IRRIGATION SCHEDULING METHODS FOR CALIFORNIA ALFALFA

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Virtually all crops in California require irrigation for top production. High producing alfalfa has one of the highest seasonal water needs all (Figure 1), with an estimated requirement of almost 48 inches in the southern San Joaquin Valley. While most of this water merely passes through the plant and is lost to the atmosphere, maintaining an adequate supply of water to the plant at all times is of vital importance in alfalfa production. Numerous studies (Stanberry, 1955; Bauder, et al., 1978; Wright, 1984) have shown that a direct relationship exists between crop water use and dry matter yield. In other words, not supplying the plants with adequate water will result in plant water stress, which reduces the plant growth rate, and ultimately, yield. Even a mild water stress will negatively affect alfalfa since vegetative growth is the plant process most sensitive to water deficiency (Hsiao et al., 1976).

So, given that alfalfa needs tremendous amounts of water, California growers must contend with the various factors affecting water in this state, including availability, cost, and political sensitivity. It's clear, however, that continued high yields and, indeed, the continued viability of the industry in certain areas, depend on good irrigation management. Maintaining an adequate supply of soil water for vigorous crop growth at all times, while minimizing non-beneficial losses of applied water, is the goal of good irrigation management.

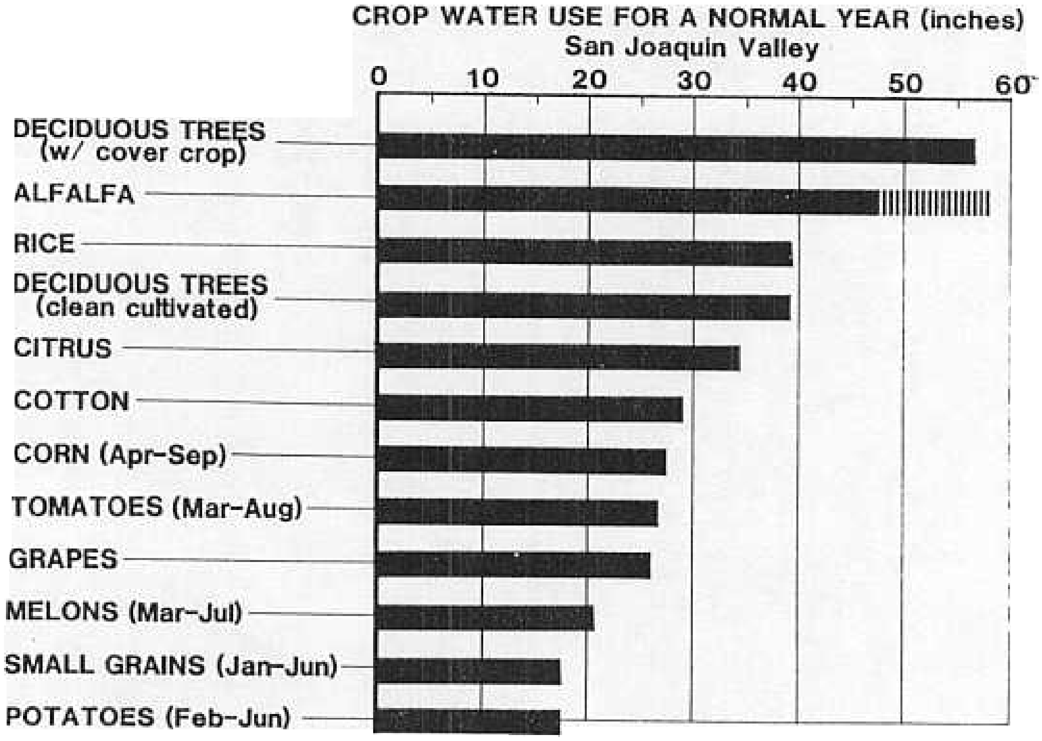

Figure 1. Long term, historical estimates of water requirements for crops grown in the San Joaquin Valley.

