IMPROVED WATER USE EFFICIENCY FOR VEGETABLES GROWN IN THE SAN JOAQUIN VALLEY

RELEVANCE and IMPORTANCE

The goals of the California Bay-Delta Program's Water Use Efficiency program include water quantity, water quality, and in-stream flow and timing improvements that directly or indirectly benefit the Bay-Delta. These goals are to be achieved through a comprehensive water conservation program in all sectors of the urban and agricultural economy. Irrigated agriculture is the largest water user in California and, as such, has the potential to make significant contributions to improving the water quantity and quality in the Bay-Delta with small percentage increases in water conservation. There are at least two areas that water savings in irrigated agriculture can be achieved; (1) during deliveries to a district and within the district, and (2) on-farm application. The focus of this project will be the potential for on-farm savings by improving estimates of crop water requirements, improved irrigation scheduling, and improved irrigation system selection and management.

According to *California Water Report* (1999), significant changes in California crop production are expected to occur over the next few years. The report predicts that in the San Joaquin Valley the acreage of vegetable crops, trees, and vines will increase, and the field crop acreage will steadily decline. This prediction is due to reductions of nearly 2.8 million acre-feet in available water supplies in the region. These reductions are expected because of economic and environmental pressures, particularly on the west side of the San Joaquin Valley (SJV) where constraints on crop production continue to grow. These constraints include increasing water demand and water-rights issues, recurring drought problems, increasing drainage water disposal problems, and soil salination and waterlogging problems due to over irrigation and lack of natural subsurface drainage. Crop production in the region is also changing because of current market conditions. For example, cotton, which had been Fresno County's leading crop for many years, is now a third of its previous acreage because of its dropping market value. Many of the high cash value vegetable crops on the other hand, including tomato, lettuce, garlic, melon, onion, broccoli and pepper, are becoming increasingly more profitable to grow in the SJV. Table 1 shows that the relative gross production value of vegetable crops to field crops in Fresno County has gradually increased from less than half in the late 1970's to more than double in 2003.

Table 1. Comparison of average gross production values of field and vegetable crops grown in Fresno County, CA over the past three decades.[1]

	Late 1970's	Late 1980's	Late 1990's	1999	2003
Field crops[2]	$ 390,221,000	$553,791,000	$563,447,000	$485,640,000	$ 499,694,000
Vegetable crops	$161,459,000	440,575,000	737,039,000	882,648,000	1,253,144,000

[1]Complied from *Fresno County Agriculture Crop and Livestock Report* 1996-1999, 2003.
[2]Estimates do not include value of pasture and range lands.

The California Agriculture Census for 2002 showed that a total of 335,000 acres were used in the production of vegetables in a 5 county area in the SJV with Fresno county having the largest acreage.

With the changes occurring in California's crop production, it is important to develop and adopt management practices that limit water and other resource losses on the farm. Over irrigation wastes millions of gallons of water each year through surface runoff or deep percolation. It also increases loss of fertilizers due to deep percolation. Coupled with the drainage issues prevalent on the west side of the SJV, over irrigation is both financially and environmentally costly to California growers.

While a great deal of effort has been spent on developing accurate crop coefficients, water requirements, and irrigation management practices for many of the field crops grown in the San Joaquin Valley (Fereres & Puech 1980, Fereres *et al.* 1980, Pruitt *et al.* 1987, Ayars & Hutmacher 1994), knowledge is lacking about crop coefficients, crop water requirements, and best irrigation management practices for vegetable crops in the region. The published crop coefficients and water requirements used by SJV vegetable growers were developed for areas with different soil and climate and these coefficients might not be applicable to this region. Changes in varieties, planting densities, irrigation systems, and cultural practices will affect the crop water requirement and thus necessitate a continual updating of crop coefficients and water requirements. Without reliable information on water requirements growers tend to over irrigate vegetable crops because these crops are believed to be relatively sensitive to water stress and marketable yields can be dramatically reduced if water requirements are not adequately met. Clearly, research is needed to develop the data needed for scheduling irrigation and effectively and efficiently applying water to grow vegetable crops in different parts of the SJV.

The acute drainage water disposal problem, water restrictions, and increased cost of pumping water to supplement surface water on the west side necessitates that on-farm irrigation efficiency and water use efficiency be maximized. Drip irrigation has excellent potential for increasing irrigation and crop water use efficiency by eliminating deep percolation and runoff losses and minimizing evaporation losses. While furrow irrigation is commonly used to irrigate vegetable crops on the west side, the use of drip irrigation by growers is increasing rapidly. In addition to increasing efficiency, drip irrigation has many other advantages over gravity irrigation systems including improved nutrient management (fertigation), potential for improved yields and crop quality, restrained weed growth, and the ability to continue field operations while irrigation is in progress. If subsurface drip irrigation is used, water and nutrients can also be applied directly to the root zone, which allows for more efficient root uptake and prevents salt accumulation at the soil surface; it also encourages deeper root development, which may increase water extraction from shallow groundwater tables. Smith *et al.* (1991) found that subsurface drip irrigation can substantially increase cotton yield and water use efficiency, simultaneously decrease deep percolation, and even contribute to drainage outflow reduction by forcing the crop to use water from the shallow saline water table, particularly at the end of the growing season. Significant yield and water use efficiency increases using subsurface drip systems have also been demonstrated in tomato, sweet corn, alfalfa, and cantaloupe (Ayars *et al.* 1999, Hutmacher *et al.* 1996, Phene *et al.* 1987). According to Ayars (2000), farmers who have implemented

subsurface drip irrigation on tomato crops have routinely reported yield increases in the 10 tons per acre range.

