for wheel-line and hand-move systems are 5/32 inch (3.96 mm), 11/64 inch (4.34 mm), 3/16 inch (4.75 mm), and 13/64 inch (5.16 mm). In some cases, a small nozzle, called a spreader nozzle, is also used along with the larger nozzle. Self levelers are recommended for wheel-line systems to ensure that the sprinkler remains upright after a move.

Factors Affecting Performance

Primary factors affecting the uniformity of sprinkler systems are pressure losses in the mainline, submains, and laterals, and the areal distribution of water between sprinklers.

Pressure Losses. Pressure losses are caused by friction between the flowing water and the pipe wall and by elevation differences throughout the field. Factors affecting friction losses are the flow rate of water, length and diameter of the pipeline, and pipe material. Pressure losses are very sensitive to pipe diameter. For a given flow rate, pressure losses along a 4-inch (102-mm) diameter lateral are nearly three times those of a 5-inch (127-mm) diameter lateral. Pressure decreases rapidly with distance along the lateral for the first one-third of the lateral length and thereafter decreases slowly with distance due to a progressively decreasing flow rate with distance along the lateral. A change in elevation of 2.31 feet (0.704 m) causes a pressure change of 1 psi (6.9 x 10^3).

Sprinkler Uniformity. Sprinkler uniformity can be measured by performing catch-can tests that measure actual applied water across a given area. Catch-can uniformity describes the real distribution of water between sprinklers. It depends on sprinkler pressure, wind speed, sprinkler and lateral spacings, sprinkler head and nozzle type, and system maintenance.

Contour plots of the water application pattern of a single sprinkler are shown in Figure 7.10. These plots were developed by first measuring the applied water at many locations around the sprinkler with catch cans. Both applied water and can location were entered into graphics software (Surfer, Golden Software, Golden, CO), which drew lines of equal water applications and then assigned colors to the water applications. Blue represents a high application; red indicates a very small application.

The water application pattern of a single sprinkler operating at an acceptable pressure shows a circular pattern, with high applications near the sprinkler (dark blue to light blue) and decreasing with distance from the sprinkler (Fig. 7.10A). Near the edge of the pattern (yellow, red), water applications decreased rapidly with distance. Insufficient pressure results in a donut-shaped pattern due to inadequate spray breakup, with large applications near the sprinkler and near the edge of the pattern (blue to green) (Fig. 7.10B). Wind distorts the pattern of a single sprinkler by blowing most of the water downwind of the sprinkler (Fig. 7.10C).

Relatively high uniformity of applied water is achieved by overlapping the water application patterns of a single sprinkler. Uniformity is highly dependent on the sprinkler spacing along the lateral, the lateral spacing along the mainline, and wind speed. The overlapped pattern of a 40 × 60 foot (12 × 18 m) spacing shows relatively small differences in applied water throughout the wetted area under low wind conditions (2 mph), resulting in a DU equal to 85 percent (Fig. 7.11A). Under high wind conditions (18 mph), large differences in applied

FIGURE 7.10

Water distribution pattern of (A) a single sprinkler operating at an acceptable pressure (low wind conditions); (B) a single nozzle operating at a low pressure (low wind conditions); and (C) a single nozzle operating at an acceptable pressure under high wind conditions. The black dots show the locations of the sprinkler for each pattern. The arrow shows the wind direction.

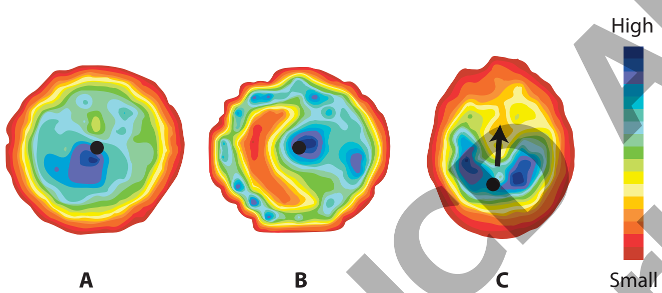
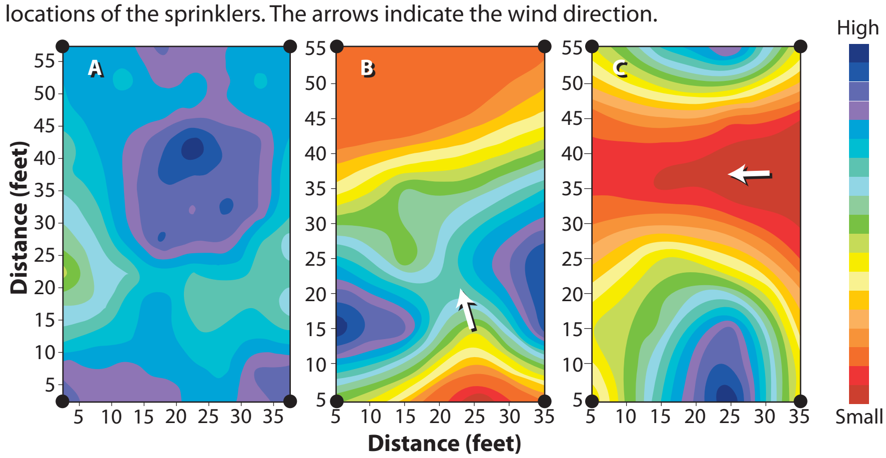


