CHAPTER FOUR

IRRIGATION

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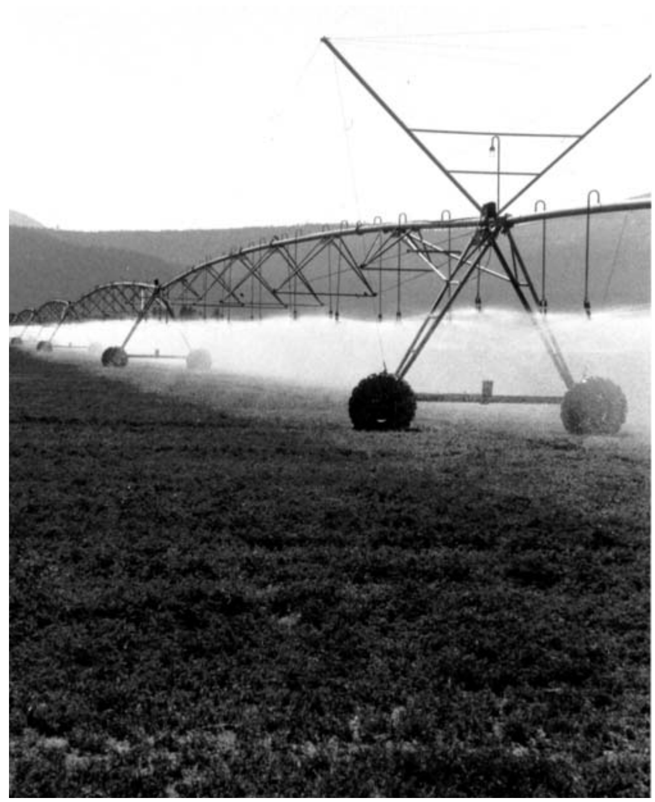

The Intermountain Region has a high-desert climate where irrigation must provide the majority of water needed for alfalfa growth. Improper irrigation management limits alfalfa yields in the Intermountain Region more often and to a greater extent than does any other aspect of alfalfa production. The return from other inputs (i.e., variety improvement, fertilizer, and pest control) will be significantly reduced or eliminated if a lack of water limits crop development. Therefore, properly applied and timed irrigations are critical for maximum yield and profit.

Figure 4.1 shows the typical alfalfa yield response to applied irrigation in the Intermountain Region. As irrigation increases, so do alfalfa yields—but only to the point where crop water needs have been met. Applying water over and above crop requirements does not improve yield and only adds to the cost of production. What is more, excess water may increase pest and disease problems and shorten alfalfa stand life.

The actual shape of the yield response curve varies from location to location and from year to year. The minimum yield without irrigation, the optimum irrigation level, and the maximum potential yield vary based on soil type, rainfall, and seasonal temperatures. Still, most alfalfa grown in the region follows the trend illustrated in Figure 4.1.

Proper irrigation management leads to increased yields, improved stand health, and a reduction in unnecessary water use. This chapter will discuss the basics of alfalfa irrigation scheduling and water application techniques. Sound irrigation practices are based on an understanding of how water is stored in the soil, crop water requirements, and irrigation system design and operation.

WATER STORAGE

Soil is the storage reservoir from which plants extract water (Figure 4.2). If too much water is applied, the storage reservoir will overflow and water will run off or percolate below the root zone of the crop. If the storage reservoir gets too low, plants will be stressed and yield reduced. The key to irrigation management is to keep the soil-water reservoir full enough to avoid plant stress but not overfill the reservoir.

Soil type determines the capacity of the soil reservoir. Soil is composed of soil particles of varying sizes,

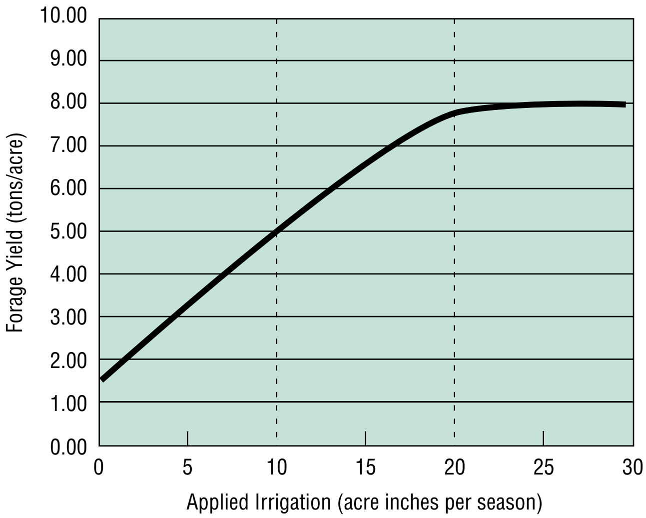

Figure 4.1. Typical yield response of alfalfa to applied irrigation in the Intermountain Region.

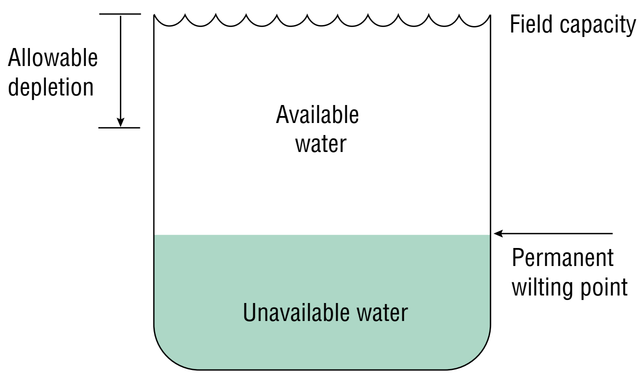

Figure 4.2. Think of the soil-water reservoir as a storage tank. Only a portion of the water in the tank is available to plants. To avoid yield reductions, keep the storage tank filled to a level between field capacity and the allowable soil depletion level.

organic matter, and voids, or pore spaces. Water occupies some of the pore spaces and is held as a film around soil particles. The more pore spaces, the greater the water-holding capacity. Sandy soils (coarse-textured soils) have large pores, but fewer total pores than clay (fine-textured) soils. Therefore, the water-holding capacity of sandy soils is far less than that of clay soils.

Available Water

After an irrigation or heavy rainfall, water fills the pore spaces; the soil is saturated. Under the influence of gravity, water drains from the larger pore spaces and gradually moves deeper into the soil profile. Downward movement of water slows considerably within 1 to 3 days after irrigation. The water that remains in the soil after this initial drainage is considered stored. When the soil has stored all the water it is capable of holding, the soil profile is full, or at field capacity.

Not all the water held in soil is available to plants. A portion is held so tightly by soil particles that it is unavailable. The amount of water plants can extract from the soil is called available water. If plants extract all the available water, the soil dries to the permanent wilting point. When this happens, plants wilt and die. Table 4.1 shows the available water content for different soil types. Note that the available water content of coarse sand is very small (less than 1 inch available water per foot of soil) compared to that of the clay soils (which have more than 2 inches available water per foot of soil). Table 4.1 cites values for general soil types. To find values for your soils consult Soil Surveys available from the Natural Resources Conservation Service, or study University of California (UC) Leaflet 21463, *Water-Holding Characteristics of California Soils.*

Water Storage Capacity

To determine the total water storage capacity of a soil, a grower must consider the rooting depth of the crop. Although alfalfa roots may penetrate as deep as 12 feet in some soils, the effective rooting depth for irrigation purposes is generally assumed to be 4 feet. The assumption is based on the fact that most of the water is extracted from the upper portion of the root system (Figure 4.3). Approximately 70 percent of the water is extracted by the upper half of the root system. To calculate the total storage capacity of the soil, multiply the available water content of the soil in inches per foot of soil by the rooting depth of the crop. For example, the calculation to determine the available water storage capacity of a sandy loam soil follows.