A large number of empirical or semi-empirical equations have been developed for assessing potential evapotranspiration (ET_o) and crop evapotranspiration (ET_c) from meteorological data. Many of these equations can only be used to estimate crop water use for extended time periods. For this reason they are used to develop regional requirements but have little value for irrigation scheduling. Some of the methods are only valid under specific climatic and agronomic conditions and cannot be applied under conditions different from those under which they were originally developed. Improvements in irrigation scheduling that result in water conservation will require methods that are not specific to a region and a limited data set. Due to its versatility in other regions of the country, the American Society of Civil Engineers Evapotranspiration in Irrigation and Hydrology Committee recommends that the ASCE Penman-Monteith equation be adopted as the standard method for calculating ET_o nationwide (Allen et al. 1998).

The California Irrigation Management Information System (CIMIS) calculates ET_o using a version of Penman's equation, developed by researchers at UC Davis (Snyder and Pruitt 1992). However, the equation has not received detailed testing against validated field measurement in the San Joaquin Valley where California's major drainage problems prevail. This has been primarily due to prohibitive costs for collecting and validating high quality evapotranspiration measurement data and difficulty in making precise measurements. Furthermore, there is uncertainty in the application of ET_o equations during wintertime due to changes in net radiation (daytime length, albedo and low sun angle) and low temperatures. To improve irrigation management in the San Joaquin Valley, the use of the CIMIS Penman equation for calculating ETo needs to be validated, particularly during periods when over-irrigation of cool-season crops could lead to increased drainage water problems. Modifications or changes to the existing equation may be necessary at various times during the year and proper crop coefficient (k_c) values and irrigation practices must also be developed along with accurate methods for estimating ET_o. There are statewide implications regarding the potential inaccuracy of the CIMIS Penman equation. If modifications in the SJV result in savings in this region due to overestimation of water requirements, then similar savings might be possible elsewhere in the state.

Objectives

This research will improve water use efficiency on the west side of the San Joaquin Valley through improved values for crop water requirements by vegetables, improved crop coefficients, and improved estimates of potential evapotranspiration using the CIMIS network. To this end, the following research objectives are proposed:

1. Evaluate and if needed modify CIMIS penman equation used to estimate reference evapotranspiration in the San Joaquin Valley.
2. Determine water requirements and yield and quality responses for a variety of vegetable crops including lettuce, garlic, onion, broccoli, and pepper under surface drip, subsurface drip, and furrow irrigation.
3. Develop seasonal crop coefficients for a variety of vegetable crops including lettuce, garlic, onion, broccoli, and pepper.

4. Use information gathered in objectives 1- 3 to update CIMIS crop coefficients and regional crop water use estimates.
5. Report results to growers, consultants, and farm advisors

TECHNICAL/SCIENTIFIC MERIT/FEASIBILITY

Methods and Procedures

Study location

Research will be conducted at the University of California West Side Research and Extension Center (WSREC) located near Five Points, California. The USDA Water Management Research Laboratory (WMRL) has operational weighing lysimeters (6.5 ft by 6.5 ft by 7.5 ft deep) installed in a 4.2 acre field (crop lysimeter), and in an adjacent 4.2 acre grassed area (grass lysimeter). At the WSREC these facilities were installed in 2001- 2002 using funds provided by California Agricultural Research Initiative (ARI) and the U.S. Bureau of Reclamation (USBR) in cooperation with the California Department of Water Resources and the CIMIS program. These were installed to replace and upgrade the facilities that had previously been constructed and used for water management studies by the WMRL for many years (*e.g.* Ayars *et al.* 1999, Davis *et al.* 1985, Howell *et al. 1985,* Phene *et al.*1985, 1990, 1993). This project will take advantage of the facilities developed for previous studies at the WSREC and will extend that information.

Weighing lysimeters are continuously-weighed soil-filled steel containers used for growing crops. The change in mass measured as a weight change by the scales is equal to the water lost by evapotranspiration. Weighing lysimeters are the most precise and only direct measurement of short-term (time periods less than one day) and long-term (seasonal) evapotranspiration of crops. They are ideal for determining crop water use and developing crop coefficients. Indirect methods that require computations based on climatic data including eddy correlation and Bowen ratio have been used successfully to measure evapotranspiration for short time periods. However, these methods are not as robust as a lysimeter and are not practical for unattended measurement sites for long time periods. They have been used successfully for short term studies.

A lysimeter control system set in feedback mode will be used in conjunction with the crop and grass lysimeters to schedule irrigations automatically (see Phene et al. 1989 for details). The lysimeter's mass is reinitialized each night to account for increases in plant mass to eliminate errors in the overall weight of the lysimeter caused by seasonal crop growth. Lysimeter irrigation water is supplied from a water storage vessel attached to the lysimeter that is refilled to a constant level daily. The lysimeter has drip tubing installed 8 inches deep in the soil and all drip irrigation treatments in the field will be watered after 2 mm of crop evapotranspiration has been measured by the crop lysimeter. The drip tubing in the grass lysimeter was installed at depth of 4 inches and the grass lysimeter is irrigated after 2mm of evapotranspiration has been measured.