Concepts

Irrigation scheduling is a term that refers to methods used to answer the following questions: 1) When to irrigate, and 2) How much water to apply. There are two fundamentally different approaches to irrigation scheduling in alfalfa. The first (soil-based measurements) involves measuring soil moisture levels, either by hand or with various devices, and then attempting to relate these measurements to plant performance. The other approach involves estimating how much water the crop is using and then applying water to meet this crop water requirement. This latter method is known as the water budget concept.

Growers of most field crops in California have flexibility in terms of both irrigation frequency (timing) and duration (amount applied). Since alfalfa is harvested numerous times during a season, timing of alfalfa irrigations depends largely on cutting dates. In other words, irrigation dates are fixed by harvest cultural practices. Generally, there are one or two irrigations between cuttings, depending mostly on soil water holding properties and root zone depths. Thus, the following discussion emphasizes factors that determine how much water to apply at each irrigation.

Soil-based Measurements

The simplest procedure for assessing soil water conditions is based on the "feel or appearance" of a soil sample. How the soil deforms when it's worked in the hand is used to indicate soil water status. For example, does a ball of soil formed in the hand break under pressure; does it ribbon out between thumb and forefinger, etc. Table 1 presents guidelines for estimating amounts of plant-available soil water based on feel appearance for different soil types.

Soil samples can be collected at different depths in the root zone with a soil tube, auger, or even a shovel. As with all soil-based methods, sampling sites should be representative of the field. Avoid obvious high or low spots. Locations affected by initial wetting affects (top of a surface irrigated field) or ponding of water, such as the tail end or the field, are usually not appropriate sampling sites. Since physically collecting soil samples is rigorous and time consuming, it's generally not used as a primary method for scheduling irrigations. However, selective soil sampling, an often overlooked or forgotten technique, can yield valuable information on current soil water conditions.

Numerous instruments have been developed to monitor soil water conditions. Tensiometers, instruments that measure soil water matric potential (tension), can be used in alfalfa, although they are more commonly found in tree and vine crops. The tensiometer gauge usually reads from 0 to 100 cb. One bar (100 cb) is a unit of pressure equal to about one atmosphere. However, the working range of the instrument is 0 to 80 cb. This represents about 25 to 50% of the water held by a soil that is available for plant use (clays to sandy loams, respectively). Since it's usually desirable to deplete more than 25% of available water between irrigations, tensiometers are better suited for sandy soils and have limited usage in heavy soils.

Tensiometers should be placed at a minimum of two depths in the crop root zone. It's impossible to provide guidelines on threshold tensiometer readings that indicate "good" or "bad" soil water conditions. Critical values depend on soil type, depth of root zone, and placement of tensiometer. The rate of change of the gauge readings is perhaps a more important parameter to monitor. Readings from the shallower instrument will change more rapidly since water is extracted from shallow depths first. A rapid change in gauge readings from the deeper tensiometer indicates that the root zone will soon be depleted of available water. Recording tensiometer readings every few days and plotting them on ordinary graph paper yields valuable information on soil water conditions. It should be recognized that tensiometers are relatively delicate devices that must be protected from equipment travelling through the field. And since they are water-filled, freezing damage can occur unless they are drained or removed during the winter.

While tensiometers function only in the wetter range of most soils, gypsum blocks work most effectively at drier soil water levels. As such, they are more suited to loam and clay soils that retain more available water than sandy soils that release most of available water at low tensions. Gypsum blocks consist of a small block of gypsum in which two electrodes are imbedded. After being installed in the soil at various depths, a meter is

Table 1. Guide for Practical Interpretation of Available Soil Water for Various Soil Textures
Adapted from SCS National Engineering Handbook, Chapter 15, 1964.
and Israelsen et al. Irrigation Principles and Practices, 1980.

