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An Advisory Service for Optimum Irrigation Scheduling in California

Principal Investigators:

Allan Fulton

**Irrigation and Water Resources Advisor
UC ANR**

Technical Completion Report for project: NIWR2010CA264B

Project period: March 1, 2010- – February 28, 2011

Project Summary

During this project, we refined the software in the Irrigation Management On-line (IMO) Scheduling program for use in California. Specifically, the ability to automatically upload reference evapotranspiration (ET_o) for short canopies from the California Irrigation Management Information System (CIMIS) was added to the IMO. The On-line Scheduling program can be accessed at the url: <<http://oiso.bioe.orst.edu/RealtimelIrrigationSchedule/index.aspx>>. In addition, the crop coefficient data base was expanded to include all known crop coefficients from California, and the software was modified to include high frequency irrigation systems (i.e. drip and micro-sprinkler) for scheduling. Based on feedback from grower-cooperators in 2010, we developed new, simpler software at the request of growers participating in the project.

Blake Sanden (Kern County), Allan Fulton (Tehama County), and Dan Munk developed active field research projects to validate the IMO program, and they developed excellent cooperation with growers to test the program. Until the IMO program was introduced into California production systems during the past two years, the program focused primarily on furrow, flood, center pivot, and hand-line and wheel-line sprinkler systems in agronomic and vegetable crops. Therefore, the UCCE farm advisors worked closely with OSU personnel to design and expand the software to apply to high frequency irrigation systems and orchard crops. They served as intermediaries between the grower-cooperators and the OSU program developers to provide feedback on how to improve the scheduling model. The farm advisors conducted several meetings with growers to train them on how to use the IMO and to gain feedback on the growers' perception about how to improve the model.

At UC Davis, we accumulated a data base of crop coefficients for expansion of the IMO into California. Using Excel software, we developed an irrigation scheduling model that accounts for water and salinity stress and during the first year of the experiment, but we were unable to find data to test the model from any source including the USDA Salinity Lab. Because of the lack of field data to test the model, we did not modify the IMO software to use the water and salinity stress model. We looked for sources of field data on interactions between salinity and water stress, but to our knowledge, none is available. However, we were able to enlist the support of the Biosaline Research Center in Dubai. Because of water and salinity stress problems in the Middle East, they have agreed to set up experimentation to validate the model. This year, they initiated field research to begin the verification process, and we will refine the experiments to validate the model in following years.

Irrigation scheduling of orchard crops is considerably more difficult than field crops because the water requirements are less well known and they often produce better in the long-term when moderate water stress is applied at certain times of the season. We chose to use almond, walnut, and prune orchards as our study crops in this project. Almond is a major water using crop throughout the Central Valley of California, and the University of California has a strong research program related to quantifying water stress in almonds. Walnut and prune are also major crops in the northern Sacramento Valley (Tehama County) that have been supported with field research quantifying the effects of deficit irrigation. The UCCE Farm Advisors worked on field

studies that related midday stem water potential readings and soil moisture monitoring for use in the Bayesian decision model used in IMO. We monitored evapotranspiration, soil moisture, and plant-based stress in each county in addition to working with growers.

There was been excellent cooperation between the Oregon State and UC Davis personnel. We emphasized irrigation scheduling of almond, walnut, and prune orchards with micro-sprinkler and drip irrigation systems because it comprises a growing part of California that differs from earlier work done in Oregon. The revised software and what we learned was a good first effort to expand IMO into California. In future years, our research group will move on to other crops to continue refining crop coefficients and water management. A detailed summary of accomplishments is provided in the following sections.

Information Transfer/Outreach Program

The potential for using computers to schedule irrigation has been recognized for at least 40 years (Jensen, 1969; Jensen et al., 1970). As of 2008, however, less than 2% of irrigated farms use computer simulation models to schedule irrigation (USDA, 2009). Yet, the demand for water has increased for some time. Still, the 'Condition of crop' and 'Feel of soil' are still the dominant methods for deciding when to irrigate (Table 1).

Over the past decade, several new irrigation schedulers were developed and new ones are under development. In addition, several new technologies present an opportunity as more robust tools for improving efficiency of irrigation. The increasing demand for water will necessitate that the next generation consider a broader range of management options.

Table 1. Methods Used in Deciding When to Irrigate (USDA, 1995, 1999, 2004, 2009)

Reported Method	1988	1994	1998	2003	2008
All farms	223,943	198,115	223,932	210,106	206,834
Any method	93.6%	94.9%	98.6%	100.0%	100.0%
Condition of crop	71.9%	68.2%	72.9%	79.4%	77.7%
Feel of soil	36.1%	39.5%	40.4%	34.8%	42.6%
Personal calendar schedule	15.4%	16.7%	18.0%	19.3%	25.1%
Scheduled by water delivery organization	10.6%	14.1%	10.1%	12.5%	11.8%
Soil moisture sensing device	7.5%	9.6%	8.0%	6.8%	8.6%
Reports on daily crop-water evapotranspiration	4.3%	4.4%	4.8%	7.2%	9.1%
Commercial or government scheduling service	4.5%	4.9%	3.2%	6.4%	8.0%
When neighbors begin to irrigate	NA	NA	NA	6.7%	6.9%
Computer simulation models	NA	2.3%	1.0%	0.6%	1.4%
Plant moisture sensing device	NA	NA	NA	1.5%	1.7%
Other	5.4%	8.7%	7.0%	8.9%	8.7%

Scientific irrigation scheduling is defined as the process of determining when and how much to irrigate (Cuenca, 1989) based on scientific principles. Conventional irrigation practices are predicated to maximize production. The National Engineering Handbook (NRCS, 1997) recommends that soil moisture be maintained above a management-defined level based on crop stress. Similarly, FAO 24 (Doorenbos and Pruitt, 1992) defines irrigation water requirements in terms of full production potential. Both of these recommendations are based on an underlying biological objective of maximizing production, and the soil moisture status tends to weigh heavily on the decision process. Irrigation Optimization is a different task which seeks to allocate water according to one or more goals rather than simply maximizing production (English et al., 2002).

According to Martin et al. (1990), optimizing an irrigation schedule has the following goals:

- maximizing net return,
- minimizing irrigation costs,
- maximizing yield,
- optimally distributing a limited water supply,
- minimizing groundwater pollution or
- optimizing the production from a limited irrigation system capacity

Shortage of water resources was identified as the reason for crop yield losses by 63% of the USA farms that reported diminished yield (USDA 2009, Table 26). Most farms have more than one field and, when the quantity of water is limited, it often affects all fields in the farm. On the other hand, when delivery capacity is limited, the shortages may apply to individual fields. In either case, the manager must consider all of the fields and the marginal value of water in each field, which is a non-trivial task. Martin and van Brocklin (1989) demonstrated some of the complexities of multi-field scheduling by using dynamic programming to schedule irrigations for a mix of crops. Lamacq et al. (1996) used a model of farmer behavior to simulate allocation of water to a group of surface irrigated fields using a network of irrigation ditches and demonstrated that decision-making must occur at the whole farm level. Bernardo (1987) used a whole farm simulation to demonstrate how, for center pivots, improved labor practices, and deficit irrigation were important adjustments for dealing with reduced water supplies.