Experimental design

Irrigation systems having potential for use on vegetable crops on the west side will be used for the research. These include; 1) a furrow irrigation system, 2) a surface drip irrigation system, and 3) a subsurface drip irrigation system installed 8 inches deep. Water will be applied with each system

at four different irrigation amounts in order to determine the effect of application amount on crop yield and quality. Amounts of applied water will be equal to either 50, 75, 100, or 125% of the crop evapotranspiration determined from crop water use in the lysimeter. Overall, there will be 12 irrigation treatments (3 irrigation systems by 4 irrigation amounts) arranged at the site in a split-plot experimental design with four replicate plots per treatment. Each plot will be 260 feet long and consist of four crop beds spaced 40 inches from center to center; outside beds will serve as borders between treatments. (Fig. 1)

Vegetable crops

Five different studies on 4 vegetable crops will be conducted over a 3-year period. The planting schedule will be as follows:

Crop	**Planting date**	**Harvest date**
Garlic	Sep . 2005	June 2006
Head lettuce	Aug. 2006	Nov. 2006
Pepper	Feb 2007	Aug. 2007
Onion	Sep. 2007	June 2008
Lettuce	Aug. 2008	Nov 2008

These crops were chosen to represent major vegetable crops grown in the San Joaquin Valley. Note that tomatoes and melons were not chosen for this study despite high harvested acreage of each crop. This is because crop coefficients and drip irrigation management practices have been well studied for these crops (Ayars *et al.* 1999, Phene *et al.* 1985, Pruitt *et al.* 1987, Wuertz & Tollefson 1992). Plants will be grown following normal cultural practices including fertigation by the drip-irrigation system in the drip treatments. Sprinkler irrigation will be used after planting for stand establishment.

Grass

A well-watered grass crop is maintained around the grass lysimeter to provide the proper conditions to evaluate the Penman equation and as reference for calculating crop coefficients. The grass is irrigated by subsurface drip in the area adjacent to the grass lysimeter and by sprinklers on the remainder of the field. The irrigation is controlled by water loss in the grass lysimeter. The field and lysimeter are mown weekly to maintain a grass length of 4-6 inches as required for the analysis. CIMIS weather station #2 is sited in the grass area adjacent to the lysimeter. There is also an open class A evaporation pan located at this site that will be used to validate pan coefficients.

MONITORING AND ASSESSMENT

Measurements

WATER APPLICATION, EVAPOTRANPSIRATION AND CROP COEFFICIENTS: The amount of water applied to each treatment will be recorded daily using flow meters installed in the irrigation manifold. Soil water balance calculations will be done as described by Phene et al. (1985). Sentek capacitance probes will be installed in the lysimeter to measure soil water content and in a crop row of a plot irrigated at 100% evapotranspiration. This will enable a continuous measurement of the soil water variation with time. To calculate daily crop coefficients (K_c), crop evapotranspiration from the lysimeter (measured by weight changes) will be divided by the reference evapotranspiration rate of well-irrigated grass (ET_o) (Doorenbos & Pruitt 1977), measured using a weighing lysimeter with a grass crop. Additionally ET_o will be estimated from meteorological measurements made by a CIMIS (California Irrigation Management Information System) station located in a grass field adjacent to the experimental field at the WSREC (Fig. 2) . Once K_c values are determined for the crops, growers will be able to use the values along with regional ET_o estimates to approximate ET_c in their fields and schedule irrigations. Bowen ratio equipment will be used intermittently to estimate ET_c. The frequency will be determined by the availability of the equipment.

CANOPY AREA AND YIELD: Vegetable crops vary widely in variety, plant spacing, cultural practice, and planting date. Assigning crop coefficients based on a standard practice thus has limited applicability. A growing body of research indicates that for many horticultural crops, the crop coefficient is closely related to light interception of the plant. Such a relationship would allow generalization of crop coefficients for a wider range of crops and conditions. We will measure canopy size through the growing season with digital infra-red photography which can discern leaf area from the background soil surface. Image analysis software will be used to determine percent of ground surface that is covered by plant canopy. Mid-day canopy light interception will be related to the crop coefficient measured in the lysimeter. Leaf area index (LAI), a precise measurement of plant transpirational surface area, has also been related to water use. LAI will be measured periodically by removing and scanning plant leaves and determining, total area of each scanned image using a computer. As we confirm canopy size relationships we will also explore the possibility to relate canopy size and LAI (and thus crop coefficient) to remotely sensed Normalized Difference Vegetation Index (NDVI). This will allow efficient estimates of canopy area and thus crop coefficient on large areas.

SOIL AND PLANT WATER STATUS: The water status of the crops will be monitored periodically over the growing season to establish whether the various irrigation methods and amounts are meeting plant water requirements. Soil water content will be measured with time domain reflectometry (TDR - mini-Trase) weekly during the growing season. Enviroscan sensors (frequency domain reflectometry) will be used to continuously monitor soil water content in the lysimeter and one fully irrigated surface drip plot. Neutron scattering probes and gravimetric measurement will be used for more deeply rooted crops (peppers).

Leaf transpiration and mid-day stem water potentials will be measured where possible (some horticultural crops are not amenable to these measurements) using a steady-state porometer (Li-Cor Model LI-1600) or a pressure chamber (Soil Moisture Equipment Model 3005), following the

recommendations of Hsiao (1990). These measurements will be made at midday (13:30-15:30 PST) on recently expanded leaves.

CROP YIELD AND QUALITY: At the end of each crop cycle, sub-plots of each treatment will be harvested and weighed. Yield will be separated into marketable and non-marketable portions. When appropriate, the yield will be evaluated for quality parameters such as size, shape, and solids content. The economic value of the crop will be determined based on yield and quality. The ratio of crop production to irrigation amount (water use efficiency) will be developed for each of the amount treatments and relationships between WUE and irrigation amount developed for each irrigation method.

