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Smart Irrigation Scheduling: Tom Rogers' Almond Ranch

By Lucy Allen

"Our goal here is use to water as it is needed, and without knowing what's going on in the soil and in temperature, you really can't water accurately. We can water according to a calendar, or we can water according to trees' needs…our goal here is to water according to the trees' needs."

-Tom Rogers, almond grower

Introduction

Wise use of irrigation water is a top priority for California growers, and many different practices and technologies can help improve on-farm water-use efficiency. Efficient irrigation systems, such as drip and micro-sprinklers, are one component. However, even these technologies do not ensure increased water-use efficiency—watering too often or for too long can lead to unproductive water use (water lost to evaporation, runoff, deep percolation, or weed growth). On the other hand, irrigating too little can cause water stress and reduce yields or crop quality. Irrigation needs vary based on a complex set of variables such as crop type, plant age, micro-climate, stored water, and soil type. Irrigation scheduling—deciding how often and for how long to irrigate—is a critical component of how efficiently water is used. Therefore, increasing the amount and quality of information available to growers is an essential first step in efficient irrigation.

Smart irrigation scheduling refers to technologies that help growers determine more precisely when crops need to be watered and how much water they require. With smart irrigation scheduling, growers are able to use their water more efficiently, either by reducing or by keeping constant the amount of applied water, while maintaining or improving yields. Having more precise knowledge of soil moisture levels also has a number of peripheral benefits, such as pest control.

Background

Decisions on when and how much to irrigate are critical both to crop health and to water-use efficiency, and there are many different methods growers use to make these decisions. According the USDA's Farm and Ranch Irrigation Survey, the most commonly used methods to schedule irrigation in California are the condition of the crop, the feel of the soil, and a personal calendar schedule (Table 1) (USDA 2009). In some irrigation districts, growers are restricted by scheduled water deliveries and must irrigate when their water arrives.

While these scheduling methods may work adequately in maintaining crop health, a more scientific approach can help growers to water more precisely to meet crop water requirements. Smart irrigation technologies make use of local weather stations that measure air temperature, humidity, wind speed, and rainfall; soil probes that measure soil moisture depth, temperature, and salinity; and plant moisture sensing devices that measure the water pressure in plant cells. Increasingly, software paired with these technologies allows growers to easily access real-time data on field conditions, receive alerts through email and text messages, and automate or control their irrigation systems remotely.

Table 1. Methods used by California farmers to decide when to irrigate, 2008
Source: Table 36 in USDA 2009

Method	Percent of CA farmers
Condition of crop	66
Feel of soil	45
Personal calendar schedule	32
Soil moisture sensing device	14
Daily ET reports	12.3
Scheduled by water delivery organization	10
Commercial or government scheduling service	9.7
When neighbors irrigate	6.1
Other	5.5
Plant moisture sensing device	3.1
Computer simulation model	2.7

Note: many farmers use more than one method when deciding when to irrigate, thus the total of all methods exceeds 100 percent.

California Irrigation Management Information System

The California Irrigation Management Information System (CIMIS), a network of more than 130 automated weather systems across the state, was developed in 1982 by the California Department of Water Resources and the University of California to encourage growers to use weather information in their irrigation decisions. CIMIS provides localized weather data online, such as temperature and wind speed, free of charge to registered users. This data can be combined with other parameters which allow farmers to replace only the water that is actually used by crops (transpiration) or lost to the atmosphere (evaporation), referred to as evapotranspiration or ETo. CIMIS provides this calculated ETo value for most of the weather stations in its network and also provides a modeled two-kilometer-grid resolution of a daily ETo map for the entire state.

Each of the CIMIS weather stations consists of sensors that measure local conditions and a data-logger to either store or calculate hourly and daily averages and totals. Sensors collect data on solar radiation, soil temperature, air temperature, humidity, wind speed and direction, and precipitation. A central CIMIS computer automatically downloads data four times per day, then calculates reference evapotranspiration rates and checks the quality of the data. This data is then stored in an online database, which can be freely accessed online (http://wwwcimis.water.ca.gov/).

CIMIS currently has over 20,000 registered users of various categories (see Figure 1 for break-down of user categories) (CIMIS website). A survey by the Department of Agriculture and Resource Economics at the University of California, Berkeley evaluated the water use and yield of all major crop types for 55 growers across California who used CIMIS to determine water application. The study found that on average, the use of CIMIS increased yields by 8% and reduced water use by 13% (DWR 1997).