1.5	in. available water/ft.
x 4	ft. of rooting depth
6	in. total storage capacity

If you are calculating the water storage capacity of a field of young alfalfa or a field with a restricted root zone, dig a hole to see how deep the roots actually go. If you used the standard 4-foot rooting depth in your calculation, the result will be inaccurate.

Table 4.1. Estimates of available water content and allowable depletion for different soil types.

SOIL TYPE	AVAILABLE WATER (IN./FT.)	ALLOWABLE DEPLETION (IN./FT.)	4 FT ROOT ZONE[1] AVAILABLE WATER (IN.)	4 FT ROOT ZONE[1] ALLOWABLE DEPLETION (IN.)
Coarse sand	0.5	0.25	2.0	1.0
Fine sand, loamy sand	1.0	0.50	4.0	2.0
Sandy loam	1.5	0.75	6.0	3.0
Fine sandy loam, loam, silt loam	2.0	1.00	8.0	4.0
Clay-loam, silty clay	2.2	1.10	8.8	4.4
Clay	2.3	1.15	9.2	4.6
Organic clay loams	4.0	2.00	16.0	8.0

1. A 4-foot root zone is a typical effective rooting depth for alfalfa.

Allowable Depletion

As soil dries, soil particles hold stored water more tightly. Extracting water becomes increasingly difficult for plants. Extraction may become so difficult that plants cannot meet their water needs. If this occurs, growth slows and yields decline. The amount of water loss that can occur before water extraction becomes too difficult is termed the allowable depletion (Table 4.1). For alfalfa, allowable depletion is 50 percent. To avoid yield reductions, irrigate the field before 50 percent of the available water has been depleted. Keep in mind, however, that 50 percent allowable depletion is a maximum value. Fields can be irrigated before 50 percent of the available water has been depleted without reducing yield.

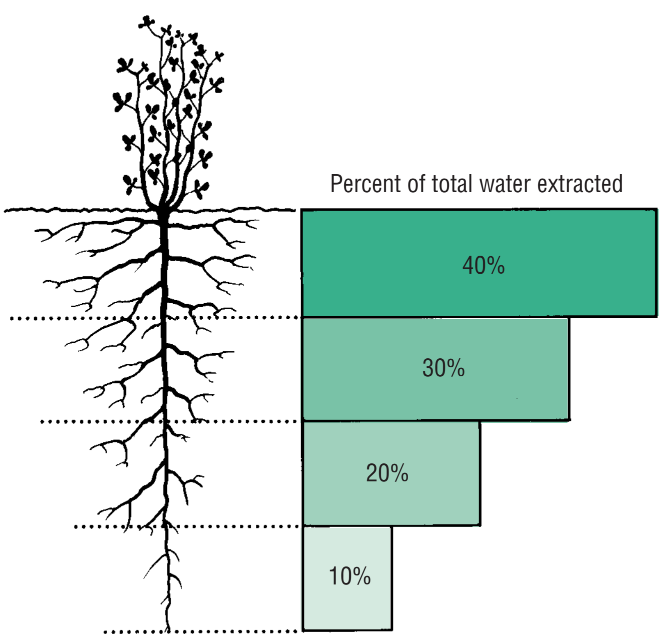

Figure 4.3. Typical water extraction pattern of alfalfa roots.

As you can see, an understanding of soil properties allows you to answer the two questions paramount to irrigation: When to irrigate? and How much to apply? Irrigate the field when 50 percent or less of the available water in the soil has been depleted. The amount of water to apply is the amount required to fill the soil reservoir to field capacity.

IRRIGATION SCHEDULING

Two principle methods are used to schedule irrigations in alfalfa fields. One method relies on soil-based measurements; the other is called the water budget method; and it involves weather monitoring. Both methods can be equally effective. The best approach, however, is to use both. Throughout the season, verify recommendations based on the water budget method by using soil-based measurements.

The Soil Moisture Method

Measuring soil moisture

The moisture status of soil can be monitored in various ways. Each of the moisture measurement techniques described below can help to schedule irrigations.

THE LOOK-AND-FEEL METHOD Enough experience with a given soil type allows a grower to estimate soil moisture conditions by simply feeling the texture and dampness of a soil sample. For example, samples from clay or clay-loam soils that can be made into a firm round ball with light hand pressure are considered to be adequately moist, but samples that crumble into powder when crushed in hand are considered to be too dry. The look-and-feel method works well for many experienced growers, but it is fairly imprecise. Its major disadvantages are that proper feel and texture vary among soil types and the ability to schedule irrigations based on feel alone requires skill and years of experience. The major advantages of this method are that it is quick and samples can be easily taken from many areas of the field. The ability to check fields often is important because the look-and-feel method does not indicate when the soil is becoming too dry. In other words, some water stress might occur before the look-and-feel method indicated the need to irrigate.

Improper irrigation . . . limits alfalfa yields . . . more often and to a greater extent than any other aspect of alfalfa production.

TENSIOMETERS Soil moisture tensiometers measure how strongly soil particles hold water. Wet soil holds water more loosely than dry soil.

A tensiometer is usually a 1-inch tube made of plastic. It is filled with water and sealed on the top with a mounted vacuum gauge. On the bottom, the tube is fitted with a porous ceramic tip. The tube is installed in soil, with the tip at the desired monitoring depth. As soil dries, water moves out of the tube, through the porous tip, and into the drying soil. The movement out of the tube creates a suction (negative pressure) that the gauge measures. The drier the soil, the greater the negative pressure measured on the gauge.

Researchers have determined the allowable soil depletion, in terms of tensiometer pressure readings, for many crops. Yield loss does not occur with alfalfa until negative pressures rise above 70 to 80 centibars—the pressure depends on the soil type. Plant stress occurs at lower tension readings in sandy soil than in heavy clay soil.

Reading a tensiometer is quick and convenient. By placing several tensiometers at different depths, you can quickly determine soil moistures at various locations in the root zone. The major advantage of tensiometers is that pressure readings can be correlated with plant yield responses.

The biggest disadvantage of tensiometers is that they need to be permanently installed. In some installations the gauge and top portion of the tensiometer is above ground. This makes haying difficult and haying equipment often damages the meters. However, more elaborate installations can be made that place the whole instrument below ground. Frequent replacement is expensive because of the cost of parts and labor.

Tensiometers must be properly installed to work correctly. Take extra care to seat the instrument's tip into the soil and to avoid gaps between the tube and soil that allow irrigation water to run down the side of the tube. Tensiometers also require frequent servicing to replace the water lost from the tube. They must be removed in the winter to prevent damage from freezing.

MOISTURE BLOCKS Although many models of moisture blocks are available, they all do the same thing. They electronically monitor the relative moisture content of a buried ceramic or gypsum block. As the soil dries, the relative moisture content of the buried block also declines. Some models measure the moisture content of the buried block by measuring the resistance between internal electrodes in the block; others measure heat dissipation between a heat source and a thermistor. Regardless of how the block works, meters are available that read in centibars, and the readings are approximately equivalent to those from a tensiometer: Allowable depletion occurs between 70 and 80 centibars, depending on soil type.