Deficit Irrigation (DI) has been demonstrated as an optimal way to maximize net returns from water and has also been demonstrated as an effective irrigation strategy when water supplies are limited (English, 1990; English and Raja, 1996). Fereres and Soriano (2006) and Geerts and Raes (2009) have reviewed the appropriate use of DI for a variety of crops. Methods for implementing DI include delaying irrigation, cancelling certain events, partial root zone drying, and reduced set times or application rates. These last two options present an important challenge for irrigation scheduling because irrigation efficiency is linked to irrigation intensity. This relationship means that the efficiency estimated at design time cannot be used to estimate application depths in water balance calculations; instead, efficiency must be simulated. The feasibility of DI also has a strong dependence on irrigation system performance, particularly on the low quarter efficiency (Rodrigues and Pereira, 2009).

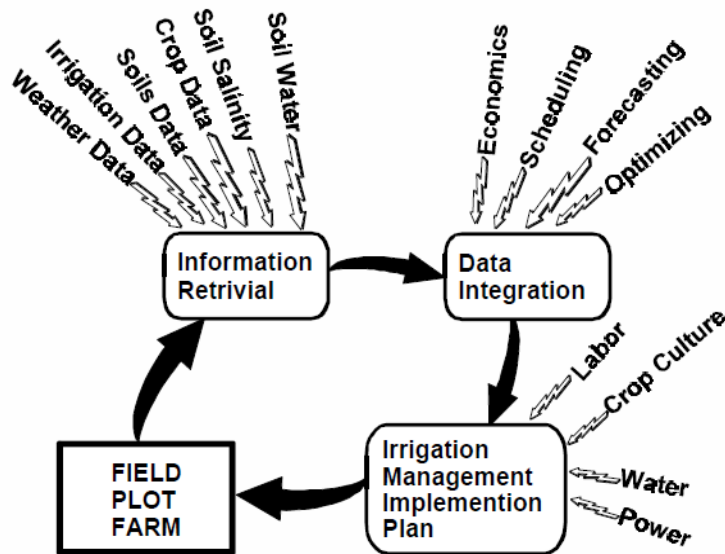
DI strategies also have implications for the accuracy of the irrigation scheduler's calculations. The NRCS National Engineering Handbook recommends that "an irrigation scheduling tool needs only be accurate enough to make the decision when and how much to irrigate" (NRCS, 1997 p. 9-22). When implementing a deficit schedule, irrigators can eliminate any potential crop yield or net return benefit through errors in timing or application amounts (Dudek et al., 1981). One of the basic assumptions built into most water balance models is that an irrigation event will fill the soil to field capacity. Filling the soil minimizes the spatial variability and uncertainty about the current soil moisture status. This assumption is not valid for DI when the strategy involves only partially refilling the soil. Implementing DI requires precision irrigation that in turn requires improved spatial and temporal resolution (Sadler et al., 2005).

The sensitivity of DI to timing errors increases risk. Events beyond the manager's control, e.g. broken equipment, delivery delays, etc., make implementing DI vulnerable to events that damage yield. Despite this, Perry and Narayanamurthy (1998) have reported effective use of DI even when delivery of water supply is uncertain. Spatial non-uniformity of applied water is a significant source of risk and the variability of net returns increases when non-uniformity is considered (Bernardo, 1988). Because the necessity to reach a prescribed level of yield reduction (for net economic returns) and the increased risk, irrigation schedulers must include yield estimates with their recommendations.

Hornbaker and Mapp (1988) demonstrated that daily plant models provide information for a more careful analysis of the value of timing irrigation. Raes et al. (2006) developed a coupled water balance model with a model of yield decline that uses different yield decline rates during various growth stages. The authors concluded that their model would be useful for developing irrigation strategies under deficit conditions. The papers, Raes et al. (2006), and Hornbaker & Mapp (1988) demonstrate the utility from incorporating yield estimates.

One can manage each of the risk sources (externalities, spatial variability, and excess yield reduction) through careful monitoring. Growers differ in acceptable levels of risk preference and will value scheduling recommendations differently based on their risk preference (Bosch and Eidman, 1987). Explicit consideration of growers risk preferences helps to provide a useful schedule.

The irrigation management cycle shown below is based on Figure 1 in Howell (1996). He identified 'sensor and Information Technology' as one potential area of research for irrigation scheduling and noted that not all of these sources of information have been fully utilized to facilitate irrigation decision making.



Irrigation Management Cycle (from Howell 1996)

Much has changed in information technology since 1996, and Web-based technologies have matured for information exchange. The availability of online databases for soils (NRCS, 2010), weather (NOAA, 2010), and crop information has expanded. Online delivery of data from on farm instrumentation is becoming commonplace. Perhaps the most encouraging development is the Department of Agriculture recent initiative to bring high-speed internet access to rural areas (USDA, 2010). Each of these factors presents opportunities for facilitating the “Information Retrieval” and “Data Integration” phases shown in the figure above. Building robust management information systems may lie more in the realm of computer science than in irrigation science however, dependence of irrigation scheduling on information means that developers of scheduling tools must have knowledge of both realms.

The technological advances are not necessarily improving grower confidence. In a survey of growers in the Hawkesbury-Nepean Catchment NSW, Maheshwari et al. (2003) found that while growers were interested in knowing more about scheduling they were not confident about what technologies were appropriate. In addition, when asked about soil moisture monitoring systems for paddock management, some growers said there was no use for it or considered it a waste of time.

NOAA has offered weather forecasts online for many years. However, depth of precipitation forecasts and the forecast data needed to calculate reference ET are recent products. The National Weather Service has recently started providing point forecasts available in an XML format (NOAA, 2010). Wang and Cai (2009) demonstrated that using weather forecasts could have a positive impact on water use. They found that, using seven day forecasts in conjunction with the SPAW model, growers would have lower water use during normal years and higher profit during dry years when compared to scheduling based only on current soil moisture status. Although weather data is increasingly available online, not all weather networks are providing data in forms readily useable by web based applications. For example, the Agricultural Water

Conservation Clearinghouse has a list of weather stations and ET networks (Agricultural Water Conservation Clearinghouse, 2010). Of the 14 networks listed there, only the CIMIS network provides weather data in an XML format, which is an easier format for data transfer and use in the IMO. Nearly all of the networks (including CIMIS) provide their data in a 'csv' format that is readily useable by spreadsheet applications.

Acquisition of reference evapotranspiration (ET_o) and crop coefficient (K_c) data is only one part of the scheduling process. Making data easy to obtain and presenting it in clear ways is a valuable feature, but the real power of irrigation schedulers lies in the potential for using the information to drive calculations that influence management decisions. In this sense, an irrigation scheduler is also a decision support system. Mohan and Arumugam (1997) indicated that expert systems are viable and effective tools for irrigation management and stressed the need to include other aspects of irrigation management such as canal and reservoir operation. This need was also indicated by Clyma (1996) who concluded that scheduling services are not adequately integrated with other farm operations that hold greater importance than irrigation decisions. Wolfe (1990) and Woodward et al. (2008) reported the need for combining irrigation tools with crop growth models. Woodward et al. also emphasized that user participation in each step of the development process is important for success of the program.