Available[1] Water (%)	Feel or Appearance of Soil			
	Sand	Sandy Loam	Loam/Silt Loam	Clay Loam/Clay
100 (Field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (1.0)[2]	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (1.5)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (2.0)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. (2.5)
75-100	Tends to stick together slightly, sometimes forms a weak ball[3] under pressure. (0.8 to 1.0)	Forms weak ball, breaks easily, will not slick. (1.2 to 1.5)	Forms a ball, is very pliable, slicks readily if relatively high in clay. (1.5 to 2.0)	Easily ribbons out between fingers, has slick feeling. (1.9 to 2.5)
50-75	Appears to be dry will not form a ball with pressure. (0.5 to 0.8)	Tends to ball under pressure but seldo holds together. (0.8 to 1.5)	Forms a ball somewhat plastic, will sometimes slick slightly with pressure. (1.0 to 1.5)	Forms a ball, ribbons out between thumb and forefinger. (1.2 to 1.9)
25-50	Appears to be dry, will not form a ball with pressure. (0.2 to 0.5)	Appears to be dry, will not form a ball. (0.4 to 0.8)	Somewhat crumbly but holds together from pressure. (0.5 to 1.0)	Somewhat pliable, will ball under pressure. (0.6 to 1.2)
0-25 (0 is permanent wilting.)	Dry, loose, single-grained, flows through fingers. (0 to 0.2)	Dry, loose, flows through fingers. (0 to 0.4)	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition. (0 to 0.5)	Hard, baked, cracked, sometimes has loose crumbs on surface. (0 to 0.6)

1/ Available water is defined as the difference between field capacity and permanent wilting point.
2/ Numbers in parenthesis are available water contents expressed as inches of water per ft. of soil depth.
3/ Ball is formed by squeezing a handful of soil very firmly.

used to measure the electrical resistance of the block. Since resistance is a function of water content, and the blocks are in equilibrium with the soil water status of the surrounding soil, gypsum block readings reflect soil water conditions. Charts provided by the manufacturer are used to interpret the raw resistance readings. As with tensiometers, care must be taken to protect the wire leads of the gypsum blocks from equipment damage. Another major disadvantage of gypsum blocks is that they dissolve slowly in the soil. Thus, they may be good for only one to three seasons. Techniques, however, are available to extend their longevity.

While tensiometers and gypsum blocks take point measurement, neutron probes provide information on soil water contents throughout the entire depth of the root zone. Neutron probe access tubes can be aluminum, steel, or PVC (with the former most sensitive to readings and the latter the least sensitive). Since it's desirable to monitor soil conditions indicative of the undisturbed profile, care must be used when installing tubes. Obtaining a tight fit between the walls of the tube and the surrounding soil is of primary importance.

The probe consists of a radioactive source of fast moving neutrons that is lowered into the soil profile through the access tubes. Once in the profile, fast moving neutrons are slowed down when they collide with hydrogen atoms. Since most of the hydrogen in a soil profile is found in water molecules, the level of slow moving neutrons present in the vicinity of the emitting source is related to the soil water content. A detector of slow moving neutrons is housed in the probe, and this data is displayed on a meter at the soil surface. Conversion of the raw neutron counts to soil water contents is accomplished with calibration curves, either provided by the manufacturer or developed by the user. Calibration curves vary according to site specific factors, such as soil chemical properties and texture. Therefore, the accuracy of using one curve for all situations is questionable.

Although neutron probes can provide a more complete picture of soil water conditions, such as the location of soil zones of maximum extraction, they are relatively costly and can suffer from many of the same limitations as the other soil-based devices; damage from equipment traffic and inability to adequately describe the field due to limited sampling sites.

The Water Budget Approach

The second fundamental approach used for irrigation scheduling is the water budget. This method requires that the crop root zone be visualized as a reservior for water. If we know the capacity of the reservior and the rate that water is being extracted from it, we can determine when the reservior needs to be refilled and how much water needs to be added.

This analogy is equivalent to knowing when to irrigate and how much water needs to be applied. Again, alfalfa growers are primarily interested in the later parameter because cutting cycles fix the irrigation dates and usually preclude setting irrigation dates based on extracting water to some predetermined level.