Like tensiometers, moisture blocks are easy to read at any time. They can be installed at several depths at a given monitoring site, and the readings correlate well with plant moisture needs. In addition, the blocks may be fitted with long underground wires that lead to a central reading station. Such a configuration greatly minimizes the risk of equipment damage to the block, and it certainly makes reading the blocks more convenient.

Disadvantages of the blocks are the high purchase cost, the care and time needed to install the blocks in the soil, and the problem of tearing out wire leads if the wires are not set underground or if reading stations are not well placed. With moisture-sensitive crops such as many vegetables, soil moisture blocks have the additional disadvantage of not being as sensitive as tensiometers under high soil moisture conditions. Fortunately, deep rooted alfalfa can tolerate lower soil moisture readings so the drier operational range of moisture blocks is adequate for irrigation scheduling in alfalfa.

NEUTRON PROBES The most technologically advanced method of measuring soil-water content is the neutron probe. This instrument contains a radioactive source and measures soil-water content by emitting fast neutrons into the soil and then measuring the return of slow neutrons back to the instrument. The number of neutrons returned is directly proportional to the number of hydrogen atoms the initial emission encountered. Most of the hydrogen atoms in the soil are components of water, so the number of returning neutrons reflects water content.

Because of cost, technical complexity, and health and safety regulations regarding the use of radioactive material, leave neutron probes to professional irrigation consultants who have the training and permits required to use the instrument.

Using soil moisture data

The best way to apply soil-moisture measurements to irrigation scheduling is to plot the measurements on a graph. The plotted data present a picture of how fast the soil is drying (Figure 4.4). For example, following a full irrigation that completely fills the soil profile, the tensiometer reading is low (point A in Figure 4.4). As alfalfa grows, it draws on the soil-water and the tensiometer readings begin to rise. After a few points have been plotted, you can estimate approximately how many days it will take for the soil to dry to the allowable depletion (80 centibars in this example). By day 10, in this example, three points have been plotted, so you can estimate that the soil will be dry enough to warrant irrigation on about day 20. The next reading, on day 14, confirms this estimate; water is applied on day 20. By that time the soil had indeed dried to the point of allowable depletion and irrigation was necessary. The graph indicates that the irrigation did not completely refill the soil profile—that is, on the day following irrigation, the tensiometer dropped to only about 40 centibars (point C). As explained earlier, the amount of water to apply in a given irrigation is determined by the soil type and the percentage depletion. The soil in this example is a fine sandy loam, so the allowable depletion is about 4 inches (1 in. x 4 ft of rooting depth). The irrigation applied at point B was less than 4 inches, so another irrigation was needed 10 days later. The second irrigation was a 4-inch irrigation, which filled the soil profile and returned the tensiometer reading to near 0 (point D).

In scheduling irrigations or in monitoring irrigation effectiveness, it is important to sample soil moisture at more than one depth. In the case of a mature alfalfa crop, place tensiometers or moisture blocks at 18 inches and 36 inches in the soil. Use readings taken at 18 inches to schedule irrigations; use the readings at 36 inches to determine if the crop is using deep water and if irrigations are completely filling the soil profile.

The Water Budget Method

UNDERSTANDING THE WATER BUDGET CONCEPT As the term budget implies, the water budget method involves tracking additions and losses

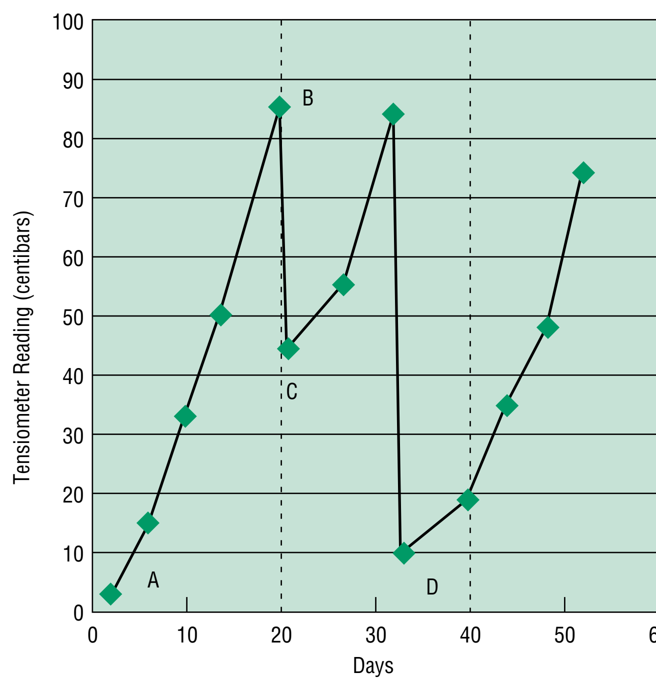

Figure 4.4. Plot of tensiometer readings following irrigation and drying cycles. A = initial low tensiometer reading following a full irrigation; B = reading indicating high pressure following several days of crop water use, just prior to an irrigation; C = reading after partial irrigation that did not fill the soil profile; D = reading after a full irrigation.

and balancing them. The losses are due to crop water use and inefficiencies in the irrigation system. The additions are due to irrigation and rainfall. The objective of the water budget method is to maintain soil moisture near the optimum level by keeping track of crop water use and then irrigating to replace the water used. Knowledge of crop water use is essential to using the water budget approach.

Crop water use is also called evapotranspiration (ET). The term *evapotranspiration* refers to the combined loss of water through evaporation from the soil and from water taken up and evaporated from the plant (transpiration). The rate at which plants use water is determined by the growth stage of the plant and by weather. Small plants use less water than large plants, for example, and all plants use more water when it is hot than when it is cool. Plants use more water on sunny days than cloudy days, and on days with high winds. For these reasons, plants use much less water in the spring and fall than during the long hot days in the middle of the summer. Figure 4.5 shows how daily water use of alfalfa near Tulelake, California, fluctuates throughout the growing season.

Over the years, irrigation scientists have quantified the effects of weather on plant water use. By using weather data you can predict with reasonable accuracy the water use of alfalfa in a specific region. The data needed include measurements of relative humidity, wind velocity, air temperature, and light intensity. Irrigation science has progressed to a point where such predictions are sufficiently accurate to be used for irrigation scheduling.

Crop water use values for irrigation scheduling may be obtained from several sources. Some local newspapers publish current values. Reference ET values for Tulelake, McArthur, and Alturas are calculated daily by the California Department of Water Resources (DWR) and can be obtained through DWR's California Irrigation Management Information System (CIMIS). You can use these ET values for other locations in the Intermountain Region by selecting the location with weather conditions most similar to those