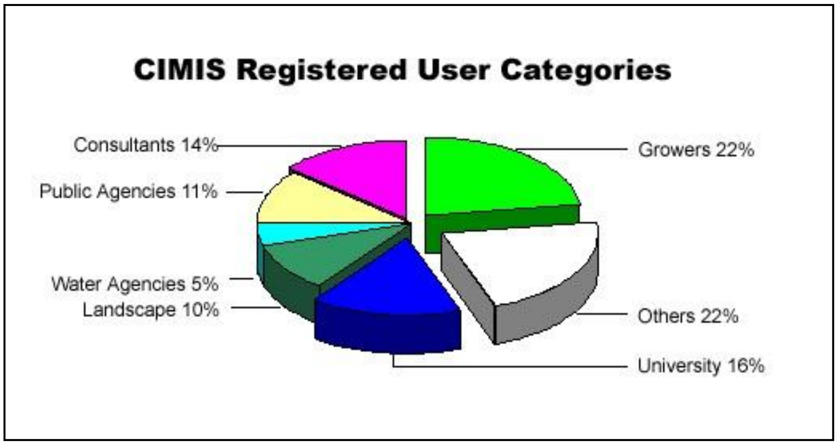

Figure 1. CIMIS Registered User Categories
Source: CIMIS website

Crop Coefficients

Growers can use CIMIS information along with crop coefficients to estimate crop water requirements. Crop water requirements (ETc) are calculated by multiplying evapo-transpiration rates (ETo), which are provided by CIMIS, by crop coefficients (Kc) using the following equation: ETc = ETo x Kc. Crop coefficients are dimensionless numbers that reflect the average water-intensity or canopy cover of a particular crop (usually between 0.1 and 1.2).

For example, if you have an orange orchard and CIMIS reports that the daily evapotranspiration rate in your area is 0.25 inches per day, you would multiply the ETo (0.25 inches per day) by the crop coefficient for oranges that you have looked up (0.55). The resulting ETc is 0.14 inches per day, which means that your oranges need about an eighth of an inch of water to meet their full crop water needs that day. This process can be even further refined if you also understand the distributional uniformity, or efficiency, of your system and also include that in your calculations. For instance, if you know that your irrigation system is only 70% efficient, then you will divide the crop water requirement (0.14 inches per day) by 0.70, which equals 0.2 inches per day of applied water.

Water Budget Method

Many growers using CIMIS data also use a simple water budget to help guide decisions on the timing and amount of irrigation water to apply. This method keeps track of inputs and outputs to soil moisture and helps to ensure that soil moisture does not get so low that it damages yields. In order to use the water budget method, the grower must know some basic data about the soil and crop, including crop coefficients (discussed above); field capacity[1]; available water;[2] how dry the soil can get before crop health or yield are effected (known as "yield threshold depletion"); and starting soil moisture. Starting soil moisture can be estimated to be approximately equal to field

[1] Field capacity refers to the amount of water stored in soil after water drains through it.
[2] Available water refers to the portion of soil moisture that can potentially be taken up by the crop.

capacity after winter rains, however, if a field is pre-irrigated, using soil moisture measuring devices provides a more accurate starting point (K. Frame, CIMIS Program Chief, California Department of Water, personal communication, January 27, 2010).

Once this starting point is determined, a grower can use CIMIS data to keep track of outputs (ETo) and inputs (precipitation and irrigation) to soil moisture. To prevent smaller yields, growers must irrigate before reaching the previously identified yield threshold depletion level. Typically, a grower will set a management allowable depletion level (MAD), which is used as a trigger to irrigate and prevents soil from reaching that yield threshold depletion level. This may be based on a percentage of available water (for example, it might be set to 50% of available water; see example below).