Estimating Alfalfa ET

The primary requirement for scheduling irrigations with the water budget is to have accurate estimates of evapotranspiration (ET). ET is the sum of transpiration from the leaves of the crop and evaporation from the soil surface. Since climatic conditions largely determine ET rates, many methods have been developed to estimate ET based on weather data. All involve measuring or calculating a "reference" value indicative of evaporative demand. These include measuring evaporation from a USWB Class A evaporation pan (E_{pan}), and calculating "Potential ET (ETP)," which approximates uncut alfalfa with the Jensen-Haise formula, and "Reference ET (ET_o)," which approximates 4-7 inch tall grass, with the Penman equation. Of these, ET_o seems to have evolved as the current standard reference crop value and will be the only estimate discussed herein.

Research has shown that ET_o is related to actual crop water use by crop factors or coefficients (K_c). These coefficients vary with the crop, its stage of development, and the frequency of irrigation at less than full crop cover. They are largely independent of location. Therefore, one set of crop coefficients can be used over a wide area. Actual crop ET is calculated by using the following equation:

$$ET_{crop} = K_c \times ET_o$$

For alfalfa, the K_c depends on the leaf area, which is reflected by plant size. As such, a distinct relationship exists between K_c and days after cutting. This relationship changes somewhat during the season as crop growth rates change.

Since K_c is a function of crop cover, it's at a maximum during roughly the two weeks prior to cutting and at a minimum immediately after cutting. The relationship between K_c and time during the growing season is presented in Figure 2. This figure represents alfalfa growing under management conditions (7 cuttings) found during a normal year in the southern San Joaquin Valley. Note that The K_c drops to 0.40 after cutting, rises slowly for the next few days, and then sharply spikes to a maximum value of 1.15, followed by a steep decline to the original slowly rising trend line. The spike reflects the high rate of surface evaporation from the wet soil after the first post cutting irrigation; soil that is, for the most part, not shaded by the crop. No spike is apparent at the time of the second irrigation (about 7 days before the next cutting) because the K_c has already reached maximum levels. Figure 2 illustrates that over most of the season, K_c reaches its maximum midway between cuttings. Thus, for a 28 day cycle, full cover ET would be achieved after 14 days.

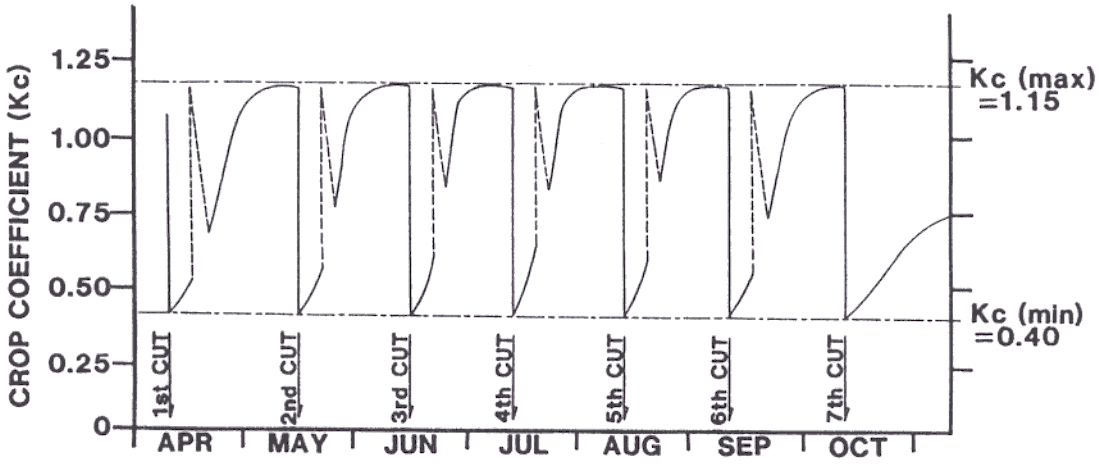

Figure 2. Relationship between alfalfa crop coefficients (K_c) and time during the growing season for a normal year in the southern San Joaquin Valley.

