California Regulated Deficit Irrigation Program and Remote Sensing to Quantify Evapotranspiration

A proposal submitted by

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REVELANCE AND IMPORTANCE

Introduction

Irrigated agriculture is the primary user of diverted water in California. Irrigation water may be used consumptively in crop transpiration or evaporation from soil; a process termed evapotranspiration (ET), and may have other sinks such as deep percolation or tailwater runoff. As in the urban and industrial sectors, irrigated agriculture has been steadily improving the efficiency of water use for decades. More efficient irrigation systems and improved irrigation management practices that reduce tail water and apply water with high uniformity, thus minimizing percolation, are being widely adopted. The development and adoption of ET information under the auspices of the CIMIS program has resulted in growers matching net applied water with ET and thus, reducing over irrigation.

Moreover, tailwater and deep percolation are usually not true water losses. Tailwater is normally collected and reused elsewhere on a grower's acreage. Unless it moves to a salty, perched water table or flows to the ocean, water "lost" to deep percolation can be pumped and reused. Thus, one field's or grower's loss is another field's or grower's source of supply. Recognizing this and the fact that most California growers have become highly efficient in their irrigation management shows that there is limited opportunity to free up net water by improving application efficiency.

On the other hand, any reductions in consumptive use (ET) result in the net saving of water to the basin in question. Thus, it's important to explore the potential of reducing ET in irrigated agriculture. Research done on soil evaporation (E) indicates that the potential for reducing E in the intensive agriculture of California is small in most situations. One exception is the few early years of orchard crops. Buried drip irrigation in mature crops can reduce E by 5-10% (Bonachela at al., 2001) but is very expensive to install and maintain (Camp, 1998). Transpiration (T) is by far the largest component of ET and is where we need to focus our objective of reducing ET.

It has been known for many decades that when T is decreased by water deficits, crop production is also reduced below its maximum potential (Hsiao, 1973; Bradford and Hsiao, 1982). This is because the processes of carbon assimilation and T take place through the stomata, the microscopic pores in the leaves of plants that are responsible for gas exchange. As water stress is imposed, the stomata close and that reduces both water loss and carbon uptake and thus, productivity (Fig. 1). Indeed, preventing water stress forms the basis for most of the water budget irrigation scheduling programs that exist today, including CIMIS. Does that mean that there is no opportunity to reduce T in irrigated agriculture?

This goal of reducing transpiration by stressing the plant has been extensively researched in the past for field and row crops but has been shown to reduce yields and also water productivity (crop yield per unit of water used) in most herbaceous crops. However, numerous studies the past 15-20 years in California, Australia, Spain and Israel (Chalmers et al., 1981; Mitchell et al., 1986; Caspari et al., 1994; Lampinen et al., 1995; Naor, 2000; Naor 2001; Teviotdale et al., 2001; Girona, 2002; Moriana et al., 2003; Goldhamer et al., 2002) have shown that regulated

deficit irrigation (RDI) can reduce consumptive use in tree crops and vines without reducing grower profits, and in some cases, even increasing grower profits. A recent review on irrigation of fruit trees has highlighted the potential of using various forms of deficit irrigation in the water management of orchard and vineyards (Fereres et al., 2003).

Background

We define RDI as a regime that purposely stresses the trees or vines at specific developmental stages of the crop such that there is little, if any, negative impact on the yield of marketable product and/or profits. The water stress is normally imposed at stages of the season when reproductive growth is relatively low. The water stress results in lower tree water status, partial stomatal closure, which reduces ET (Fig. 1). Water deficits imposed at those stages also generally reduce vegetative growth (and thus pruning costs and agricultural burning potential problems) and may impact of other plant processes, often improving fruit quality. Numerous