Available water (AW) in root zone = 5.0 inches
Management allowable depletion (MAD)= 50%AW = 2.5 inches
Yield threshold depletion (YTD) = 2.6 inches

Date	Effective Rainfall	Irrigation (inches)	Crop ET	Depletion	Before MAD
July 1	0.00	0.00	0.00	0.00	2.50
July 2	0.00	0.00	0.30	0.30	2.20
July 3	0.00	0.00	0.19	0.49	2.01
July 4	0.00	0.00	0.22	0.71	1.79
July 5	0.00	0.00	0.28	0.99	1.51
July 6	0.00	0.00	0.25	1.24	1.26
July 7	0.00	0.00	0.26	1.50	1.00
July 8	0.00	0.00	0.28	1.78	0.72
July 9	0.00	0.00	0.32	2.10	0.40
July 10	0.00	0.00	0.36	2.46	0.04
July 11	0.00	2.50	0.40	0.36	2.14
July 12	0.00	0.00	0.22	0.58	1.92
July 13	0.42	0.00	0.11	0.27	2.23
July 14	0.25	0.00	0.15	0.17	2.33
July 15	0.00	0.00	0.25	0.42	2.08

Figure 2. Water Budget Scheduling Example for Alfalfa
Source: Frame 2003

In-field Monitoring and Irrigation Scheduling Systems

Increasingly, growers are using in-field monitoring systems to inform their irrigation decisions. These systems typically combine in-field measuring devices, including soil probes, plant moisture sensors, and weather stations, paired with software that allows the grower to easily access and interpret the measurements collected. Many provide near real-time data, which can be accessed from anywhere with an internet connection, and may have additional features such as email or cell phone alerts and remote control or automation of the irrigation system.

These types of systems greatly increase the amount and precision of information available to growers on key parameters such as soil moisture. For example, many systems allow the grower to monitor soil moisture at various depths, and in various field locations. User-friendly interfaces allow growers to access and interpret this data (see examples of soil moisture graphs from PureSense and Ranch Systems LLC below).

This information can be used to irrigate much more precisely as it can provide 24-hour tracking of the soil moisture profile, which tells the grower how much applied water is leaching through the ground without being taken up by the plants.