FIGURE 7.11

Contour plots of the applied water for overlapped sprinklers (40 ft × 60 ft [12 m × 18 m]) for (A) a low wind condition (11/64 in. [3.96 mm], 55 psi, 2 mph, DU = 85%), (B) a high wind condition with the lateral perpendicular to the wind direction (11/64 in. [3.96 mm], 40 psi, 18 mph, DU = 35%), and (C) a high wind condition with the lateral parallel to the wind direction (11/64 in. [3.96 mm], 40 psi, 18 mph, DU = 25%). The black dots show the locations of the sprinklers. The arrows indicate the wind direction.



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water occurred throughout the wetted area, as indicated by the colors ranging from dark blue to red. The DU was 34 percent for a wind direction perpendicular to the sprinkler lateral (Fig. 7.11B) and 25 percent for a wind direction parallel to the sprinkler lateral (Fig. 7.11C).

The contour plots in Figure 7.12 show the effect of sprinkler spacings on the DU. The DU decreased slightly as the sprinkler spacing increased for low wind conditions (2 mph) (Fig. 7.12A). Relatively low DUs occurred only for very large spacings. High wind conditions (10 mph) resulted in large decreases in DU as sprinkler spacing increased (Fig. 7.12B). High DUs occurred only for relatively small spacings. The DU decreases in a straight line manner as wind speed increases (Fig. 7.13).

Improvement Measures. Methods for improving the uniformity of existing wheel-line or hand-move systems include the following:

- Install flow-control nozzles where the pressure variation is excessive.
- Use appropriate sprinkler spacings.
- Maintain adequate sprinkler pressure.
- Offset laterals (beneficial for high wind conditions).
- Maintain system. Avoid mixing nozzle sizes; repair malfunctioning sprinklers and leaks; replace rubber orifice in nozzles periodically; and maintain risers in a vertical position.

FIGURE 7.12

Distribution uniformity for a 11/64-in. [3.96-mm] diameter nozzle at 55 psi for different sprinkler spacings for (A) wind speeds of 2 mph and (B) 20 mph (mph × 1.6 = km/hr; ft × 0.304 = m).

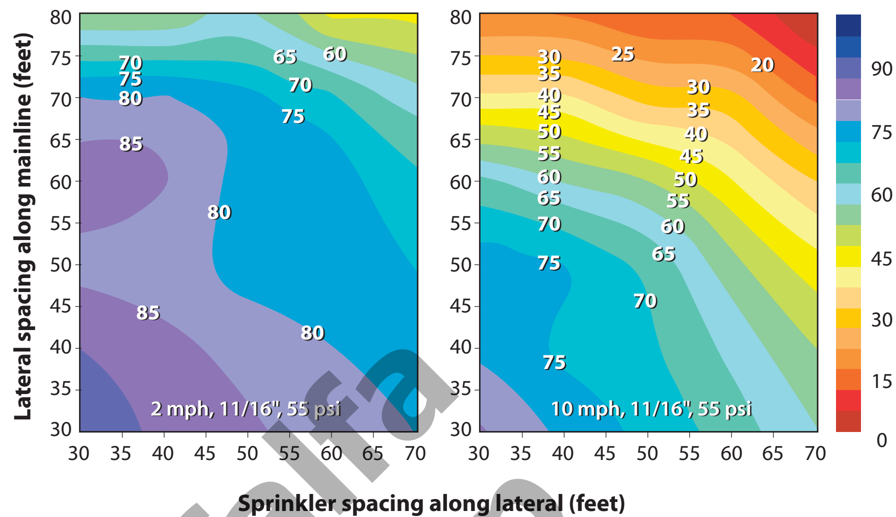
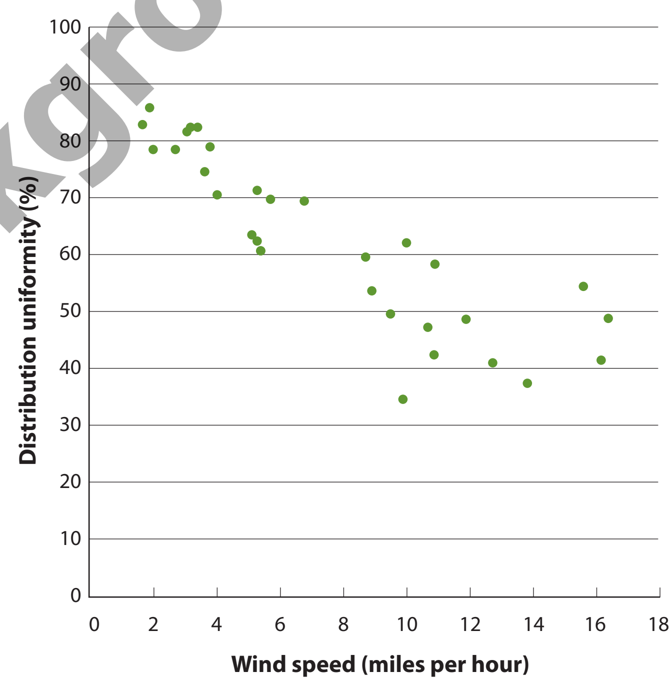