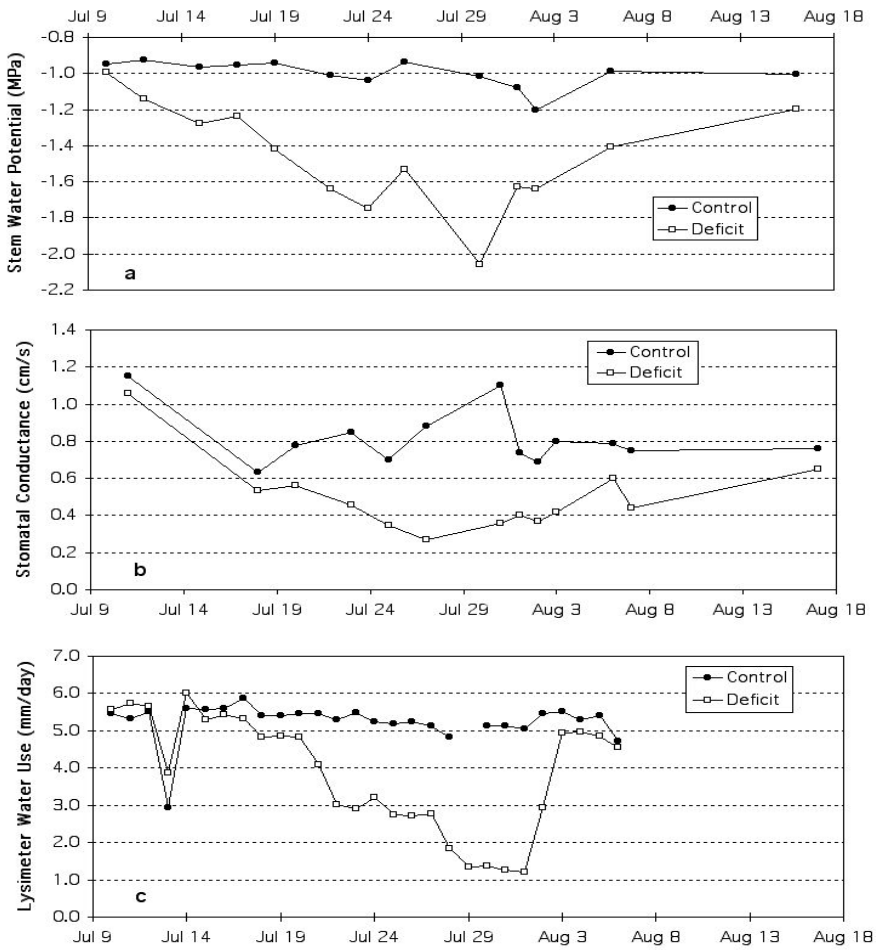


Figure 1. Impact of progressively more severe deficit irrigation from July 10 to August 1 on a) midday stem water potential, 2) midday stomatal conductance, and 3) ET of mature peach. Control was fully irrigated. Deficit trees returned to full irrigation on August 2. Adapted from Goldhamer et al. (1999), Fereres et al. (1999), and Mata et al. (1999).

positive horticultural impacts, primarily on fruit quality, that increase grower profit, and thus, are a powerful motivation for adoption, have been achieved with RDI (see Section 2, Technical/ Scientific Merit). The objective of RDI is to maintain or increase farm profits while reducing the consumptive use of water.

The potential amount of consumptive use reduction that can be achieved in California's orchards and wine grape vineyards with RDI depends not only on the results of the RDI research to date but also on existing irrigation management. We have good estimates of the former but there is more uncertainty in the later. Nevertheless, using our research and that of others (Larson et al., 1988; Matthews et al., 1990; Prichard et al., 1991; Prichard, 2003; Kennedy et al., 2002; Lampinen et al., 1995; Fereres and Goldhamer, 1990; Goldhamer and Viveros, 2000; Goldhamer and Salinas, 2000; Goldhamer and Beede, 1993; Goldhamer et al., 1993; Girona et al., 1993; Boland et al., 2000; Ebel et al., 1995; Naor et al., 2001) and estimates of current practices in orchards and vineyards, we have calculated potential water savings for the major tree crops (almonds, citrus, pistachios, prunes, peaches, olives, and apples and pears) and wine grapes in California. These estimates are based on RDI regimes that do not reduce grower profits. We estimate that consumptive use could be reduced by about 1 million acre-ft using existing knowledge and technologies (Table 1). Two tree crops have been excluded from these calculations; walnuts and avocados. Past work has shown little evidence that RDI can be successful on walnuts although there is ongoing work that may provide different results. While some believe that RDI can be successful with avocados, there has been no work to date to validate that testimonial evidence. We expand on potential consumptive use savings in Section 3 (Monitoring and Assessment).

Table 1. Range of estimated potential water savings relative to current practices using regulated deficit irrigation (RDI).