Statistical Analysis

To relate crop water use to the phenological stages of development, LAI, and canopy size for each crop, least square regressions will be performed on sections of the relevant K_c curves plotted from emergence to harvest. Crop growth characteristics, plant water and nutrient status, crop water use, and yield data will be analyzed using multiple-factor analysis of variance (Gomez & Gomez 1984). Where time is a factor, repeated measure ANOVAs will be used (Moser *et al.* 1990).

Facilities and Resources

The USDA WMRL is located at the San Joaquin Valley Agricultural Sciences Center near Parlier, Ca. Electronic and general workshops are available for general use. Equipment in the laboratories available for this project include neutron probes, dataloggers, flatbed scanning system, minirhizotron camera system, pressure chambers, porometer, rapid flow analyzer, ICP emission spectrometer, ion chromatographs, digestion block, fume hoods, pH meters, soil penetrometer, refractometer, microgram and gram balances, refrigerator/freezers, drying ovens, plant/soil grinders, and Pentium PC's.

The grass and crop weighing lysimeters at the WSREC are fully operational and the WMRL is responsible for the daily maintenance and operation of these facilities. Land and agricultural production support are provided by the West Side Research and Extension Center of the University of California under a Memorandum of Understanding and Research Support Agreement with USDA-ARS. Data from the lysimeters is downloaded and analyzed daily. The experimental field was recently graded to improve the operation of the furrow irrigation system used in the research. The grass lysimeters is being operated to provide data for the CIMIS program. The CIMIS station is maintained by DWR while the grassed area is maintained by the WMRL.

Environmental Documentation

This is not a "project" as defined by CEQA.

Timeline

See Table 1 for a timeline of the planned research.

RESULTS AND DISSEMINATION

We will participate in field days at the WSREC to discuss our results and address irrigation and fertilization management issues facing vegetable growers on the west side of the valley. The results of the various portions of the proposed research project will be presented at industry and scientific meetings, and published in a timely manner in peer-reviewed journal articles, articles in popular trade journals (*e.g. American Vegetable Grower*, *California Agriculture, Irrigation Journal*) and UC Coop. Extension Bulletins. Pamphlets and fact sheets will also be published to provide information to growers on seasonal crop coefficients and best irrigation management practices for growing vegetables on the west side of the San Joaquin Valley. This information will also be useful to others servicing the needs of farmers in the region including:

- Irrigation consultants, farm advisors, PCAs and CCAs
- Irrigation equipment manufacturers
- Water suppliers (water/irrigation districts)
- Crop commissions and other grower groups
- The Irrigation Association
- University of California Cooperative Extension
- CIMIS
- Agricultural scientists and engineers

The research will also provide important information to those interested in reducing the environmental impacts of irrigated agriculture in the Central Valley (*e.g.* California Department of Water Resources, USDA Natural Resources Conservation Service).

BENEFITS

Economic Value

In this proposal, we are testing several water management practices that may reduce waste of water and fertilizer on the farm while increasing yields and product quality. The results of these tests will help Central Valley farmers select irrigation systems and management strategies that have high potential for increasing profitability of growing crops in California and increase economic value per unit of water used. It will also help irrigation manufacturers and consultants make better recommendations regarding irrigation in the region.

The benefits from this research will result from the application of the improved crop coefficients that will result in improved water use efficiency. Using the 335,000 acres of vegetables as a basis and assuming that an average of 2 ac-ft of water required for a crop, a 10% water savings will result in 67,000 ac-ft of water saved. If it is determined that the CIMIS Penman equation needs to be modified there is the potential to save water throughout the state. Improved water use efficiency will also result in reduced deep percolation losses and reduced drainage water.

Improving irrigation and fertilization management has the potential to increase yields significantly while using the same amount of irrigation (Ayars et al., 1999). This is also an increase in water use efficiency which allow farmers to maintain yields even in the event of reduced water allocations.

The costs associated with this research are primarily in the area of administration. We are seeking funds to support the salaries and benefits for a Post-Doc and a full time technician for the project. Funds are needed for travel to the site, to present results at meetings, and to cover the cropping costs. The WMRL will supervise the research and provide the funds needed to keep the sites in operation. The value of the lysimeter and field equipment is approximately $300,000. The WMRL has 20 years of experience in operating and maintaining this type of facility and are acknowledged as a world authority in this type of research. The WMRL support will be in-kind through the salaries of the PI's and the maintenance of the lysimeter facility. The University of California will also support this research through the provision of labor and land at the West Side Research and Extension Center, Five Points.

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B.S. Case Western Reserve University, Mechanical Engineering, 1972.
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Ph.D. Colorado State University, Agricultural Engineering (Soil and Water), 1979.

Employment

1995 - Pres Research Leader and Supervisory Agricultural Engineer, USDA-ARS Water Management Research Laboratory, Fresno, CA
1982 - 1995 Agricultural Engineer, USDA-ARS, Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho.
1978 - 1982 Research Assistant Professor, Department of Agricultural and Chemical Engineering, Colorado State University.

Research Areas

Principal research area is farm-level irrigation water management with emphasis on surface and micro-irrigation systems. Present work includes studying factors that affect infiltration rates and water distribution uniformity under irrigation, determining crop water requirements, and developing alternatives to methyl bromide fumigation.