Table 1 indicates that 'condition of the crop' is the most commonly used indicator for scheduling irrigation. This implies that an irrigation scheduler that uses plant-based measurements would be more compatible with grower's current thinking. However, scheduling via plant-based measurements is not without problems (Jones, 2004). Using plant based measurements coupled with a mechanistic model has been demonstrated to be effective (Steppe et al., 2008), but the authors point out that the lack of universal parameter values for different crops is a serious limitation at present.

Nearly every region in the western USA has a scheduling tool available and a weather network that can supply data needed to perform scheduling calculations. The tools may have varying features and the weather networks varying measurement densities but all of the tools require some effort to setup and use. Even when scheduling services are free and 'self service' there is still a cost embedded in the time required to use them. The success of irrigation scheduling applications depends on more than their accuracy, ease of use, or cost. Shearer and Vomocil (1981) described the challenges and obstacles that they faced over 25 years of promoting irrigation scheduling in Oregon. They emphasized that if irrigation services are not supported externally to the farm then the growers will stop using the service. In other words, growers are willing to use irrigation scheduling, but other farm activities are considered a better use of their time.

Two examples of successful scheduling services are the IASA in La Mancha Spain (Rodriguez et al., 2002; Manas et al., 1999; Smith and Muñoz, 2002) and the El Dorado Irrigation District in northern California (Taylor, 2009). IASA, the Irrigation Advisory Service of Albacete, provides irrigation scheduling advice and decision support to growers in the Castilla-La Mancha region of Spain and has been providing this service for more than 15 years. IASA staff visit participating

farms on a weekly basis, collect information for the advisory service, and disseminate scheduling information through various mediums, and provide site-specific scheduling recommendations to the participating farms. The El Dorado Irrigation District (EID) in northern California is another example of how service can make irrigation scheduling successful.

The EID uses TrueISM software (TruePoint Solutions, 2008) that was custom built for their district. Automated weather stations, permanently installed soil moisture monitoring sites, and regular visits by the EID staff all reduce the effort required for the grower. The service has been operating long enough to establish accurate system characterizations and positive relationships with the growers. The El Dorado program originated nearly three decades ago, and they were one of the original cooperators in the development of CIMIS. Its success, to a large extent, is related to having long-term technical support and rapport with the growers to assist in the adoption of irrigation scheduling. The District's commitment to provide staff to support the adoption of irrigation scheduling approaches and computer programs was arguably more important than the specific approaches and computer programs. The use of TruePoint illustrates that the techniques used have improved over time. Originally, EID used an extensive neutron probe monitoring network.

Both IASA and EID are providing scheduling services, that is, the irrigation schedule is produced by applying scientific principles, but the schedule is delivered to the grower as a product of the organization. In both cases, the service involves significant hands on work by the service personnel and this time investment reduces the burden on the irrigator. Additionally, a reputation for the accuracy of the service has been established over time. This model of an irrigation scheduler does have limitations, particularly the need for continued funding, however, as Shearer & Vomocil argued, it does motivate the use of irrigation scheduling.

The IMO and this project were proposed as the next generation (NG) for irrigation scheduling programs. The goal is to make the IMO an irrigation optimization tool. As such, it will provide the following features:

- Explicit consideration of farm level constraints. Limitations in water allocations apply to the whole farm and should be included in the analysis as such. Limitations in supply capacity can affect at the farm or field level (either demand exceeds pumping capacity or canal flow is less than ordered). Temporal limitations on both of these (e.g. midseason changes in allocation, and restrictions on delivery timing) will also be considered.
- Conjunctive scheduling of all fields in a farm (or management unit). Irrigators make decisions at the farm level so a scheduler will facilitate that decision process.
- Alternative or unconventional scheduling strategies. These strategies would include reduced adequacy, partial season irrigation, critical growth stage scheduling.
- Full Season forecasting. This feature will allow growers to evaluate different irrigation strategies and for planning under different water use scenarios.
- Consideration of economic consequences. The impact of management recommendations will be expressed in economic terms as well as agronomic terms.

The IMO will support Deficit Irrigation (DI), which includes the following features:

- Explicit analysis of irrigation efficiency. Implementing DI often involves manipulating irrigation intensity. Irrigation efficiency is linked to irrigation intensity and cannot be assumed a priori. Successful implementation of DI is dependent on system uniformity and efficiency.
- Estimation of yields and potential yield losses. DI involves some level of yield reduction relative to full production potential. Furthermore, when DI is used to maximize net economic returns, yields are an explicit part of the objective function. For both of these reasons, consideration of yields is an essential part of implementing deficit irrigation strategies.
- Consideration of irrigator's risk preferences. DI implies an increased risk of yield loss. People have different preferences for risk and financial status of farming enterprises may limit the amount of risk they can tolerate. Therefore, analysis of risk must be explicit in the planning of deficit strategies.

In order to support the previous two items, the IMO needs greater precision in its calculations and have smaller tolerances for errors in their forecasts. This need requires that the simplifying assumptions associated with full irrigation will no longer apply. The IMO will have the following features to support increased precision:

- Multiple types of physical measurements will be used. Plant based, soil moisture based, atmospheric, and remote sensing measurements will all be incorporated into the calculation of the soil water balance instead of relying completely on any one source of information for scheduling decisions.
- Schedulers will allow for quality weighting of various measurements. Different types of measurement have different magnitudes of error or uncertainty. Further, growers have differing levels of trust associated with newer technologies. The farmer's own opinion in addition to the physical evidence should be given credence when combining various measurements.
- Schedulers will be explicit about spatial and temporal variability. Soil physical properties, crop characteristics, and depth of applied water all vary spatially. Using deficit irrigation strategies means that schedulers will need to consider spatial variability and its effect on the variability of its recommendations. Being explicit about the variability will help the grower to visualize the range of possible outcomes from their scheduling decisions.
- Schedulers will be explicit about the risk and uncertainty of their recommendations. No measurement technology can give a perfect picture of field conditions and the accuracy of weather forecasts is well known. No physical model is perfect. Each of these factors introduces uncertainty that cannot necessarily be separated. Being explicit about the uncertainty will help the grower assess the verity of the recommendations.

The IMO will include information management systems.

- Schedulers will use relevant data from online databases. This will include weather networks, soils databases, and remote sensing data. The scheduler will handle downloading, parsing, and integration of the data into its recommendations.
- Schedulers will be integrated with the growers own instrumentation. Personal weather stations have been available and affordable for some time. Increasing availability of cell phone and wireless communications means that users will be able to access the data remotely. However, at present manufacturers often use proprietary or nonstandard formats for data exchange. The NG will leverage existing standards for data exchange to automate the process of extracting instrumentation data.
- Schedulers will use weather forecasts. The NG will use weather forecasts to improve forecasts of irrigation needs instead of relying on historical averages.
- Schedulers will be integrated with irrigation hardware. Providing accurate forecasts requires knowledge of previous water use. The NG will obtain this information automatically via instrumentation on the irrigation system or through the software used to control the systems.
- Schedulers will be online applications. The NG will deliver scheduling recommendations using more than one web based modality. These different forms will include HTML, Web Services, and interfaces appropriate for mobile devices.