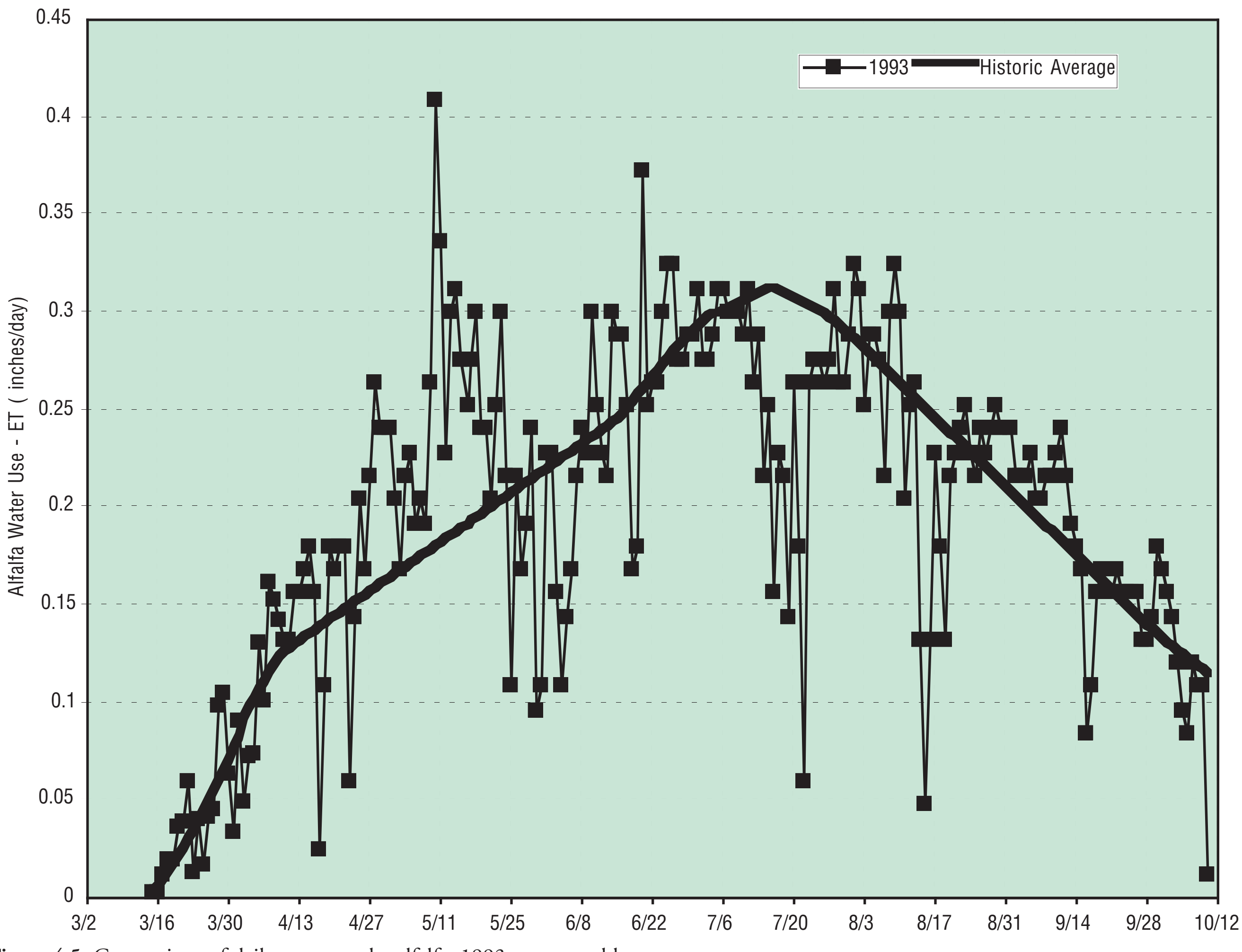

Figure 4.5. Comparison of daily water use by alfalfa: 1993 season and long-term average.

in your area. The reference values are based on pasture use, however. You must modify them to estimate alfalfa water use before using the values for irrigation scheduling. UC Farm Advisors can assist you with the conversion. In most situations, historical long-term averages of water use by alfalfa suffice for irrigation-scheduling purposes. Table 4.2 shows average long-term water use values for Tulelake. Adjust long-term averages to reflect current weather conditions, since weather can vary significantly from year to year and there is no such thing as an "average" year. For example, contrast the daily water use shown in Figure 4.5 with the long-term average daily use.

When to Irrigate

At the start of the production season, the soil profile is filled with water from rainfall or irrigation. From that point on, the grower tracks daily crop water use and keeps a running total of it. Once total crop water use, or total soil water depletion, equals or approaches the allowable depletion, the field should be irrigated (Figure 4.6). After irrigating and refilling the soil-water reservoir, daily crop water use is again calculated and added to the total water use to date. Another irrigation is scheduled when soil-water depletion since the last irrigation approaches the allowable depletion. Figure 4.7 summarizes the steps of the water budget method.

Water requirements of alfalfa are based on weather conditions and do not change because of soil type. Many believe that alfalfa grown on sandy soil needs more water than that grown on another type of soil. The fact is that alfalfa grown on sandy soil does not need more total water; it does, however, need irrigation more frequently and at lower volume (for a shorter set time or with smaller nozzles). This is so because sandy soil has less water storage capacity than do other soil types. Table 4.3 shows minimum recommended irrigation frequencies for different soil types in the Intermountain Region. The recommendations are based on historical data on crop-water use. Looking at Table 4.3, compare the irrigation frequency for a sandy soil to that for a clay soil. During July for example, a

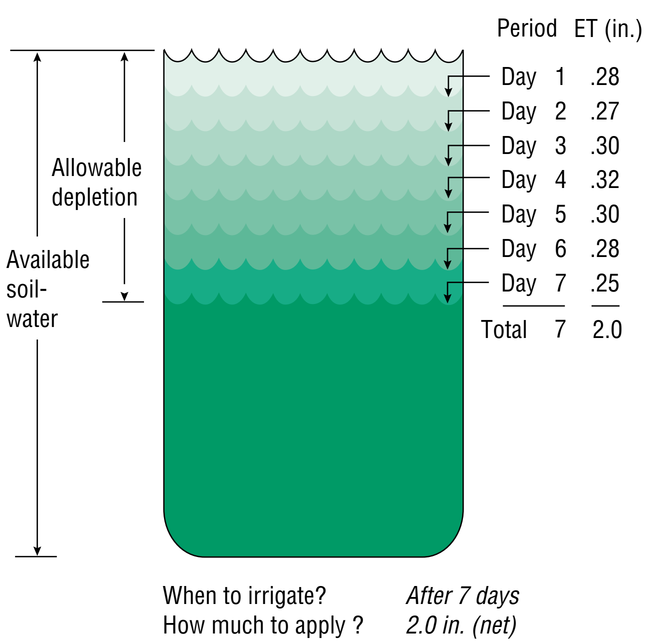

Figure 4.6. The water budget method. Daily ET is accumulated until the allowable depletion is reached. The field is then irrigated to refill the soil-water reservoir.

Table 4.2. Average weekly and daily water use by alfalfa in the Tulelake Basin.[1]

WEEK BEGINNING (MO. AND DAY)	WEEKLY TOTAL (IN.)	DAILY AVERAGE (IN.)
3/15	0.10	0.01
3/22	0.32	0.05
3/29	0.59	0.08
4/5	0.83	0.12
4/12	0.95	0.14
4/19	1.04	0.15
4/26	1.13	0.16
5/3	1.22	0.17
5/10	1.30	0.19
5/17	1.39	0.20
5/24	1.48	0.21
5/31	1.57	0.22
6/7	1.66	0.24
6/14	1.76	0.25
6/21	1.91	0.27
6/28	2.05	0.29
7/5	2.13	0.30
7/12	2.18	0.31
7/19	2.14	0.30
7/26	2.05	0.29
8/2	1.93	0.28
8/9	1.81	0.26
8/16	1.69	0.24
8/23	1.56	0.22
8/30	1.44	0.21
9/6	1.33	0.19
9/13	1.19	0.17
9/20	1.07	0.15
9/27	0.95	0.14
10/4	0.85	0.12

1. Based on long-term average weather data

Table 4.3. Recommended irrigation frequencies for alfalfa produced on different soil types in the Intermountain Region. (see notes below.)