Selected Recent Publications

Pereira, L.S. and T.J. Trout. 1999. Irrigation Methods. Chapter I.5.4 in *CIGR Handbook of Agricultural Engineering*, Hubert N. van Leir, ed. ASAE, St. Joseph, MI.

Trout, T.J. 2000. Environmental effects of irrigated agriculture. Acta Horticulturae 537. pp. 605-610.

Trout, Thomas J. 2001. Sediment Transport in Irrigation Furrows. *In:* Stott, D.E., R.H. Mohtar, and G.C. Steinhardt (eds). Sustaining The Global Farm: Selected papers from the 1999 Intern'l Soil Conservation Org. meeting. W. Lafayette, IN., May 24-29, 1999. pp 710-716.

Hanson, B.R. and T.J. Trout. 2001. Irrigated agriculture and water quality impacts. In: Ritter, W.F. and A. Shirmohammadi. (Eds). Agricultural Nonpoint Source Pollution. Lewis Publishers, Boca Raton. pp. 169-206.

Trout, T.J. and J. Gartung. 2002. Energy Use for Microirrigation. *In.* Energy, climate, environment and water - issues and opportunities for irrigation and drainage. Proc. of joint US CID and ASCE Env. and Water Resources Inst., San Luis Obispo, CA July 10-13.

Kincaid, D.C. and T.J. Trout. 2002. Squeezer: a device for indirect pressure measurement in thin-wall drip irrigation tubing. Appl. Engr. in Agri. 18(6):685-690.

Ajwa, H.A., T. Trout, J. Mueller, S. Wilhelm, S.D. Nelson, R. Soppe, and D. Shatley. 2002. Application of alternative fumigants through drip irrigation systems. Phytopathology 92(12):1349-1355.

Kincaid, D.C. and T.J. Trout. 2003. Fluid pressure measurement by mechanical compression of thin-walled tubing. U.S. Patent #6,622,565. (Patent).

Bryla, D.R., T.J. Trout, R.S. Johnson, and J.E. Ayars. 2003. Irrigation management practices for maximizing growth and improving crop water use efficiency in young peach trees. *Hort Science* 38(6):1112-1116.

Ayars, J.E., R.S. Johnson, C.J. Phene, T.J. Trout, D.A. Clark, R.M. Mead. 2003. Water use by drip irrigated late season peaches. Irrigation Science 22:187-194.

Ajwa, H.A. and T.J. Trout. 2004. Drip Application of alternative fumigants to methyl bromide for strawberry productions in California. Hort Science 39(7): 1707-1715.

Skaggs, T.H., T.J. Trout, J. Simunek, P.J. Shouse. 2004. Comparison of HYDRUS-2D simulations of drip irrigation with experimental observations. J. Irrig. and Drainage Engr. 130(4):304-310.

Trout, T.J. and J.Gartung. 2004. Irrigation water requirements of strawberries. Acta Horticulturae. No. 664: . Dec.

Ajwa, H., T. Trout, and M. Bolda. 2005. Drip Fumigation. In: IPM Pest Management Guidelines - Strawberry. Published by Univ. of Calif. (In Press).

Johnson, R.S. L.E. Williams, J.E. Ayars, T.J. Trout. 2005. Weighing Lysimeters for Studying Tree and Vine Water Relations. California Agriculture (accepted).

CURRICULUM VITAE

Michelle Le Strange

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Education

M.S., Plant Science-Agronomy, University of California, Davis, 1985
B.S., Plant Science, University of California, Davis, 1981

Employment 1985-present

Farm Advisor with University of California Cooperative Extension, Tulare and Kings Counties
Specialty: Vegetable Crop Production, Weed Management, Turf and Landscape Management, Master Gardener Volunteer Program

Extension Experience

- Conduct a broad educational program to extend information and research to professionals in vegetable crop and landscape industries.
- Conduct applied research on important topics relevant to the landscape and vegetable crop industries.
- Organize and manage a volunteer Master Gardener Program.

Research

- Broccoli and cauliflower adaptation in San Joaquin Valley
- Nitrogen management in broccoli
- Evaluation of fresh market tomato varieties
- Evaluation of compost topdressing in bermudagrass turf
- Evaluation of nitrogen management and irrigation scheduling in turfgrass
- Weed management in turfgrass and the landscape

Professional Organizations

California Weed Science Society - Steering Committee
American Society for Horticultural Science
Pesticide Applicators Professional Association
American Society of AgronomyB California Chapter

List of Relevant Publications

Geisel, P., M. Le Strange, and C. Elmore. 2000. Home Garden Weed Management. California Weed Science Society. 7 pages.

Le Strange, M., P. Elam, and R. Meyer. 1998. Topdressing compost on turfgrass: Its effect on turf quality and weeds. Proceedings, California Weed Science Society Conference. pp. 28-31.

Le Strange, M., J. P. Mitchell, and L. E. Jackson. 1998. Determining nitrogen best management practices for broccoli production in the San Joaquin Valley. Proceedings, California Plant and Soil Conference. pp. 89-90.

Le Strange, M., S. Koike, J. Valencia, and W. Chaney. 1996. Spinach Production in California. UC DANR Publication 7212. 4 pages.

Le Strange, M., K. Mayberry, S. Koike, and J. Valencia. 1996. Broccoli Production in California. UC DANR Publication 7211. 3 pages.

Table 1. Time line of proposed research.