The IMO will serve as part of a service provided to the grower rather than a standalone tool. It will have the following features:

- Schedulers will have a substantial 'service' component. As described in the previous sections, successful schedulers have done most of the time consuming work for the grower. The NG will follow this pattern in that most of the work of preparing the schedules will be done by an organization external to the farm. The service may be public or private and may include some type of fee to the grower.
- Federal and local organizations will be involved in delivering the service. Federal agencies will continue to provide support from irrigation scheduling and this support will be an integral part of the irrigation scheduler through either software development or research that supports irrigation scheduling.
- Schedules will be accessed by irrigation districts and watershed organizations. This will allow irrigation districts to better plan and manage canal networks.

This introduction attempt outlines the requirements for the next generation of irrigation schedulers, and the IMO was designed to meet these requirements. Some of the challenges that schedulers face as well as new opportunities available to them were described. These challenges were: the complexity of irrigation optimization, the requirements for and risk implications of deficit irrigation, changes in information management technology and its potential impact, and the importance of support from organizations external to the farm enterprise. The current and future features of the IMO were described.

Background on Evapotranspiration Symbols and Terms

Actual evapotranspiration (ETa) was measured in several orchards using the eddy covariance and surface renewal methods (Paw U et al., 2005; Shaw and Snyder, 2003). Note that crop coefficient (Kc) values are computed as the ratio of unstressed crop evapotranspiration (ETc) and ETo (i.e. $K_c = ET_c/ET_o$). When evapotranspiration is measured in the field, however, there is a chance that the crop is experiencing water, salinity, or other stresses that can reduce the actual crop evapotranspiration to some value lower than ETc (i.e. $ET_a \leq ET_c$). One can estimate ETc as $ET_c = ET_o \times K_c$, where Kc is a crop coefficient used to estimate unstressed crop evapotranspiration from ETo. Actual crop evapotranspiration is estimate as $ET_a = ET_c \times K_s$, where Ks is a stress factor that varies from 0 when there is no transpiration to 1.0 when the crops is unstressed. Thus, one can estimate the observed actual evapotranspiration as $ET_a = ET_o \times (K_c \times K_s)$ or $ET_a = ET_o \times K_a$, where $K_a = K_c \times K_s$ is the actual crop coefficient. One of the reasons for studying stem water potential in this project was to attempt to estimate Ks, which will improve our estimates of ETa and hence the IMO program. In general, we assume that Ks = 1.0 for a well managed, well-irrigated crop; however, almonds are often stressed during the harvesting period, so $K_s < 1.0$ is likely during late August and early September. Since this is research in progress, we will present the coefficients to estimate ETa as $K_c \times K_s$ in this report. Eventually, we will estimate the Kc and Ks values separately.

Notable Achievements

Results from measuring actual crop evapotranspiration (ETa) with energy balance methods for the almond orchard on the Corning West farm for three seasons (2008-2010) are shown in Figures 1-3. The observed Ka values were considerably higher than those reported in the literature. During mid-season, the Ka values were on the order of 1.00 to 1.20 with slightly higher values in 2010. We are still investigating the reason for year-to-year variability.

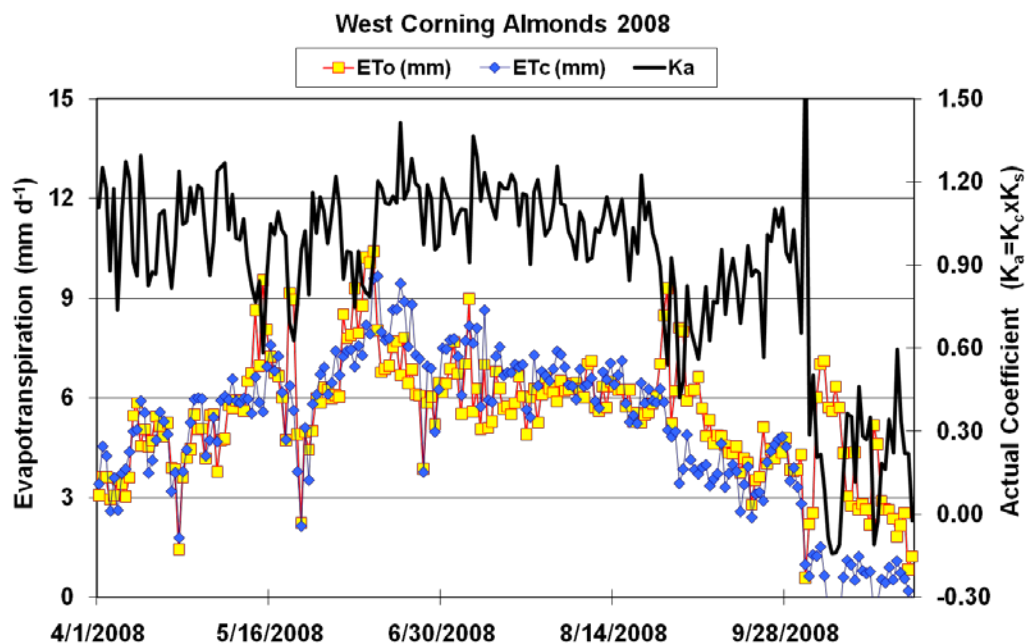


Figure 1. ET and $K_a = K_c \times K_s$ data from West Corning in the Sacramento Valley during 2008.

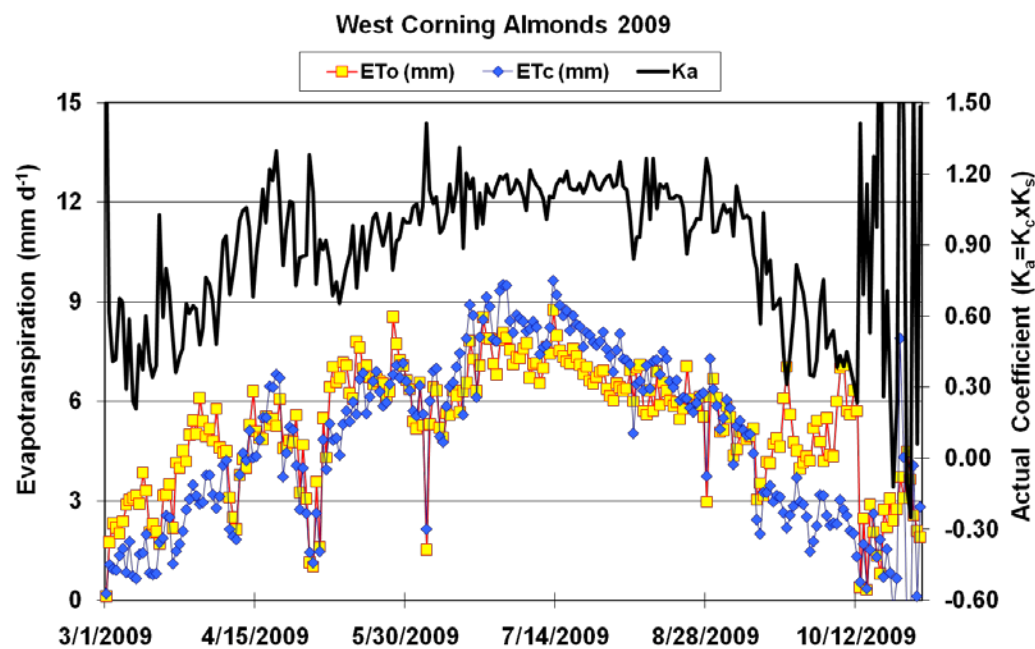


Figure 2. ET and $K_a = K_c \times K_s$ data from West Corning in the Sacramento Valley during 2009.