		Irrigation Frequency[1] (Days between irrigations)					
Soil Type	Irrigation Amount[2]	Apr.	May	June	July	Aug.	Sept.
Coarse sand	1.00	7	5	4	3	4	6
Fine sand, loamy sand	2.00	14	10	8	7	8	12
Sandy loam	3.00	21	15	13	10	12	18
Fine sandy loam, loam, silt loam	4.00	29	20	17	13	15	24
Clay-loam, silty clay	4.40	–	22	18	15	17	26
Clay	4.60	–	23	19	15	18	27
Organic clay loams	8.00	–	–	33	27	31	–
Daily crop water use (in.)		**.14**	**.20**	**.24**	**.30**	**.26**	**.17**

1. Irrigation frequency is calculated by dividing the irrigation amount, or allowable depletion, by daily crop water use.
2. Irrigation amount is the net amount of water to apply (the allowable depletion for that soil type from Table 4.1 multiplied by 4 ft of rooting depth). The actual amount that should be applied is the net amount in the table divided by the irrigation efficiency. (This accounts for inefficiencies in the irrigation system and is explained in detail later.)

Notes:

a. The values in the table are based on irrigations occurring when 50% of the available soil moisture is depleted (50% allowable depletion).

b. For the months where no values are listed, irrigation scheduling should be based on soil moisture monitoring. Dashes mean that the soil-water-holding capacity is so great that irrigation frequency is significantly less than once per month.

c. For the early part of the year, use soil moisture monitoring to determine the first irrigation. The values in this table can then be used to determine the time of subsequent irrigations.

Figure 4.7. The steps of irrigation scheduling according to the water budget method.

Water Budget Irrigation Scheduling

1. Estimate daily crop water use by using published daily estimates, data from CIMIS, or tables of long-term average crop water use (see Table 4.2 for an example).
2. Add the daily water use to the running total of water use to date. The result is the soil water depletion to date.
3. Subtract any water additions—irrigations or rainfall—from soil-water depletion to date.
4. Schedule irrigation to replace the accumulated water use by the crop.

The goal: Keep soil-water depletion above the allowable depletion, without adding water in excess of the water-holding capacity of the soil. Remember that letting the soil dry beyond the allowable depletion results in lost yield and that applying more water than the soil can hold leaches nutrients and wastes energy and water.

fine sand or loamy sand must be irrigated every 7 days, while a clay soil must be irrigated every 15 days.

Compensating for production practices and limitations

The water budget theory of irrigation scheduling is relatively straightforward, but alfalfa production practices complicate putting the theory into practice. For example, cutting affects water use by alfalfa. Generally, water use is near zero immediately after cutting and rises slowly after a few days, as the crop begins to grow. After about 10 days, alfalfa regrowth fully covers the ground and full crop water use resumes. A grower must compensate for this reduction in water use after cutting or he or she will overirrigate. Sophisticated methods for calculating the reduction are available, but a practical method is to consider alfalfa water use to be zero for 5 days after cutting. After 5 days switch to full-use estimates until alfalfa is cut again. (See Studying a Practical Example, later in this chapter, to understand how this rule of thumb is applied.)

Harvesting and curing operations also complicate irrigation scheduling. Water cannot be applied too close to a cutting because irrigation wets the soil. On wet ground, harvest equipment may get stuck and is more likely to cause wheel ruts and compaction. Also, alfalfa that is cut and laid on moist soil to dry will cure very slowly. The preferred interval between irrigation and cutting depends on soil type. It may be as short as 2 days for sandy soils and as long as 10 to 15 days for fine-textured clay soils. Furthermore, fields obviously cannot be irrigated while alfalfa is curing, which typically requires from 5 to 8 days.

Because cutting delays irrigation, fields usually need water as soon after cutting as possible. Alfalfa is most sensitive to water stress when regrowth begins after cutting. When irrigation is postponed after cutting, dramatic yield reductions can result.

So, to summarize: (1) Fields should not be irrigated too close to cutting, and (2) fields should be irrigated as soon as possible after the hay has cured and been removed from the field. (The practical example later in this chapter shows how irrigation scheduling can be adjusted to allow for harvesting and curing.)

To account for seasonal differences in water requirements, growers must either change irrigation frequency or change set times to adjust the amount of water applied per irrigation (or both). Two 12-hour sets per day prevail in wheel-line- and hand-line-irrigated alfalfa fields in the Intermountain Region. (Though each set is described as 12 hours long, actual irrigation time is shortened by the amount of time workers take, between sets, to move the lines.) Longer or shorter set times are unusual because of labor constraints and the difficulty of moving irrigation lines at night. Set times for flood-irrigated fields are also inflexible; they are determined by the length of time required for the water to travel from the head to tail end of the field. Therefore, the most convenient method for scheduling alfalfa irrigations is to vary the irrigation frequency or the number of days between irrigations (see Table 4.3).

However, sometimes the number of days between irrigations is fixed because of delivery or irrigation system limitations. Under these conditions, record the accumulated crop water use between irrigation dates. Adjust irrigation set times to deliver the amount of water that has been depleted since the last irrigation.

Whenever using the water budget method to schedule irrigations, monitor soil moisture regularly to "ground-truth" the accuracy of the water budget method.

Studying a practical example

An example should help clarify the preceding discussion on practical irrigation scheduling. To follow along with this example, refer to the accompanying water use table, Table 4.4, and to the graph of soil-water depletion, Figure 4.8. This example relates to a healthy, well-established alfalfa field on sandy loam soil in the Tulelake region.

On May 12, the field was given a 12-hour irrigation that supplied 2.4 inches of water (net). This irrigation completely refilled the soil profile, so the soil-water depletion on this date was 0.00 (see point A on the table and graph). For 6 days, the crop was assumed to use water in amounts typical for the region (Table 4.2 supplies this information). The average crop water use was added each day to the soil depletion balance. On May 18 the field received 0.50 inch of rain, so 0.50 inch of water was subtracted from 0.96, the soil depletion balance. The daily crop water use, 0.20 inch, was then added. So, soil-water depletion on May 18 (point B) was calculated to be 0.66 inch (0.96 – 0.50 + 0.20 = 0.66).

The objective of the water budget is to maintain soil moisture near the optimum level by keeping track of crop water use and then irrigating to replace the water used.

After May 18, average crop water use figures were again added each day to the soil-water depletion balance. On May 26 (point C) the accumulated depletion totaled 2.29 inches. Because this soil depletion approximated the net amount applied in a 12-hour irrigation, the field was irrigated the next day, May 27. On that day, the 2.4-inch application of water was subtracted from 2.29, the soil depletion balance; 0.21 inch of average crop water use was added, resulting in a net soil-water depletion of 0.10 inch (point D). Important note: The 2.29 inches of soil-water depletion that occurred before the May 27 irrigation was less than the 3 inches of allowable depletion for this sample sandy loam soil (Table 4.1). Therefore, no yield reduction occurred due to moisture stress prior to this irrigation. The irrigation

Table 4.4. Water use table for a sample alfalfa field, Tulelake area.