OBJECTIVES

To increase water use efficiency on the west side of the San Joaquin Valley through improved values for crop water use by vegetable, improved crop coefficients, and improved estimates of potential evapotranspiration using the CIMIS network, the following research objectives are proposed:

1. Evaluate and if needed modify CIMIS penman equation used to estimate reference evapotranspiration in the San Joaquin Valley.
2. Determine water requirements and yield and quality responses for a variety of vegetable crops including lettuce, garlic, onion, broccoli, and pepper under surface drip, subsurface drip, and furrow irrigation.
3. Develop seasonal crop coefficients for a variety of vegetable crops including lettuce, garlic, onion, broccoli, and pepper.
4. Use information gathered in objectives 1- 3 to update CIMIS crop coefficients and regional crop water use estimates.
5. Report results to growers, consultants, and farm advisors

	2006	2007	**2008**
Objective	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
1	S ----------C	S ---------- C	S ---------- C
2	S ---------- C S ----------C	S ----------C S ----------C	S ----------C
3	S-----C S --------C	S --- C	S --C S—C
4	S ----------	----------	---------- C
5	S ----------	----------	---------- C

S - start
C - complete

Figure 1. Experimental layout of crop field at West Side Research and Extension Center.

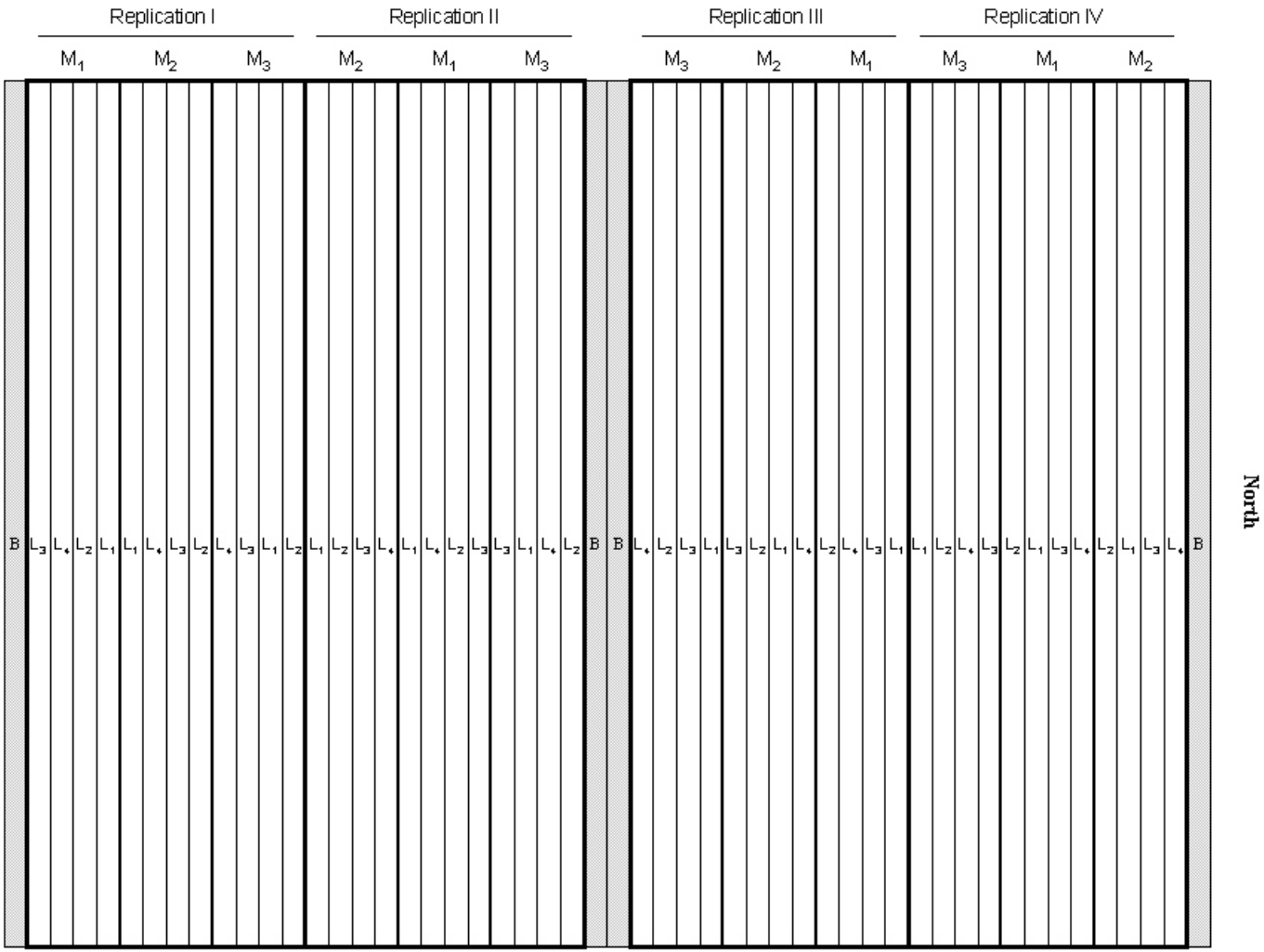
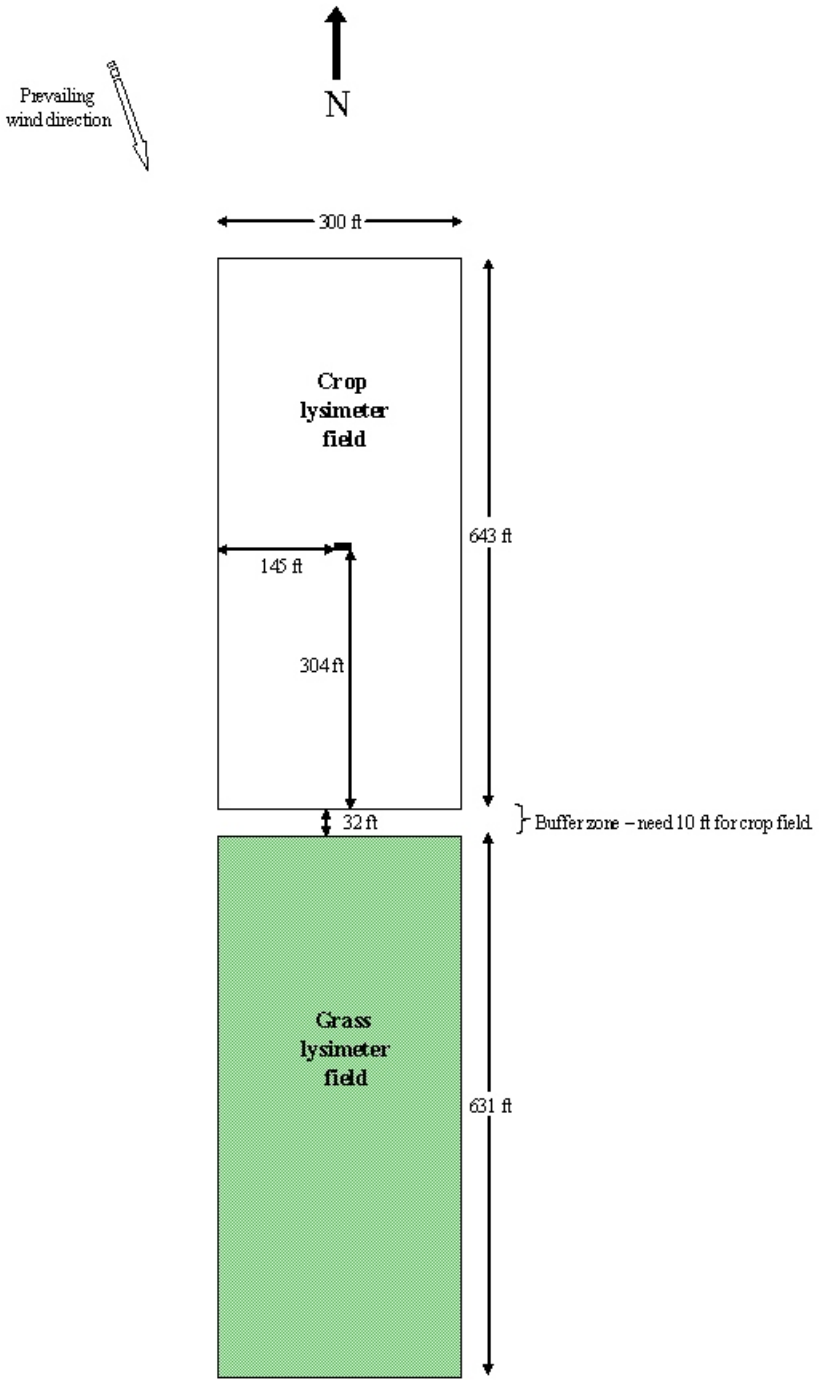