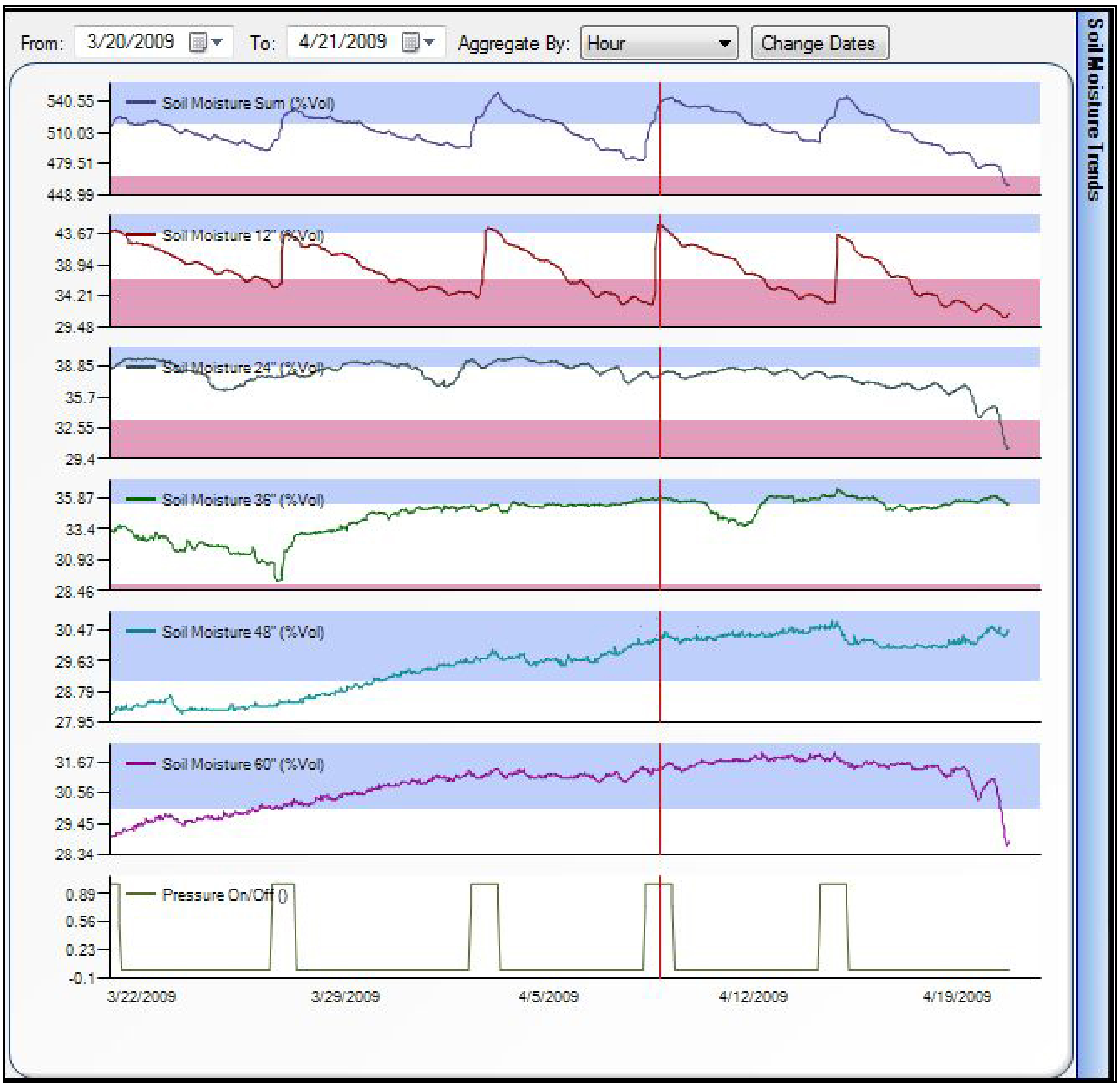

Figure 3. Graph created by PureSense software showing soil moisture over time by depth

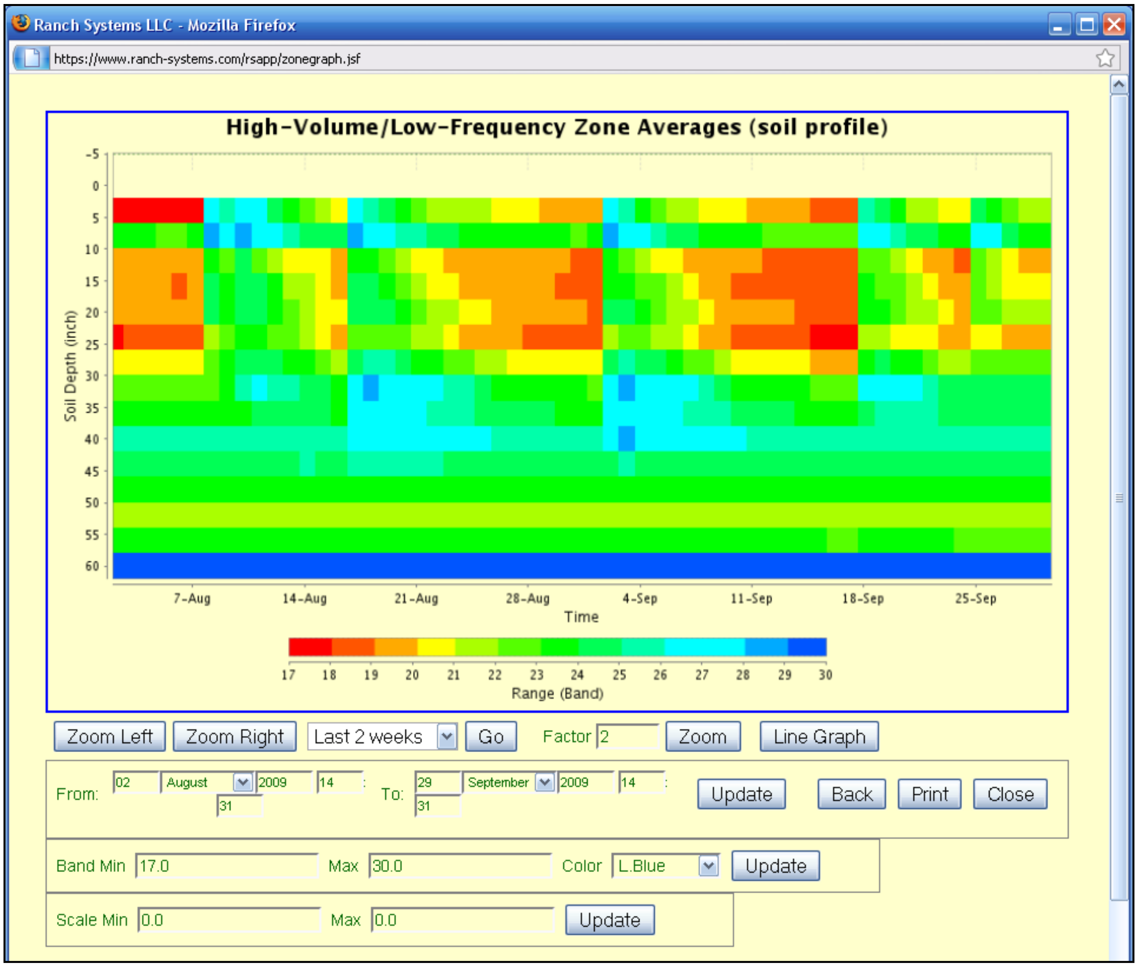

Figure 4. Graph created by Ranch Systems LLC software showing soil moisture by depth, over time
Note: Different colors indicate different soil moisture levels; thresholds for different colors can be set by the user.