Crop	Bearing Acreage (acres)	Estimated Savings (inches)	Water Savings With RDI (acre-ft)
Almonds	600,000	8	400,000
Wine grapes	480,000	8	320,000
Citrus	244,000	6	122,000
Pistachios	78,000	10	65,000
Prunes	76,000	6	38,000
Peaches	70,000	4	23,000
Olives	36,000	6	18,000
Apples and Pears	49,000	4	16,000
Walnuts	196,000	Unknown	Unknown
Total			**1,002,000**

In 2003-4, we discussed barriers to RDI adoption with numerous grower groups, including those directly involved in water issues. Of particular note were comments from Mike Wade, Executive Director of the Farm Water Coalition, and the Advisory Committee of the State Water Plan. The latter is a committee composed of 60+ representatives of various stakeholder groups that assist the Department of Water Resources (DWR) in developing a forecast of water supply and demand

over the next 25 years and make recommendations for actions to maintain a reliable, safe source of water for all Californians. Agricultural representatives acknowledged that RDI has the potential to reduce consumptive use in California's orchards and vineyards but didn't agree, in some cases, with the magnitude of our estimated savings, in part because of uncertainties in current usage. Moreover, these grower representatives argued that most RDI studies to date had been for three or four years and longer duration studies were needed to observe possible detrimental effects, including disease and salinity buildup. They urged that more LONG TERM RDI research be conducted. Groups and individuals representing competing interests, urban and environmental types, also supported a long term RDI demonstration/research study in addition to current educational efforts toward grower adoption.

California Regulated Deficit Irrigation Program (CARDIP)

We clearly recognize that achieving the promise of RDI in California's orchards and wine grape vineyards depends on growers recognizing the benefits of managed water stress and having their concerns addressed about potential long term problems. We believe that we can demonstrate on a large scale that RDI can be successful in their terms--profits are maintained or increased--and that the higher level of irrigation management required is within the ability of on-farm personnel. At the same time, we can provide estimates of reductions in consumptive use possible with RDI. The dual objectives of demonstration and applied research are not mutually exclusive; both can be achieved in same field plots.

While it was recognized that Prop. 50 was a possible funding source, most interested parties, including Sen. Mike Machado, Vice Chair of the Senate Agriculture and Water Resources Committee, and his staff, agreed that the study should begin as soon as possible.

In 2004, CARDIP was created to demonstrate RDI and document reductions in consumptive use. Funding of $222,000 was provided by the U.S. Bureau of Reclamation. A total of seven sites with four crops (almonds, citrus, pistachio, wine grapes) operated by five UC researchers were established in Kern, Tulare, Madera, San Luis Obispo, San Joaquin, and Tehema Counties. Details of each site are presented in Section 2 (Technical/Scientific Merit, Feasibility) and plot maps are in Appendix D. The original plan called for USBR funding to establish and operate the sites in 2004 and other public funding to be secured for subsequent years. With orchards and vineyards, where there are potential carryover effects of stress on following year(s)' production, no confident conclusions can be made with only a single year of data.

The DWR has graciously provided partial CARDIP funding for 2005. This will allow for an improved effort using the soil water balance technique to estimate 2005 consumptive use reductions with RDI (outlined in detail in Section 3) as well as to insure a continuum of production data monitoring.

The USBR, DWR, and the University of California team have invested considerable resources in the startup and initial two years of CARDIP. The CARDIP team has demonstrated its interest and ability to establish and operate a coordinated demonstration/research effort. We believe that Prop. 50 funding for operation in 2006-2008, inclusive, will result in a long term, high quality study that will address grower concerns about potential problems with RDI adoption as well as

document reductions in consumptive use. In addition to continuing the original seven CARDIP sites that use drip or microsprinkler irrigation, we plan to add a site (peach) to demonstrate that RDI can be successfully used with border strip (flood) irrigation

CARDIP Project Goals

1) To conduct a long term RDI field demonstration/research study on almonds, citrus, pistachio, peach and wine grapes covering a range of environmental conditions found growing regions of California.

2) To provide detailed, high quality information on the impacts of RDI on all horticultural aspects of production and their integrating parameters; yield of marketable product and profit. This includes developing a publication entitled "Regulated Deficit Irrigation Management for Orchard and Vineyard Crops."