Even with the oscillations illustrated in Figure 1, K_c can be determined accurately for short time periods; daily if desired. Computerized irrigation scheduling programs use this technique. For most growers, however, using an average K_c is less cumbersome, and maintains the accuracy of the water budget. Careful analysis of research data yields a mean K_c of 0.95 that remains relatively constant throughout the growing season.

Using the mean value K_c of 0.95 during the growing season and historical ET_0 data, monthly alfalfa ET estimates for a normal or average year were calculated and appear in Table 2. Estimates for the major alfalfa growing areas in California are shown, including San Joaquin and Sacramento Valleys, Central Coast interior valley and plains, and the Northeastern mountain valleys. This information is a good first approximation of ET requirements, and can be used for scheduling purposes if current (real time) information is not available. However, it should be emphasized that a normal year seldom occurs. A major research project, the California Irrigation Management Information System (CIMIS), is currently developing a network of automated weather stations throughout the state to provide data for ET estimates. Using a modified Penman equation with hourly integrated weather data, this crop water use information will soon be available for anyone with a computer terminal and telephone modem. Current season meaurements of E_{pan} are being made by the State Department of Water Resources. ETP is being calculated by the U. S. Bureau of Reclamation, and other public and private agencies are providing crop ET data. All of this information is available to the public; most of it free of charge. While one set of crop coefficients <u>cannot</u> be used interchangeably between E_{pan}, ETP, and ET_0 conversion factors are available.

Table 2. Monthly estimates of long term, normal alfalfa ET*
for the major production areas of California.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
					(inches/month)								(inches)
Sacramento Valley	1.2	1.8	3.1	4.3	5.8	7.1	7.7	6.6	5.2	3.5	1.7	1.0	49.0
San Joaquin Valley	1.0	1.4	3.2	4.6	6.3	7.3	7.6	6.4	4.8	3.2	1.4	0.7	47.9
Central Coast Interior Valleys	1.7	2.2	3.3	4.3	5.5	6.1	6.6	5.9	4.7	3.7	2.4	1.6	48.0
Central Coastal Plains 1/	1.8	2.3	3.1	3.8	4.5	4.8	5.2	4.6	3.8	3.3	2.3	1.6	41.1
Northeastern Mountain Valleys 2/	0.6	1.0	2.1	3.6	4.9	5.7	7.7	6.8	4.8	2.9	1.0	0.5	41.6

* Estimated ET (Consumptive Use) based on past rates of measured water use.

1/ Coastal areas of San Mateo, Santa Cruz, Monterey, San Luis Obispo and Santa Barbara Counties.

2/ Mountain Valleys of Shasta, Lassen, Modoc and Siskiyou Counties.

Irrigation Efficiency

Tabulating cumulative ET defines the net volume of water to be applied at each irrigation date. However, certain losses of irrigation water are unavoidable, even with the best managed system. Efficient use of water dictates that we apply water in a manner designed to minimize losses while still providing the desired amount of water to the plants.

Efficient irrigation depends, in large part, on how uniformly water infiltrates throughout the field. Perfect (100%) uniformity means that the same amount of water infiltrated at all locations. For surface irrigation (border, flood), uniformity depends mostly on how fast water advances across the field; fast advance results in high uniformity. With sprinklers, uniformity is determined mainly by system design factors, including nozzle and head characteristics, operating pressure distribution, and head spacing along the laterals. Deep percolation losses can be minimized by high application uniformity and by applying only enough water to refill the soil water reservior. Runoff losses with surface irrigation can be minimized by using tailwater recovery systems or cutting back on onflow rates after water has reached the end of the field. In practice, cutback irrigation requires good coordination of on-farm water management and may not be practical in all cases.

Determining irrigation application efficiency is relatively easy for sprinklers and more difficult for surface irrigation methods. Soil Conservation Service and local farm advisor offices are good sources of information for measuring or estimating application efficiency.