Fig. 1. Vegetable crop field layout at the University of California West Side Research and Education Center located near Five Points, CA. Split plot design with three irrigation methods (M_1, M_2, M_3) as main plots and four irrigation levels (L_1, L_2, L_3, L_4) as subplots, in four replications. Each subplot is 270 feet long and consists of four 40-inch wide beds. Irrigation levels are based on a percentage of the crop lysimeter evapotranspiration (ET_{lys}). M_1 = furrow, M_2 = surface drip, and M_3 = subsurface drip; L_1 = 50% ET_{lys}, L_2 = 75% ET_{lys}, L_3 = 100% ET_{lys}, and L_4 = 125% ET_{lys}. B = border rows.

Figure 2. Grass and experimental field layout at the West Side Research and Extension Center.



2004 Water Use Efficiency Proposal Solicitation Package

APPENDIX A: Project Information Form

Applying for: ❑ Urban ✠ Agricultural

(Section A) Urban or Agricultural Water Use Efficiency Implementation Project

- ❑ (a) implementation of Urban Best Management Practice, #_____
- ❑ (b) implementation of Agricultural Efficient Water Management Practice, #_____
- ❑ (c) implementation of other projects to meet California Bay-Delta Program objectives, Targeted Benefit # or Quantifiable Objective #, if applicable _____
- ❑ (d) Specify other: _____

(Section B) Urban or Agricultural Research and Development; Feasibility Studies, Pilot, or Demonstration Projects; Training, Education or Public Information; Technical Assistance

- ☒ (e) research and development, feasibility studies, pilot, or demonstration projects
- ❑ (f) training, education or public information programs with statewide application
- ❑ (g) technical assistance
- ❑ (h) other

3. Principal applicant (Organization or affiliation): USDA-ARS, Parlier, CA

4. Project Title: Improved water use efficiency for vegetables grown in the San Joaquin Valley

5. Person authorized to sign and submit proposal and contract:

Name, title	Dr. Andrew Hammond, Associate Area Director
Mailing address	800 Buchanan St., Albany, CA 94710
Telephone	510 559 6071
Fax.	510 559 5779
E-mail	ahammond@pw.ars.usda.gov

6. Contact person (if different):	**Name, title.**	**Dr. James E. Ayars**
	Mailing address.	**9611 S. Riverbend Ave**
		Parlier, CA 93648
	Telephone	**559 596 2875**
	Fax.	**559 596 2850**
	E-mail	**jayars@fresno.ars.usda.gov**

7. Grant funds requested (dollar amount): **372,150**

(from Table C-1, column VI)

8. Applicant funds pledged (dollar amount): **375,000**

9.Total project costs (dollar amount): **$747,150**

(from Table C-1, column IV, row n)

10. Percent of State share requested (%) **50**

(from Table C-1)

11. Percent of local share as match (%) **50**

(from Table C-1)

12. Is your project locally cost effective?

Locally cost effective means that the benefits to an entity (in dollar terms) of implementing a program exceed the costs of that program within the boundaries of that entity.