	DATE	CROP WATER USE (IN.)	RAIN OR IRRIGATION (IN.)	SOIL WATER DEPLETION (IN.)	EVENT
A	5/12	0.19	2.4	0.00	12-hour irrigation
	5/13	0.19		0.19	
	5/14	0.19		0.38	
	5/15	0.19		0.57	
	5/16	0.19		0.76	
	5/17	0.20		0.96	
B	5/18	0.20	0.5	0.66	0.5 in. rain
	5/19	0.20		0.86	
	5/20	0.20		1.06	
	5/21	0.20		1.26	
	5/22	0.20		1.46	
	5/23	0.20		1.66	
	5/24	0.21		1.87	
	5/25	0.21		2.08	
C	5/26	0.21		2.29	
D	5/27	0.21	2.4	0.10	12-hour irrigation
	5/28	0.21		0.31	
	5/29	0.21		0.52	
	5/30	0.21		0.73	
	5/31	0.22		0.95	
	6/1	0.22		1.17	
	6/2	0.22		1.39	
	6/3	0.22		1.61	First cutting
E	6/4	0.00		1.61	
	6/5	0.00		1.61	
	6/6	0.00		1.61	
	6/7	0.00		1.61	
	6/8	0.00		1.61	
	6/9	0.24		1.85	
	6/10	0.24		2.09	
F	6/11	0.24		2.33	
G	6/12	0.24	2.4	0.17	12-hour irrigation
	6/13	0.24		0.41	
	6/14	0.25		0.66	
	6/15	0.25		0.91	
	6/16	0.25		1.16	
	6/17	0.25		1.41	
	6/18	0.25		1.66	
	6/19	0.25		1.91	
	6/20	0.25		2.16	
H	6/21	0.27	2.4	0.03	12-hour irrigation
	6/22	0.27		0.33	
	6/23	0.27		0.60	
	6/24	0.27		0.87	
	6/25	0.27		1.14	
	6/26	0.27		1.41	
	6/27	0.27		1.68	
	6/28	0.29		1.97	
	6/29	0.29		2.26	
I	6/30	0.29	2.4	0.15	12-hour irrigation
	7/1	0.29		0.44	
	7/2	0.29		0.73	
	7/3	0.29		1.02	
	7/4	0.29		1.31	
	7/5	0.30		1.61	
	7/6	0.30		1.91	
	7/7	0.30		2.21	
J	7/8	0.30	2.4	0.11	12-hour irrigation
	7/9	0.30		0.41	
	7/10	0.30		0.71	
	7/11	0.30		1.01	
	7/12	0.31		1.32	
K	7/13	0.31	1.2	0.43	6-hour irrigation
	7/14	0.31		0.74	
	7/15	0.31		1.05	
	7/16	0.31		1.36	
	7/17	0.31		1.67	Second cutting
L	7/18	0.00		1.67	
	7/19	0.00		1.67	
	7/20	0.00		1.67	
	7/21	0.00		1.67	
	7/22	0.00		1.67	
	7/23	0.30		1.97	
	7/24	0.30		2.27	
M	7/25	0.30	2.4	0.17	12-hour irrigation
	7/26	0.29		0.46	
	7/27	0.29		0.75	
	7/28	0.29		1.04	
	7/29	0.29		1.33	
	7/30	0.29		1.62	
	7/31	0.29		1.91	
	8/1	0.29		2.20	

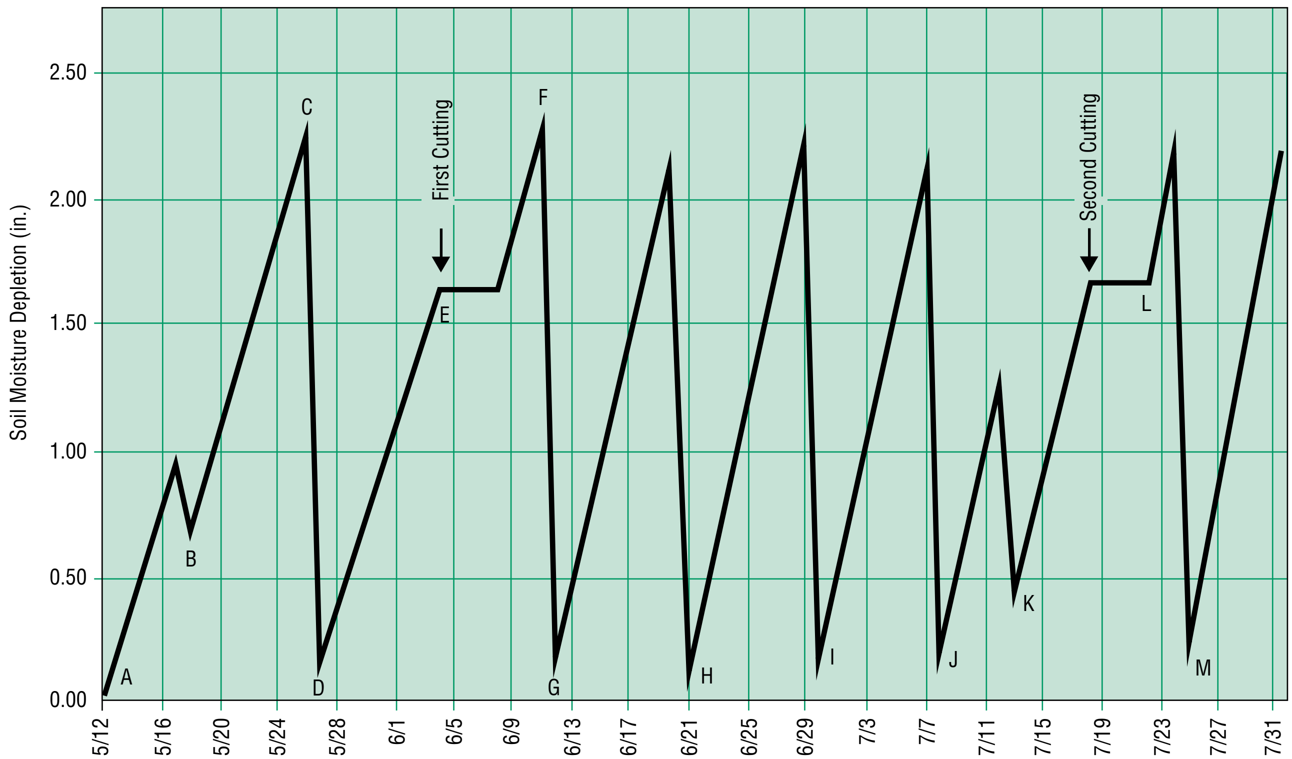

Figure 4.8. Soil-water depletion in sample alfalfa field, Tulelake area.

occurred 7 days before the first cutting, on June 3, allowing ample time for the soil to dry for harvest.

As explained earlier, it is acceptable to assume that for 5 days after cutting, crop water use is zero. After that time switch to using full-use estimates. In this example crop water use was estimated as zero from June 4 through June 8 (period E). On the sixth day following cutting, June 9, the use of full-use estimates resumed.

After soil-water depletions totaled 2.33 inches on June 11 (point F), irrigation was applied on June 12 (point G). This allowed ample time for the hay to cure after cutting on June 3. In a similar manner, normal irrigations were scheduled for June 21 and 30 and July 8 (points H, I, andJ). Irrigations were more frequent during this period because of the increased water demand of midsummer.