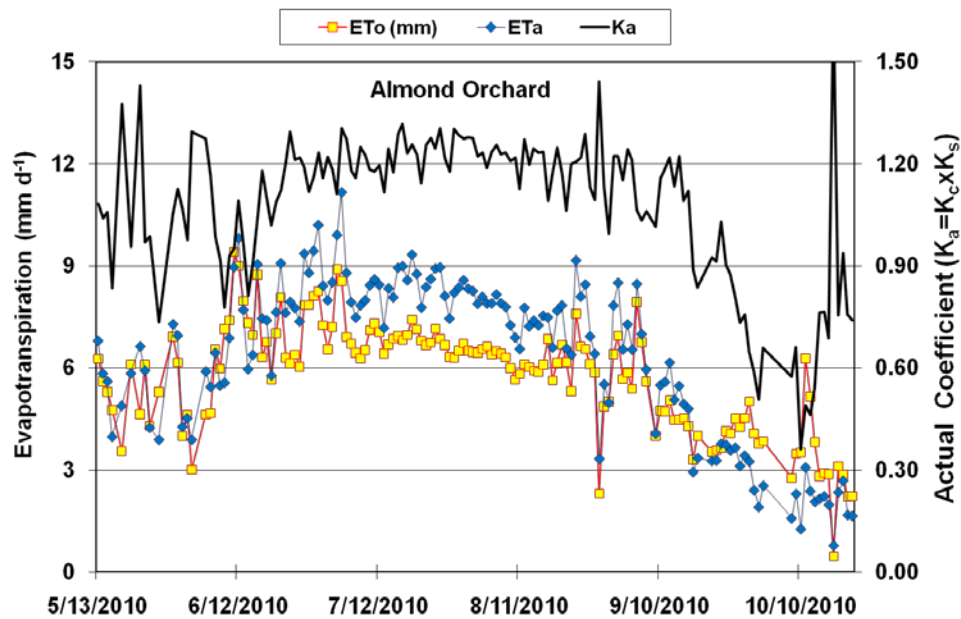


Figure 3. ET and $K_a = K_c \times K_s$ data from West Corning in the Sacramento Valley during 2010.

In 2010, evapotranspiration was also monitored at the M&T Ranch near Chico, California in cooperation with Joe Connell, Farm Advisor Butte County. The ETo, ETa, and $K_a = K_c \times K_s$ data from 2010 are plotted in Figure 4. The K_a values were slightly less but similar to the values at West Corning.

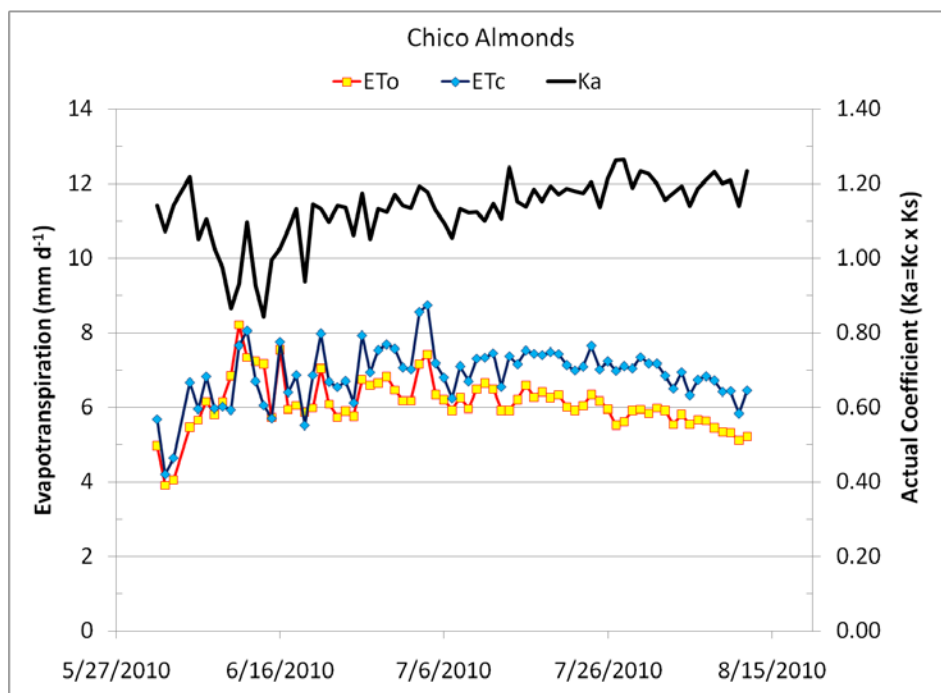


Figure 4. ET and $K_a = K_c \times K_s$ data almond orchard near Chico in the Sacramento Valley during 2010.

Results from the San Joaquin Valley (Kern County)

Prepared by: Blake Sanden, Irrigation & Agronomy Advisor

Project Demonstration Setting

More than 40 hours of outreach occurred during March and April 2009 to secure and provide preliminary training to five grower cooperators farming almonds and pistachios using micro-sprinkler (fanjet) or drip irrigation systems. From May 1-13, 2009 a total of 34 monitoring sites were installed consisting of a PVC neutron probe access tube to a depth of 9 feet and a small in-line flow-meter fitted to the hose/emitters serving that site. Four monitoring sites with access tubes to a depth of 6 feet were in existence from earlier studies to provide a total of 38 monitoring sites over 22 fields, each of which has been monitored weekly since the middle of May 2009. Many measurement locations (i.e. 28) were chosen at each site because either Watermark blocks (electrical resistance sensors) or tensiometers were already installed at the site.

Eight second count readings of neutron backscatter at one foot increments with a Campbell Pacific Nuclear Hydroprobe 503 DR (neutron probe) provide a measurement of soil water content with depth every week. These readings, combined with the metered record of applied water for the week, are supplied to the growers via email every Wednesday or Thursday so that they can update field soil moistures and irrigations in the IMO program on a regular basis.

Grower Adoption

Considerable effort was expended to encourage use of the IMO software by cooperating growers. Unfortunately, the growers did not feel comfortable with the original IMO format and complexity of content due to 1) lack of time spent to become completely familiar with the entry protocols and 2) having found their initial entry sessions to be somewhat cumbersome and that weekly data entry has to be done on a line by line, depth by depth basis for each field instead of allowing a sort of "one-stop" Excel file type upload. As a consequence, the growers tended to look at the processed/averaged neutron probe soil water content data and a summarized "percentage available moisture" that was provide with our weekly monitoring. They continued with their "normal year" scheduling as long as the field was not to dry or too wet. (See Table 1 for an example.)

An additional 20 hours of consultation over the 2010 season with the five cooperating growers did little to alter their initial opinions about the IMO program from the 2009 season. This problem is compounded by the fact that at the start of this irrigation season we told them that a simpler, more user friendly version of the IMO program would be available late spring and, at that time, we would do more training to facilitate their irrigation scheduling operations. Unfortunately, due to programming difficulty, the project was unable to deliver a simpler program and growers pretty much maintained the status quo from 2009 (i.e. they just reviewed our "soil moisture update" email and, if needed, adjusted their irrigation scheduling by hand calculation.