(If yes, provide information that the project in addition to Bay-Delta benefit meets one of the following conditions: broad transferable benefits, overcome implementation barriers, or accelerate implementation.)

☐ **(a) yes**

☒ **(b) no**

11. Is your project required by regulation, law or contract? ☐ **(a) yes**
☒ **(b) no**

If no, your project is eligible.

If yes, your project may be eligible only if there will be accelerated implementation to fulfill a future requirement and is not currently required.

Provide a description of the regulation, law or contract and an explanation of why the project is not currently required.

12. Duration of project (month/year to month/year): **1/06 -12/08**

13. State Assembly District where the project is to be conducted: **30**

14. State Senate District where the project is to be conducted: **16**

15. Congressional district(s) where the project is to be conducted: 20

16. County where the project is to be conducted: Fresno

17. Location of project (longitude and latitude) 36°20' 11" N 120° 6' 47" W

18. How many service connections in your service area (urban)? NA

19. How many acre-feet of water per year does your agency serve? NA

20. Type of applicant (select one):

- ☐ (a) City
- ☐ (b) County
- ☐ (c) City and County
- ☐ (d) Joint Powers Authority
- ☐ (e) Public Water District
- ☐ (f) Tribe
- ☐ (g) Non Profit Organization
- ☐ (h) University, College

- ❑ (i) State Agency
- ☒ (j) Federal Agency
- ❑ (k) Other
  - ❑ (i) Investor-Owned Utility
  - ❑ (ii) Incorporated Mutual Water Co.
  - ❑ (iii) Specify _____

21. Is applicant a disadvantaged community? If 'yes' include annual median household income.

    (Provide supporting documentation.)

- ❑ (a) yes, _____ median household income
- ☒ (B) NO

Table C-5 Project Annual Physical Benefits (Quantitative and Qualitative Description of Benefits)

QUALITATIVE DESCRIPTION - REQUIRED OF ALL APPLICANTS			
Description of physical benefits	Time Pattern and location of benefit	Project life: Duration of Benefits	State Why Project Bay-Delta benefit is Direct or Indirect or both
Bay-Delta: This project will reduce "existing irrecoverable losses" which is one of the primary goals of the WUE proposal. This is done by more precisely defining the crop water requirement and improving irrigation scheduling such that less irrigation water will be required to produce a crop. This may result in additional water left in the river/Delta. This will also reduce deep percolation losses to saline groundwater. Reduced deep percolation loss will lower shallow groundwater and reduce lateral return flows to drains and rivers. With reduced return flows there will be less transport of salt and trace elements (selenium, boron) and improved water quality in the river and Delta.	This benefit will be gained throughout the year, but primarily during the irrigation season. Primary benefit will be in the San Joaquin River and Bay Delta (improved quality and potential increased quantity).	The benefits continues as long as there are irrigated vegetables in the SJV.	This is direct benefit to the project through a reduction in the total water needed to maintain current levels of irrigated vegetable crop production.
Local: The local (grower and water district) benefit will be improved ability to allocate limited water supplies for maximum vegetable production, reduced potential for waterlogging and reduced need for on-farm drainage and management of drainage water, and possible improved crop yield and quality.	The primary benefit occurs during the irrigation season on the west side of the SJV where vegetable crops are grown. Potential benefits accrue to all irrigated vegetable growers and all who use ET based irrigation scheduling.	The benefits of improved irrigation scheduling knowledge will continue as long as there is irrigated agriculture.	N/A

Applicant: James Ayars total 3 years

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Section A projects must complete Life of investment, column VII and Capital Recovery Factor Column VIII. Do not use 0.

Table C-1: Project Costs (Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[1]								
	Salaries, wages	$481,500	0	$481,500	$240,000	$241,500	0	0.0000	$0
	Fringe benefits	$156,450	0	$156,450	$84,000	$72,450	0	0.0000	$0
	Supplies	$30,000	0	$30,000	$15,000	$15,000	0	0.0000	$0
	Equipment	$30,000	0	$30,000	$30,000	$0	0	0.0000	$0
	Consulting services	$0	0	$0	$0	$0	0	0.0000	$0
	Travel	$6,000	0	$6,000	$3,000	$3,000	0	0.0000	$0
	Other	$0	0	$0	$0	$0	0	0.0000	$0
(a)	Total Administration Costs	$703,950		$703,950	$372,000	$331,950			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (10% overhead)	$37,200	0	$37,200	$0	$37,200	0	0.0000	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0	0	0.0000	$0
(m)	Report Preparation	$6,000	0	$6,000	$3,000	$3,000	0	0.0000	$0
(n)	**TOTAL**	$747,150		$747,150	$375,000	$372,150			$0
(o)	Cost Share -Percentage				50	50			

1- excludes administration O&M.