On July 13 (point K), an early irrigation consisting of 1.2 inches, half the normal amount of water, was applied. If this irrigation had been delayed until 2.4 inches of water had been depleted, the irrigation would have been too close to the second cutting, on July 17. The early, partial irrigation was scheduled to carry the alfalfa through the postharvest period without a water deficit. Again allowing for zero crop water use for 5 days after cutting (period L), the next irrigation was scheduled for July 25 (point M).

ADJUSTMENTS TO ACHIEVE UNIFORMITY AND EFFICIENCY

Information on crop water use (Table 4.2) indicates the net water requirement of alfalfa, not the actual amount that should be applied. The amount of water in an irrigation must supply crop water requirements as well as compensate for inefficiencies in the irrigation system. Irrigation water can be lost from runoff; deep percolation (movement of water below the root zone of the crop); and, in the case of sprinklers, spray evaporation and drift. Most irrigation water losses are attributable to nonuniformity of water application. If every part of the field received the same amount of water, uniformity would be 100 percent. However, no irrigation is perfectly uniform—some parts of the field receive more water than do others. To compensate for nonuniformity, some parts of the field must be overirrigated so that others will be adequately irrigated. To avoid underirrigation of large areas of the field, use the equation that follows to calculate the gross irrigation requirement—that is, the amount of water needed to meet plant needs (crop water needs) and compensate for irrigation inefficiency.

$$\text{Gross irrigation requirement} = \frac{\text{Net irrigation requirement}}{\text{Irrigation system efficiency}}$$

Irrigation system efficiency

For example, if the alfalfa uses 4 inches of water (that is, if the net irrigation requirement is 4 inches) and the system efficiency is 80 percent, the application required to meet plant needs is 5 inches (4 inches ÷ 0.8 = 5 inches).

The efficiency of an irrigation system is difficult to measure. Numerous field studies show however, that an irrigation efficiency of 75 percent can be used to calculate gross irrigation requirement when irrigating with wheel-line or hand-move sprinkler systems. Use 85 percent when irrigating with center-pivot machines (Table 4.5). The irrigation efficiency of flood systems varies from 65 to 80 percent, depending on soil type, slope, border length, and other factors. Select a value within this range based on knowledge of your irrigation system.

APPLICATION RATE

Knowing how much water the crop needs is of little benefit if you do not know how much water is being applied in an irrigation. Knowledge of the application rate is a prerequisite to using the water budget method.

The application rate can be calculated from the irrigation system flow rate. Several methods are available to ascertain the flow rate of an irrigation system. On a whole-field basis, a flow meter is the most precise and convenient means where the water supply is delivered in pipes. The drawback to flow meters is their cost (approximately $800 or higher, depending on pipe diameter). Flow rates can also be estimated by using the pump capacity or with data collected from a pump test (often performed by utility companies). Flumes and weirs are used to determine the flow rate for systems where ditches deliver water. (Flow rates and water volumes are often expressed in different units, but each can be easily converted—see Table 4.6.)

Table 4.5. Typical application efficiencies for different irrigation systems.

SYSTEM	APPLICATION EFFICIENCY
Sprinkler	
Wheel line	65–80
Hand line	70–80
Center pivot	75–90
Flood	
Border strip	65–80

Table 4.6. Conversions useful when scheduling irrigation.

1 acre-inch	=	27,154 gallons
1 acre-foot	=	325,848 gallons
1 cubic ft per second (CFS)	=	449 gpm
1 CFS	=	approx. 2 acre-feet per day
1 CFS	=	approx. 1 acre-inch per hour

After you know the flow rate, you are ready to calculate application rate. The calculation you use depends on the type of irrigation system you have.

Wheel-Line and Hand-Move Sprinkler Systems

To calculate the application rate for one of these systems, use the following equation:

$$\text{Application rate (in./hr.)} = \frac{96.3 \times Q}{Sm \times Sl}$$

where

Q = average sprinkler discharge, expressed in gallons per minute (gpm)

Sm = spacing along the main line (that is, the distance between moves) expressed in feet

Sl = spacing along lateral (that is, the distance between sprinklers) expressed in feet

Figure 4.9 presents an example that uses the equation.

To determine sprinkler discharge, divide the system flow rate by the number of sprinklers or slip a hose over a nozzle and measure the volume of water collected in a given time period. Or, as an alternative to using the equation above, you can estimate application rate for a sprinkler system from irrigation tables provided you know the nozzle size, pressure and sprinkler spacing. (Table 4.7).

The average depth of water applied during an irrigation is estimated by multiplying the application rate, in inches per hour, by the set time in hours.

Center-Pivot Systems

The equation that follows will allow you to calculate the average depth of water applied per revolution of a center-pivot irrigation system:

$$\text{Depth applied (in.)} = \frac{Q \times H}{449 \times A}$$

where

Q = flow rate, expressed in gpm

H = hours per complete revolution

A = area irrigated with pivot, expressed in acres

Figure 4.10 is an example that employs the equation.

Border-Strip Flood Systems

The average depth of water applied per set with a flood-irrigation system is calculated as follows.

$$\text{Depth applied (in.)} = \frac{Q \times T}{449 \times A}$$

where

Q = flow rate, expressed in gpm

T = irrigation set time, in hours

A = area, in acres

Figure 4.11 shows how to apply the equation.

Table 4.7. Sprinkler application rate (in./hr.) for 40- by 60-ft spacing.

NOZZLE SIZE (IN)	APPLICATION RATE (IN/HR) 40 PSI	50 PSI	60 PSI
3/32	.06	.07	.08
7/64	.09	.10	.11
1/8	.11	.13	.14
9/64	.15	.16	.18
5/32	.18	.20	.22
11/64	.22	.25	.27
3/16	.26	.29	.32
13/64	.31	.34	.38
7/32	.36	.40	.44

Figure 4.9. Sample calculation to determine the application rate of a wheel-line or hand-move sprinkler system.

Pump capacity = 675 gpm
Number of sprinklers = 96
Main line spacing = 60 ft
Lateral spacing = 40 ft
Set time = 12 hr

Average application rate:

$$Q = \frac{675 \text{ gpm}}{96 \text{ sprinklers}} = 7 \text{ gpm/sprinkler}$$

$$\text{in./hr} = \frac{96.3 \times 7 \text{ gpm}}{40 \text{ ft} \times 60 \text{ ft}} = 0.28 \text{ in./hr.}$$

Average depth applied:

$$D = 0.28 \text{ in./hr} \times 12 \text{ hr} = 3.36 \text{ in. total}$$

Figure 4.10. Sample calculation to determine average depth of water applied by a center-pivot system.

Flow rate = 900 gpm
Hr/revolution = 70 hr
Area irrigated = 125 acres

Average depth applied per revolution:

$$D = \frac{900 \text{ gpm} \times 70 \text{ hr}}{449 \times 125 \text{ acres}} = 1.12 \text{ in./revolution}$$

Note: Acreage under pivot is equal to

$$\frac{(r)^2 \times 3.14}{43{,}560}$$

where: r = radius of the pivot (ft)

Figure 4.11. Sample calculation to determine the average depth of water applied by a flood-irrigation system.