FIGURE 7.13

Effect of wind speed on distribution uniformity (mph × 1.6 = km/hr).



Flow-control nozzles that contain a flexible orifice that changes diameter as pressure changes can be installed; thus, less variation occurs in sprinkler discharge rate with pressure compared to standard nozzles. Note: the rubber orifice in these nozzles will eventually harden, resulting in much higher and nonuniform nozzle discharge rates. They should be periodically checked and replaced every 2 to 3 years.

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Center-pivot/Linear-move Sprinkler Irrigation

Center pivot machines consist of a lateral pipeline mounted on top of self-propelled towers. The lateral is suspended about 10 feet (3 m) above the ground. Distance between towers or span length can range from 90 to 250 feet (27–76 m). A flexible joint connects the spans together. A typical lateral length is about 1,300 feet (396 m), which can irrigate about 130 acres (52.6 ha), for a complete circle. The common lateral diameter is 6 5/8 (6.625) inches (168 mm), but diameters up to 10 inches (254 mm) also are available. The lateral rotates around a fixed pivot point, with the rate of rotation controlled by the outermost tower.

High-pressure center pivots use impact sprinklers mounted on top of the lateral. Low-pressure systems use spray nozzles, spinners, or rotator nozzles installed at the end of drop tubes. The drop tube is suspended just above the plant canopy. The drop-tube approach is less susceptible to wind effects compared with impact sprinklers.

Because the center-pivot machines rotate about a fixed point, more and more area is irrigated per unit length of lateral as the distance along the lateral from the pivot point increases. Thus, application rates must increase with distance from the pivot point to maintain high field-wide uniformity. Application rates are increased by using progressively larger nozzles, progressively smaller sprinkler spacings, or some combination of both. Application rates may exceed several inches (mm) per hour near the end of the lateral, whereas application rates are a fraction of this near the center of the pivot.

Center-pivot systems are best suited for soils with high infiltration rates, relatively uniform topography, and no aboveground obstructions. The high application rates of center-pivot systems have restricted their use in many areas of California because infiltration rates of many California soils, particularly in the Central Valley, are too low to be suitable for this irrigation method.

Linear-move sprinkler machines use the same technology as center-pivots, but they travel in a straight line. A water supply ditch or pipeline that parallels the travel direction is required. A guidance system is used to keep the machine traveling in a straight line. An engine-driven pump is mounted on the tower adjacent to the ditch to supply water and electrical power to the lateral. These systems are best suited for rectangular fields with no obstructions and a relatively uniform topography. An uneven topography can cause problems with the guidance system. In contrast to center-pivot systems, the application rate along the lateral length is relatively constant since all towers travel at the same speed. This system can be used on soils with low infiltration rates.

Distribution uniformities of center-pivot and linear-move sprinkler machines normally are higher than those of hand-move and wheel-line sprinklers. The more-or-less continuous movement of these machines maintains a better precipitation pattern even as the wind speed increases. Potential distribution uniformities of these machines are 80 to 90 percent.

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Drip Irrigation

Drip irrigation precisely applies water throughout a field, in terms of both amount and location. Potential advantages of drip irrigation include increased crop yield, reduced water and energy costs, and reduced fertilizer costs. Potential disadvantages include the high capital cost of drip irrigation systems, possible increased energy costs compared with those of flood or border irrigation, and maintenance costs to prevent clogging and repair leaks. One advantage of drip irrigation of alfalfa is that irrigations could continue during the harvest period as long as no wetting of the soil surface occurs. However, drip irrigation is not widely used in alfalfa, and important practical limitations must be considered.