Some of these systems create an irrigation schedule for the grower, taking into account the specifics of the irrigation system, soil moisture and other measurements, and pre-determined plant water needs (see screenshot of PureSense irrigation scheduler, Figure 5 below). These programs can help the grower to plan for water needs throughout various growth stages. By combining the schedule provided by the software, graphs of their actual soil moisture at various depths, and knowledge of plant water requirements, growers can irrigate to match crop water needs.

Figure 5. Screenshot of PureSense irrigation scheduling software

Another important feature that can help improve water-use efficiency is automated irrigation control. Some irrigation scheduling systems allow growers to program irrigation valves to turn off or on according to parameters of their choice, such as a certain soil moisture level. This can help ensure that the irrigation schedule is implemented as planned. It also allows the grower to water when evapotranspiration is minimal, i.e., at night when field staff are not working, and to water in short intervals without increasing the amount of labor needed to turn the system on and off (J. Uhl, Director of Business Development, Ranch Systems, personal communication, January 27, 2010).

Benefits of Smart Irrigation Scheduling

> ***"How we manage water is critical to being able to sustain our vineyards... precise water management is the fastest and best way to improve wine quality. When we really understand that interaction of water, how much to use, and precisely the right time, we'll improve our fruit quality, which improves our wine quality."***
>
> **-Karen Ross, Past-President, California Association of Winegrape Growers**

Smart irrigation scheduling has a number of benefits to the grower derived from the ability to closely monitor stress to plants, including deficit irrigation, which itself has a number of benefits including increased quality in some crops and disease and pest management, as well as a number of peripheral benefits.

Increased water-use efficiency

Increasing water-use efficiency benefits growers by increasing yields and/or decreasing the costs associated with irrigation, including the cost of water and energy needed to pump water. Smart irrigation scheduling may result in a decrease or an increase in water applied, but has been shown to consistently increase water-use efficiency. Here, we define water use efficiency to mean the ratio of outputs to inputs, where outputs are yield and crop value, and inputs are irrigation water.

Using the right amount of water is essential to plant health and efficient photosynthesis—and therefore can lead to increases in yield; a number of studies have found that smart irrigation scheduling can increase yield relative to water inputs. For example, a study in Kansas found that smart irrigation scheduling reduced water use by 20% and resulted in a net gain of nearly $13 per acre (Buckleiter et al. 1996). Kranz et al. (1992) found that irrigation scheduling in Nebraska reduced the applied water on corn by 11% while improving yields by 3.5%.

Irrigation scheduling consultants also report increases in water-use efficiency. A consulting firm in Washington providing irrigation scheduling and soil moisture monitoring services found that some farmers were able to reduce their water use by as much as 50%. Others were found to be under-irrigating, and were able to increase yields by increasing applied water (Dokter 1996). A consulting firm in eastern Oregon found that clients reduced their water use by about 15% on average (Dokter 1996).

Crop quality

Irrigation scheduling can also be an important tool in improving crop quality. For example, studies suggest that regulated deficit irrigation, or intentionally imposing water stress during drought-tolerant growth stages, can improve crop quality (Williams and Matthews 1990, Girona et al. 2006). Irrigation scheduling can help growers safely implement regulated deficit irrigation, avoiding long-term damage to the plants.

Particularly for winegrapes and tree crops, in which the value of the crop is contingent on quality, increased crop quality as a result of technological irrigation scheduling can result in significant economic returns for the grower. A survey of users of irrigation scheduling in Washington indicated that the primary reason they were willing to invest in technological irrigation systems was to “insure quality of high-value crops” (Leib et al. 1998).

Pest and disease management

Too much or too little water can cause plant stress, which can lead to disease and vulnerability to pests. Studies show that more precise watering can be used to reduce pest infestations and weed growth. For example, the University of Minnesota Extension reports that scheduling irrigation appropriately can significantly reduce white mold in dry beans (UME 1999). Daane et al (1995) found lower leafhopper densities on vines which received less irrigation. Recent studies on almonds highlight the importance of proper timing and amount of irrigation for pest management, particularly in preventing hull rot (Curtis 2007).