Our technical staff has continued to enter all current soil moisture data in an attempt to encourage program access and use by the cooperators, but we have not been actively contacting them to encourage them to log on due to the above reasons

Table 2. Example of compiled weekly soil moisture report sent to each grower cooperator containing the fields for that grower, soil water content at the indicated date and applied water to each field at the monitoring site location over the previous week.

Soil Water Content (in/ft)											9/27/10	ETo (in)	1.24	Rain (in)	0.00	AVAILABLE WATER			
	PLOT # Check	DEPTH									TOTAL 0-5FT	6-9FT	Rootzone to 5'		Irrig (in)	Cum (in)			
		1	2	3	4	5	6	7	8	9			%	Inch					
602 Alm NE	NP	1.00	0.70	0.80	1.49	1.66	2.79	1.90	1.83	0.97	5.64	7.49	9%	0.64	2.38	59.41			
605 Alm SE	NP	1.52	1.49	1.07	0.73	0.56	0.52	0.59	0.49	0.52	5.37	2.13	5%	0.37	0.81	47.83			
602-605 Avg	9/27	1.26	1.17	1.00	1.13	1.23	1.89	18"	36"		5.79	6.99	11%	0.79	1.31	52.15			
tension (cb)											0	-75							
606E Alm SW	NP	1.21	0.90	1.28	1.93	1.97	1.69	2.52	1.90	1.14	7.29	7.25	33%	2.29	0.02	38.34			
606W Alm NE	NP	1.59	1.25	0.97	1.28	1.21	1.21	1.76	1.11	2.11	6.30	6.19	22%	1.30	0.15	30.57			
606 Alm	9/27	1.40	1.07	1.13	1.61	1.59	1.45	18"	36"		6.79	6.72	27%	1.79	0.09	34.45			
tension (cb)											-37	0							
601 Alm SE	NP	1.25	1.31	1.14	1.18	1.49	2.35	2.62	3.03	3.34	6.36	11.35	19%	1.36	0.75	49.22			
307 Alm NW	NP	1.83	1.52	1.90	1.56	0.87	0.73	0.56	0.49	0.42	7.67	2.20	38%	2.67	1.28	44.68			
601-307 Avg	9/27	1.54	1.42	1.52	1.37	1.18	1.54	18"	36"		7.02	6.77	29%	2.02	1.01	46.95			
tension (cb)											0	-39							
601B Pist E	Pist	1.20	1.31	1.80	2.90	4.39	4.70	4.58	4.33	4.39	11.61	18.01	41%	4.11	0.29	18.65			
601B Pist W	Pist	1.10	1.17	1.20	1.04	2.56	3.53	0.00	0.00	0.00	7.06	3.53	7%	0.56	0.32	20.58			
601B Pist	9/27	1.15	1.24	1.50	1.97	3.48	4.12	18"	36"		9.33	10.77	24%	2.33	0.30	19.62			
tension (cb)											-58	-24							
Cherries	9/27	1.46	1.09	1.22	2.79	2.48	1.19	1.26	1.73	1.63	9.03	5.81	58%	4.03	0.78	38.83			

Evapotranspiration and Crop Coefficient Development

Actual crop evapotranspiration (ETa) was measured over an almond orchard at Paramount Farming during 2008, 2009, and 2010. The product actual coefficient $K_a = K_c \times K_s$ was determined as the ratio ET_a/ET_o with ET_o coming from the nearby CIMIS station. The ET_o , ET_a , and K_a data from the energy balance surface renewal (EBSR) measurements for 2008 are shown in Figure 5. The results from the energy balance sonic anemometer (EBSA) measurements are shown in Figure 6. The K_a results were similar for the two methods except for a bit more fluctuations in the EBSA data.

Mean weekly $K_a = K_c \times K_s$ values for the three seasons are plotted in Figure 7. A plot of the weekly mean K_a values, averaged over 2008-2010, K_c values used in Kern County during recent years, and K_c values widely used in the San Joaquin Valley from older literature is shown in Figure 8. Clearly, the new coefficients are higher than those used in Kern County and they are considerably higher than the older San Joaquin Valley coefficients. Although reasons for the higher K_a values are not definitive at this time, the higher values are likely due to more dense plantings, frequent micro-sprinkler irrigation, and better management than 30-50 years ago. Also, the measurement methods used today are likely to be more accurate. Coefficient data from the Sacramento Valley and from Fresno County were similarly higher than in the past. Note that there was a dip in the K_a during late-August and early-September that was likely due to a cutback in irrigation during harvest. The large dip in K_c during October and November 2010 (Fig. 7) was likely due to rainy weather and instrument problems. Of course that affected the November dip during November (Fig. 8).

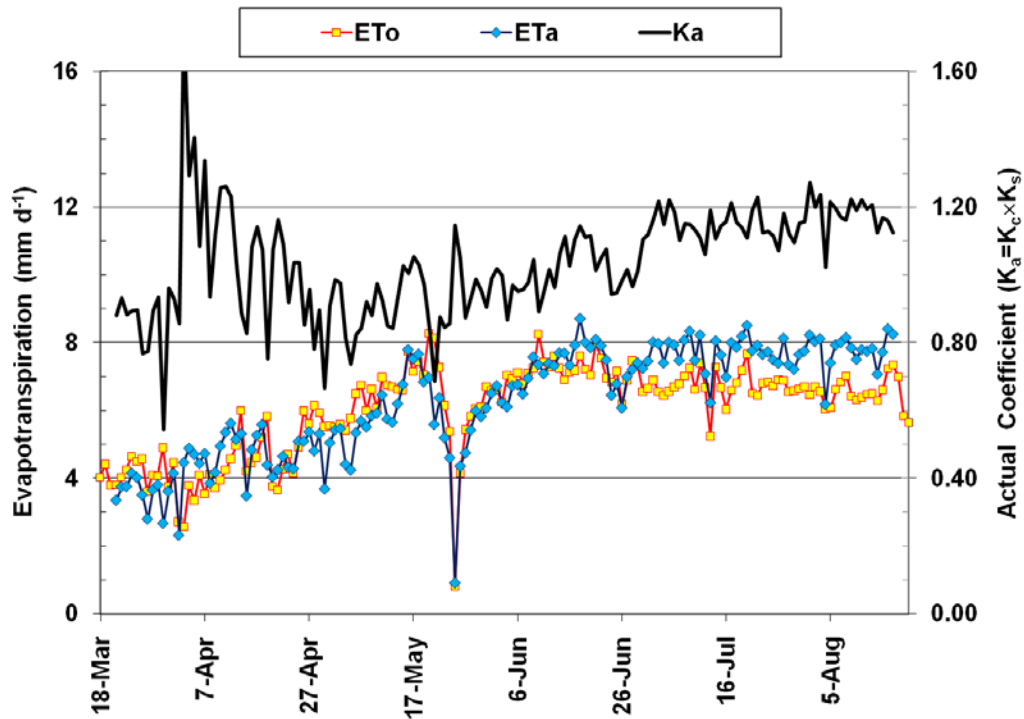


Figure 5. Reference (ETo) and actual (ETa) crop evapotranspiration rates from the EBSR method collected during 2008 in Kern County.