One advantage of drip irrigation of alfalfa is that irrigations could continue during the harvest period as long as no wetting of the soil surface occurs.

Drip irrigation systems discharge small amounts of water through emitters periodically installed at set distances along drip lines. Emitter discharge rates can range from 0.13 gallons (0.59 l) per hour to 2 gallons (9.1 l) per hour, depending on the type of material and size of hose used for drip laterals.

Components of a drip system include pump, filters (primary and secondary), injection equipment for fertigation and chemical treatment for clogging, flow meter, mainline and submains, manifolds, drip lines and emitters, pressure regulators, and flushing valves/manifolds. More detail about drip irrigation systems is found in Hanson et al. (1997).

Normally, drip irrigation of row crops uses a flexible drip tape that inflates upon pressurization. The drip tape may be either installed on the ground surface (surface drip system) or buried (subsurface drip systems). Depending on the grower's preferences for cultivation equipment and crop rotation, drip lines are usually installed at depths of 9 to 18 inches (229–457 mm). Because of harvesting and other traffic considerations, surface drip is not practical for alfalfa. Subsurface drip lines may need to be installed as deep as 18 to 24 inches (457 to 610 mm) to prevent wetting of the soil surface during irrigation, which could cause problems for the harvesting equipment. A drip tape wall thickness of 15 mil provides sufficiently heavy walls to prevent damage by wireworms and other subterranean insects with scraping mouthparts that can cause pinhole leaks in the tape. However, a 10-mil wall thickness is the most common compromise between cost and this type of possible damage, usually providing adequate performance.

For deeper installations, heavy-walled drip tubing with inline emitters is recommended. Drip tubing is a flexible hard hose that retains its roundness when empty. Drip tubing may be needed for alfalfa drip irrigation systems because the drip lines may need to be installed at depths deeper than 15 inches (38 cm) to prevent surface wetting of the soil, which can cause problems with the harvesting equipment.

Drip emitters are highly susceptible to clogging. Suspended materials in the irrigation water, such as algae, sand, silt, and clay, can block the flow passage in the emitters. Precipitation of chemicals such as calcium carbonate and iron oxide, biological growths, and root intrusion can also reduce or block flow. Thus, proper filtration must be used to remove suspended materials from the irrigation water, and chemical treatment of the water may be needed to prevent or correct clogging problems caused by precipitation or biological growths. These matters are addressed in Schwankl et al. (2008). Fields to be used for drip irrigation of alfalfa should be free of burrowing rodents before installing a drip system. Irrigation setups that allow occasional flood irrigations for alfalfa may assist in controlling burrowing rodents, which have been found to have increased populations in drip systems.

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Does drip irrigation of alfalfa pay? Factors that determine the answer to this question include the capital and maintenance costs of the drip systems, the effect of drip irrigation on energy costs, yield, and water and fertilizer use. Crop price will also play a major role. If the combination of yield increase and crop price increases profits under drip irrigation compared to other irrigation methods, then drip irrigation pays. However, low crop prices may prevent drip irrigation from being more profitable compared to other irrigation methods, even though drip irrigation results in higher yields. The answer is very site specific and cannot be predicted with any degree of confidence without first experimenting with drip irrigation of alfalfa.

The potential for yield improvements (and therefore improvements in water-use efficiency) are potential positive features of drip irrigation for alfalfa, but there are important cost and practical limitations.

Does drip irrigation save water? Because proper irrigation scheduling with a drip system reduces stress in alfalfa, the crop can potentially use more water than with other irrigation systems. From the production function shown in Figure 7.1, increased yield means that the crop is using more water. So, unless surface runoff from the field is substantial and not reused, or the soil is very sandy with lots of deep percolation lost below the root zone, water savings may not result from using drip irrigation. Hutmacher et al. (2001) found little savings of water with drip compared with surface irrigation systems, and some practical problems with some drip configurations, but significant yield improvements with buried drip compared with surface systems. The potential for yield improvements (and therefore improvements in water-use efficiency) are potential positive features of drip irrigation for alfalfa, but there are important cost and practical limitations.

Summary

Irrigation management is one of the most critical aspects of successful alfalfa production. Water levels (deficit or excess) limit alfalfa production to a greater degree than any other factor in western states. Key management factors include (1) irrigation system design for maximum uniformity and efficiency, (2) irrigation scheduling to determine when to apply irrigation water and how much to apply, using data on evaporative demand and soil characteristics, and (3) soil moisture monitoring to determine accuracy of irrigation application, presence of soil moisture, and to monitor moisture over the season.

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