Flow rate = 1,120 gpm
Set time = 8 hr
Area irrigated = 3.6 acres

Average depth applied:

$$D = \frac{1{,}120 \text{ gpm} \times 8 \text{ hr}}{449 \times 3.6 \text{ acres}} = 5.54 \text{ in.}$$

SYSTEM DESIGN REQUIREMENTS

The key to efficient irrigation management begins with the irrigation system and its flow rate. The system flow rate of many irrigation systems in the Intermountain Region is inadequate. To fully meet crop needs, the system flow rate must be sufficient to irrigate the field adequately during the period of peak evapotranspiration (typically July) without exceeding the allowable soil moisture depletion. The following equation can be used to calculate the necessary flow rate:

$$Q = \frac{449 \times A \times D}{T}$$

where

Q = flow rate, expressed in gpm

A = area irrigated in acres

D = gross depth of water to be applied, in inches

T = actual irrigation time, in hours

The interval between irrigations is determined by dividing the allowable soil moisture depletion by the daily peak ET rate (from Table 4.2). The gross depth of water to be applied is the allowable soil moisture depletion divided by the irrigation efficiency of the system (discussed in previous section). The hours of irrigation is the time required to irrigate the field. The fewer the hours of irrigation, the higher the flow rate needs to be.

Figure 4.12 presents a system flow rate calculation typical of the Intermountain Region. A grower needs 326 gallons per minute to irrigate a 40-acre alfalfa field. This equates to 8 gallons per minute per acre of wheel-line-irrigated alfalfa. The required flow rate would be slightly less (approximately 7.5 gpm) for irrigation systems that do not involve downtime during which the lines are moved.

IRRIGATION SYSTEM IMPROVEMENTS

Sprinkler Systems

System design factors that affect irrigation efficiency include sprinkler spacing, operating pressure, pressure differences throughout the system, and nozzle type and size. Several changes in system design improve uniformity and performance of sprinklers (Figure 4.13).

The most common sprinkler spacing in intermountain alfalfa fields is 40 by 60 feet (in other words, 40 feet between sprinkler heads and 60 foot moves). Numerous field evaluations show that this spacing results in good uniformity when large ($^{11}/_{64}$ or larger) sprinkler nozzles are used under low to moderate wind conditions.

Sprinkler pressure should be above 35 pounds per square inch (psi). Minimize pressure losses due to friction in the lateral lines by using appropriate pipe diameters. The most common lateral pipe diameter is 4 inches. However, pressure losses can be greatly reduced —and energy saved—by using 5-inch diameter pipe for laterals. Analyze pressure losses due to friction in the main line as well; change the pipe size if necessary.

Knowing how much water the crop needs is of little benefit if you do not know how much water is applied in an irrigation.

Select the proper nozzle type. Types of nozzles include standard circular orifices, low-pressure nozzles, and flow-control nozzles. Field evaluations reveal that standard nozzles are adequate for systems with pressures of 35 psi or greater. Use flow-control nozzles for systems with pressure losses exceeding 20 percent of the design pressure.

Wind lowers the uniformity of sprinkler systems by distorting the spray pattern of sprinkler nozzles. Its impact can be significant, especially when wind velocity is high. Changes, such as closer spacing or lower pressure, can lessen the effects of wind, but its impact cannot be completely eliminated. Sprinkler systems that move continuously (that is, center-pivot or linear-move systems) are not as affected by wind as are wheel-line or hand-move systems.

Figure 4.12. Sample calculation to determine the system flow rate for a 40-acre alfalfa field.

Type of irrigation system = wheel-line sprinkler
Allowable soil moisture depletion = 3.0 in.
Peak ET = 0.3 in./day
Irrigation efficiency = 75 percent

1. Interval between irrigations

$$= \frac{\text{Allowable soil moisture depletion}}{\text{Peak ET}}$$

$$\frac{3.0 \text{ in.}}{0.3 \text{ in./day}} = 10 \text{ days}$$

2. Hours of operation for an irrigation system operated continuously except during moving
   = 22 hr/day x 10 days
   = 220 hr

3. Gross depth

$$= \frac{3 \text{ in.}}{\text{irrigation efficiency}}$$

$$= \frac{3 \text{ in.}}{0.75}$$

   = 4 in.

4. System flow rate

$$= \frac{449 \times 40 \text{ acres} \times 4.0 \text{ in.}}{220 \text{ hr}}$$

   = 326 gpm

5. Required flow rate

$$= \frac{326 \text{ gpm}}{40 \text{ acres}}$$

   = 8 gpm per acre (approx.)

Flood Systems

The uniformity of flood irrigation depends on how long water stands or ponds on the soil surface at various distances along the border length. The longer the ponding time at a particular distance, the more water infiltrates. The ponding time depends on how fast the water flows to the end of the field (this speed is determined by border length, inflow rate, infiltration rate, slope, and surface roughness) and how fast the water disappears after the irrigation water is cut off.

Figure 4.13 Ways to improve uniformity and efficiency of sprinkler irrigation systems.

- Determine the application rate and average depth of water applied.
- Irrigate during low-wind periods when feasible. (The uniformity of irrigation is greatly reduced at wind speeds greater than 10 to 15 mph.)
- Offset lateral locations to improve seasonal uniformity.
- Use flow-control nozzles when the pressure variation between the first and last nozzle exceeds 20 percent.
- Repair leaks and malfunctioning nozzles.
- Maintain adequate pressure (above 35 psi at the last nozzle for wheel lines) by adjusting the pump impeller of semi-open impellers, repairing or replacing a worn pump, or reducing the number of laterals operating.
- Use the same nozzle size throughout the irrigation system.
- Use closer spacing, boom-mounted nozzles, and/or rotating-type nozzles for center-pivot systems.

Generally, water stands longer along the upper part of a field than along the lower part, resulting in more infiltration along the upper part.

Uniformity of flood systems can be improved by getting the water to the end of the field faster. To improve uniformity, use higher flow rates into the border, shorten border lengths, and improve land leveling. The higher the flow rate, the faster water flows to the end of the field and the more uniform the application. The appropriate field length depends on soil type (Table 4.8). Field lengths for clay loam soils should not exceed ¼ mile; field lengths for sandy soils should not exceed ⅛ mile. The width should be compatible with the system flow rate and also with the harvesting equipment. Many of these efforts to increase uniformity may increase surface runoff, thus requiring a tailwater return system to capture and reuse the runoff. Failure to do so could result in higher pumping costs and increased water use.

Table 4.8. Suggested field lengths and unit flow rates for border or flood irrigation of slopes of 0.1 to 0.2 percent.

SOIL TYPE	LENGTH (FT.)	UNIT FLOW RATE (GPM/FT. OF WIDTH)
Clay	1,300	7–10
Clay loam	1,300	10–15
Loam	1,300	25–35
Loam	600	15–20
Sandy loam	600	25–30
Sandy	600	30–40

Source: 1974. Border Irrigation. SCS National Engineering Handbook, Section 15. Washington, DC.

IRRIGATION STRATEGIES FOR LIMITED WATER SUPPLIES

Sometimes the supply of irrigation water (from a pumping plant or an irrigation district) is insufficient to supply the full seasonal water requirements of alfalfa. When this occurs, irrigate fully in the spring rather than trying to "spread out" an insufficient water supply and deficit-irrigate for the entire season. The amount of irrigation water required per ton of alfalfa is less for the first cutting than for the second or third. Temperatures are cooler in the spring and the chance of rainfall is greater. First-cutting yields usually surpass second- and third-cutting yields. Also, the quality and price of first-cutting hay is usually higher than those of second-cutting hay.

Research and field experience throughout much of California have demonstrated that irrigation water can be withdrawn or reduced following the first cutting without significantly reducing stand density or yields the following year. Deficit irrigating forces alfalfa into a drought-induced dormancy. The stand usually recovers fully when it receives adequate water the next production season.

ADDITIONAL READING

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