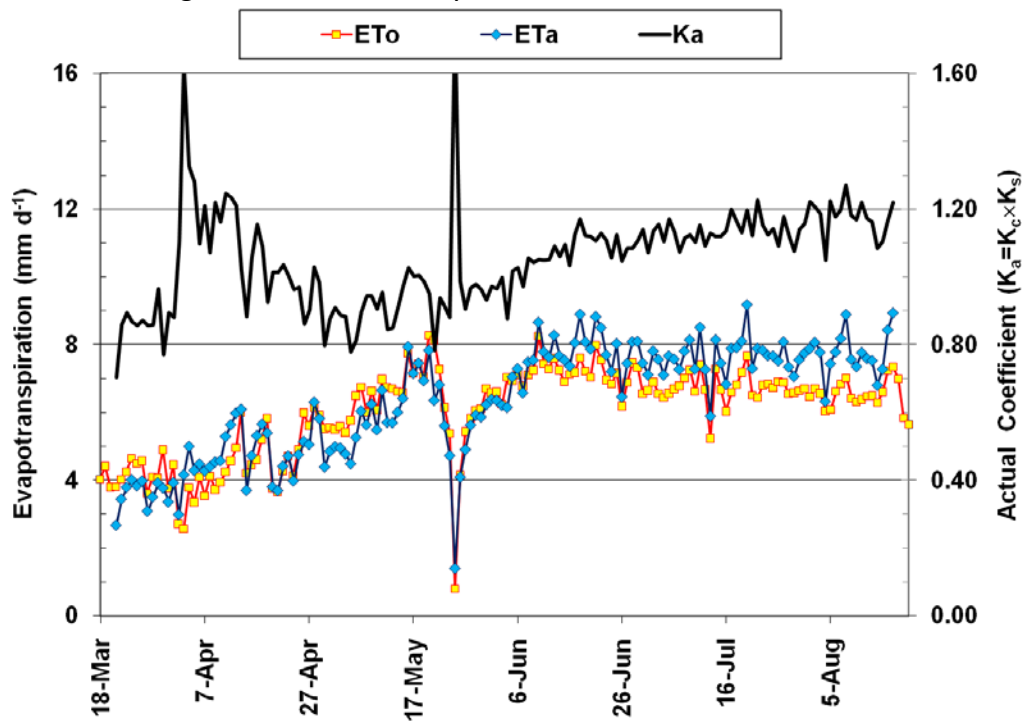


Figure 6. Reference (ETo) and actual (ETa) crop evapotranspiration rates from the EBSA method collected during 2008 in Kern County.

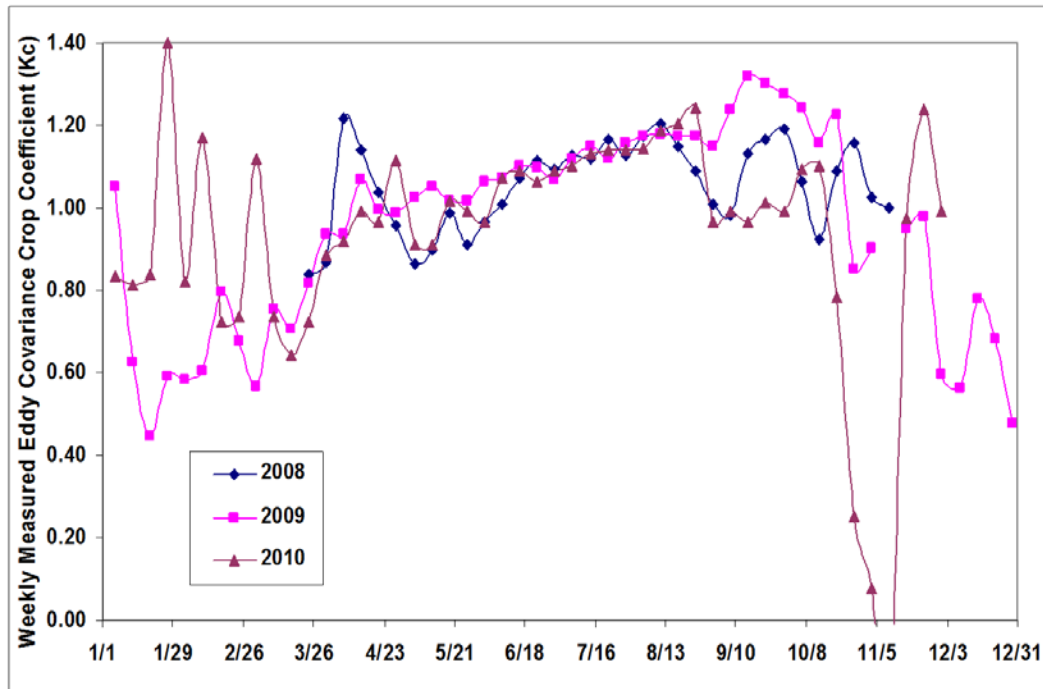


Figure 7. Mean weekly actual coefficient $K_a = K_c \times K_s$ values for almonds during 2008, 2009, and 2010 seasons

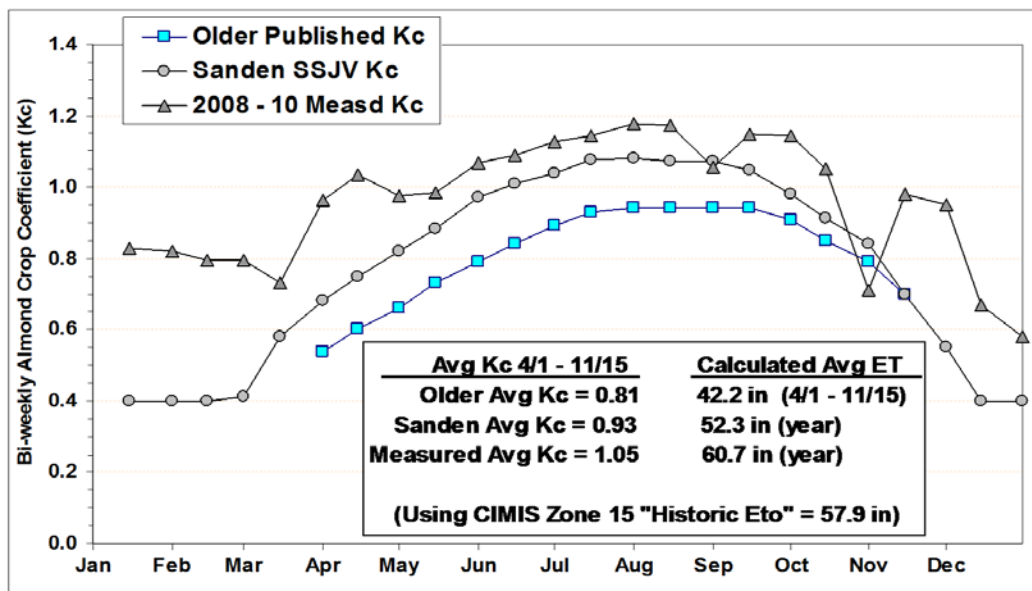


Figure 8. Mean bi-weekly actual coefficients $K_a = K_c \times K_s$ for almonds averaged over 2008-2010, K_c values used in Kern County during recent years, and older published K_c values for the San Joaquin Valley (Fereres and Puech, 1982). Note that the $K_s = 1.0$ was assumed for the $K_a = K_c \times K_s$ data prior to this project.