Reduced input costs

In addition to potential reduced water and associated pumping costs, smart irrigation scheduling can result in reduced fertilizer and pesticide applications. In part, reduced pesticide needs are related to the pest management benefits outlined above. But in addition, reductions in water runoff and deep percolation can reduce the loss of fertilizer and pesticides, and therefore reduce the amount that needs to be applied. Automated soil moisture, weather, and other monitoring may also reduce labor costs.

Frost protection

Frost protection is another benefit of many in-field monitoring and irrigation scheduling systems. Some systems can be programmed to alert the grower, through email or cell phone, to conditions which may cause frost damage; other systems can automatically turn on fans or sprinklers when frost damage may occur.

Environmental benefits

Reducing the amount of applied water, and therefore runoff and deep percolation, can have environmental benefits by decreasing the amount of pesticides and fertilizers entering waterways and groundwater. In parts of California where the soil contains high levels of selenium, which can be toxic to wildlife, irrigation scheduling can help to reduce drainage and therefore decrease inputs of selenium to local waterways.

Tom Rogers' Almond Ranch: Smart Irrigation Scheduling in Action

> ***"In order to know what's going on, you have to monitor... it's just absolutely imperative that you know where your water is, and if you're actually using it or flushing it through the system."***
>
> **– Tom Rogers**

Tom Rogers and his brother farm 176 acres of almonds in Madera County, California. Following in their father's footsteps, they see accurate water monitoring as central to their on-farm water management. Today, they use a combination of careful soil moisture monitoring and weather information from on-site stations to help them decide when and how much to irrigate. Rogers estimates that irrigation scheduling has reduced their water use by up to 20% in some fields, while their yields are higher than many of their neighbors', which he attributes to the careful monitoring of crop water use (T. Rogers, almond grower and Vice-President of the Madera County Farm Bureau, personal communication, September 29, 2009).

Soil probes on the Rogers farm measure soil moisture in the first five feet, the tree root profile. Readings are taken every 15 minutes, giving a detailed picture of how water is moving through the soil, and whether it is actually being taken up by the trees or flushing through the soil. Weather stations in his fields provide information on temperature above and below the tree's canopy, humidity, wind speed, and rainfall. This allows him to keep track of how much water is being added to his fields through precipitation and lost through evaporation and transpiration. All of the information from the moisture probes and the weather stations is looked at together to decide when and how much to irrigate.

Irrigation scheduling has resulted in a number of benefits on the Rogers farm, including good plant health and yields, reduction of water use, and frost protection. Combined with improvements in fertilization of his almonds, Tom estimates that technological irrigation scheduling has resulted in higher water-use efficiency and yield gains. With permanent crops like almond trees, attentiveness to long-term plant health is particularly important. Tree age and health, permeability of soils, and microclimates all affect tree's water needs and mean that different parts of orchards may have different water needs. Tom's soil moisture probes allow him to be attentive to the differing water needs of his trees of different ages and trees of different production levels. Tom also sees off-farm benefits, including his ability to show water officials or the public that water used on his farm is being used carefully and put to beneficial use.

Conclusions

Growers already using smart irrigation scheduling have shown it to be useful in improving water-use efficiency and to have a number of additional benefits. Moreover, scheduling irrigation based on ET and in-field monitoring will become increasingly important in the future, as climate change adds uncertainty about future climatic conditions and basing future irrigation decisions on past conditions becomes increasingly unviable. However, available data suggest that these methods are still used by relatively few California growers (USDA 2009). Increasing the amount and precision of information available to growers to make their irrigation decisions, therefore, is an essential part of better management of agricultural water in California.

There are a number of hurdles that may prevent growers from implementing technological irrigation scheduling. First, some growers receive scheduled irrigation deliveries, and therefore must irrigate when they receive water. Improving irrigation delivery at the irrigation district level, including increased automation of head-gates, is needed so that technology-based irrigation scheduling is a possibility for all growers. Secondly, upfront costs of installing in-field systems can be significant. Providing low-interest loans for on-farm improvements (for example, through irrigation districts) is one potential solution (see Chapter 7). Finally, continuing to expand and improve the CIMIS program can ensure that basic ETo information for scheduling irrigation is freely available to all growers.

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