Developing the Water Budget

In practice, the development of a water budget for irrigation scheduling on alfalfa means that water loss through ET is totalled between irrigation dates. These dates are fixed by the cutting schedule. Irrigation amouns must equal cumulative ET plus any losses associated with each irrigation. The following example shows the development of an irrigation schedule for alfalfa during part of a growing season.

Crop: Alfalfa
Location: San Joaquin Valley
Soil: Sandy loam
Rooting Depth: 6 ft.
Irrigation Method: Border
Border Size: 2500 x 150 ft (8.6 acres)
Water Onflow Rate: 800 gpm
Irrigation Application Efficiency: 75%
Irrigation Frequency: Twice between cuttings; 1 week before and after cuttings

1 Reference ET Data (available from the State Department of Water Resources, Sacramento)

	Date	ET_0 (inches)	
	June 1	0.30	
	2	0.31	
	3	0.27	
	4	0.22	
	5	0.20	
	6	0.21	
	7	0.23	
Irrigation →	8	0.27	
	9	0.27	
	10	0.26	
	11	0.27	
	12	0.25	
	13	0.22	
	14	0.24	
	29	0.30	
3rd Cutting →	15	0.25	
	16	0.26	3.75 in
	17	0.29	
	18	0.30	
	19	0.30	
	20	0.27	
	21	0.28	
Irrigation →	22	0.29	

	Date	ET_0 (inches)	
	23	0.32	
	24	0.32	
	25	0.32	
	26	0.32	
	27	0.30	
	28	0.33	
	29	0.30	
	30	0.29	4.41 in
	July 1	0.31	
	2	0.34	
	3	0.33	
	4	0.32	
	5	0.29	
Irrigation →	6	0.32	
	7	0.33	
	8	0.33	
	9	0.32	
	10	0.31	
	11	0.31	
	12	0.31	
4th Cutting →	13	0.32	

2) Crop Water Use

Between the June 8 irrigation and the projected June 22 irrigation, ET_0 totalled 3.75 in. Using the mean crop coefficient of 0.95, crop water use is calculated as:

$$\begin{aligned} ET_{crop} &= K_c \times ET_0 \\ &= 0.95 \times 3.75 \text{ in} \\ &= 3.6 \text{ in} \end{aligned}$$

The projected July 6 irrigation calculation is:

$$\begin{aligned} ET_{crop} &= 0.95 \times 4.41 \text{ in} \\ &= 4.2 \text{ in} \end{aligned}$$

3) Gross Irrigation Requirement

Taking into account the estimated irrigation application efficiency of 75% (i.e., 25% of the applied water is lost) yields the following for the June 8 irrigation:

$$\frac{\text{net irrigation requirement}}{\text{application efficiency}} \quad \frac{3.6\text{ in}}{0.75} = 4.8\text{ in}$$

The following approximation can be used to calculate hrs of discharge (set time) needed to apply the desired depth of water:

$$\text{Discharge duration (hrs)} = \frac{\text{Ave. depth (inches) required} \times 450 \times \text{acres}}{\text{gpm}}$$

$$\frac{4.8 \times 450 \times 8.6}{800}$$

$$23.2\text{ hrs}$$

For the July 6 irrigation:

$$\frac{\text{net irrigation requirement}}{\text{application efficiency}} = \frac{4.2\text{ in}}{0.75} = 5.6\text{ in}$$

The above approximation shows that 27.1 hrs of discharge into the border are needed.

Summary

The dramatic negative impact of plant water stress on alfalfa yields is well documented. Therefore, good irrigation management is of prime importance for optimal production.

Many methods of irrigation scheduling are available for California alfalfa growers. Since current (daily) ET data is available for many growing areas in the state, one attractive option would be to use the water budget approach as the principle scheduling approach but verify soil water levels periodically throughout the season. This can be done by hand or with a soil-based monitoring instrument. With just a little work, irrigation scheduling can promote high yields while, at the same time, make the most effective use of a valuable and politically sensitive resource.

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