The following activities served as vehicles to discuss and promote scientific irrigation scheduling in general and the IMO program in particular where appropriate.

1. More than **40 hours of outreach** was used in March and April, 2009 to secure and provide preliminary training to **5 grower cooperators farming almonds and pistachios** using microsprinkler (fanjet) or drip irrigation systems.
2. One Kern County irrigation workshop on April 8, 2010 with a newsletter and meeting handout (attached). 54 attending.
3. One statewide popular press interview and article: "Farmers look at net returns when making irrigation plans". Ag Alert Apr 26, 2010 pp.7-8
4. One statewide irrigation symposium with a session on irrigation scheduling 2/2/10, flyer attached. 88 attending.
5. Six grower irrigation scheduling consultations on farms and in office

Report from the San Joaquin Valley (Fresno County)

Prepared by: Daniel Munk, Irrigation & Agronomy Advisor

We completed our initial goals and objectives aimed at developing new information on the water use and irrigation management habits of San Joaquin Valley Almond growers by observing field management practices and monitoring specific water management parameters. Our local team has continued to monitor one grower site near Firebaugh, CA and is continuing its efforts to build an appropriate data base for testing the IMO scheduling program initiated by the Department of Engineering and Bio-Resources at Oregon State University. Our goal is to develop a data base that can test a variety of farm water management variables and work to increase the farm water decision options thereby improving farm water efficiency and manage problems caused by improper irrigation management. We believe that knowledge gained by developing detailed information on a small number of fields will later translate into a more broad understanding of farm water management problems and assist in finding solutions.

The orchard we monitored was a high yielding almond orchard using a water management regime similar to other fields operated by the grower as well as other farms in the region. The monitoring field utilizes double row drip, as does the majority of Almonds fields in this region and is scheduled with the assistance of the CIMIS (California Irrigation Management System) weather system and verified by the data we are collecting using the surface renewal (SR) and eddie covariance (EC) methods that were installed in the winter of 2008. The cooperating grower also developed similar strategies using the IMO program for evaluating whole farm water supply management and incorporated learning from the study field to establish weekly water applications to other almond orchards on the farm.

Together with the support of a field technician, we were able to accomplish the major goals and objectives that we established for the project. This year's monitoring activity included developing soil water information using the neutron probe to establish multiple location soil water readings, midday stem water potential readings and together with Department of Water resources maintained and developed the SR and EC stations and data. Eight neutron probe tubes were monitored on a 7 to 9 day interval along with stem water potential readings on multiple trees. We summarized the water applied and soil water extraction information. At each visit we

maintained the SR and EC equipment and downloaded the necessary data for the ETa calculations. The seasonal ET and Ka plots from 2009 are shown in Figure 9.

In terms of outreach activities, I participated in a March 2, 2010 regional meeting by presenting project goals and objectives as well as summary findings to more than 50 almond and cotton growers. This meeting was sponsored by UCCE and organized by the San Joaquin Sustainable farming project in Dos Palos. I also participated in a UCCE/Sustainable Farming Systems field day held near Los Banos on June 23, 2010 to discuss some of the findings from this farm water management program to more than fifty growers and industry participants.

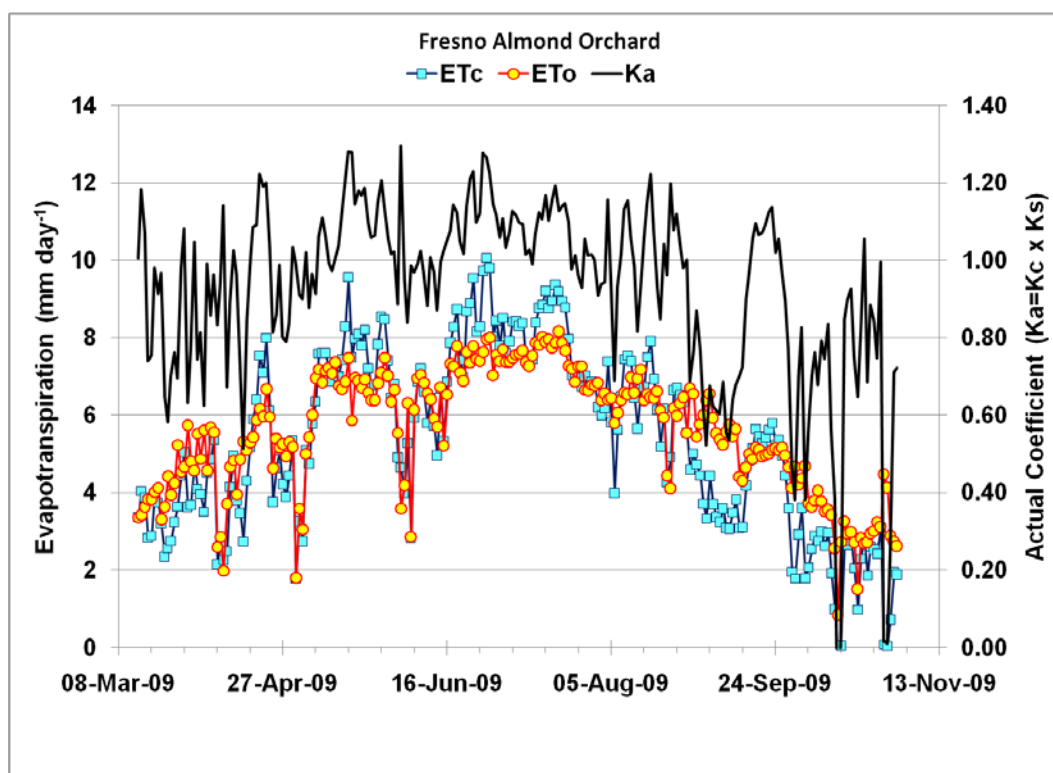


Figure 9. ET and $K_a = K_c \times K_s$ data from the Fresno County almond orchard in the San Joaquin Valley during 2009.

Report on the Oregon State Scheduling (IMO) Model Development

Prepared by Marshall English, Professor of Biological and Agricultural Engineering

Systems analyst/programmer support

The Oregon State research team has worked with the system analyst to: (i) redesign of the IMO system, and (ii) providing training in use of the IMO system. The primary focus for this year has been evaluation and support of the features developed last year. Technical support was provided (and continues) to the farm advisors and some growers during the 2010 irrigation season. Particular attention was given to calibration of the participating farms using data from the previous year. Numerous bug fixes were implemented prior to and during the two-year project. Some interface enhancements were developed to facilitate spread sheet upload of soil moisture

measurement data. Also, requisite system maintenance for the server, database, and software systems was performed.

Development and implementation of the Bayesian method for utilization of soil moisture measurements continued during this year. We developed the theoretical framework necessary to integrate the Bayesian method with the Irrigation Efficiency Model's internal representation of soil moisture. Preliminary implementation of this framework has begun.