3) To quantify reductions in consumptive use with techniques ranging from a water balance on a small scale to remote sensing on a large scale

Remote Sensing To Quantify ET

The Challenge of Quantifying Consumptive Use in Orchards/Vineyards

While it's relatively easy to document the gross water savings of applied water using RDI, it is very difficult to convert them into net savings of water due to uncertainties associated with measuring the contribution of soil moisture to ET. There are two fundamentally different approaches to estimating ET in the field. One approach is to conduct a soil water balance, attempting to quantify all sources and sinks of water, and calculate ET by difference. Allen et al. (1998) reviewed the methods used to compute ET. In herbaceous crops (i.e., annuals and forages) the soil water balance technique is the standard quantification technique but this method runs into difficulties in orchards and vineyards for two reasons. For one, the widespread use of microirrigation generates a spatially variable water application pattern so that soil based sampling of total water use is difficult. The second reason is the uncertainty in the distribution of the root system and associated water extraction patterns. These additional complications can be partially overcome by using a large number of soil moisture observations. However, there are practical limits, primarily the cost, on the extensiveness of soil water measurements in field studies. Moreover, water lost from the root zone by deep percolation and/or extractions of deep soil moisture (beyond monitored depths) by the tree/vines also can contribute to errors using the soil water balance technique. Nevertheless, we believe that the soil water balance approach being proposed for the work described herein is reasonable compromise between the number of soil water observations required and finite financial resources. Soil water balance studies have provided good ET estimates over the last decades when the intensity of the measurements has been adequate. Our approach soil water balance methodology is described in detail in Section 2 (Technicial/Scientific Merit, Feasibility). However, we clearly recognize that the uncertainties of the soil water balance technique are unavoidable and more exact methodologies are needed.

The other approach to determine ET is to actually measure it in the field. There are multiple techniques that can be used at the tree and orchard levels to determine ET; all with strengths and weaknesses. Until recently, lysimeters were the only measurement technique used, mostly in field crops. Technological and scientific improvements now allows for the direct measurement of water vapor fluxes leaving the orchard or vineyard using eddy covariance (Villalobos et al., 2000). One limitation of this technique is that it requires uniform and relative large plots (at least 6-8 acres). At the tree level, measuring sap flow using heat balance (Sakuratani, 1981) or heat pulse sensors (Cohen et al., 1981; Cohen et al., 2001) has been improved in recent years and offers an independent estimate of tree transpiration. While these techniques can yield good relative measurements (stressed trees versus well water ones), it is difficult to obtain quantitative transpiration because one must know the cross sectional area of the conducting tissue. Estimates of absolute ET did not compare well with lysimeter measurements in peach (Cohen et al., 2001). Nevertheless, if one can determine the reduction in sap flow of a stressed tree relative to under non-limiting soil water conditions, as would be the case with a fully irrigated control treatment, transpiration of the stressed tree can be estimated based on the relative differences. Accuracy would then depend on the accuracy of the reference crop water use (ETo) and crop coefficient (Kc) values used to estimate full ET.

At the orchard level, the use of eddy covariance (Testi et al., 2004a) or Bowen ratio techniques can provide actual measurements of orchard ET. Furthermore, orchard ET models based on canopy structure and assumptions on leaf conductance and aerodynamics are being developed that could also provide independent estimates of orchard ET (Testi et al., 2004 b and c). Nevertheless, these methods are all generally costly and labor intensive to apply to large areas. Therefore, to assess the water savings potential of RDI beyond the field scale, a technique that estimates ET at large scales is highly desirable. There have been some promising recent developments in determining actual ET using remote sensing information and ET models based on the original developments of Jackson's group at the USDA Water Conservation Laboratory in Phoenix, AZ, during the 1980's (Jackson, 1982). Algorithms to compute ET in herbaceous crops from an assessment of the energy balance by remote sensing, including SEBAL (Bastiaanssen et al., 1998) and METRIC (Allen et al., 2003) have been proposed. It would be desirable to extend this type of approach to the determination of orchard and vineyard ET.

However, the present resolution of ET computed by the aforementioned remote sensing techniques with the NASA satellite LANDSAT 5 is 30 to 120 m. Using the ASTER satellite, resolution is 90 m. Therefore, the minimum field size that could be monitored via METRIC is about 240 m x 240 m to insure that the "thermal" pixel of LANDSAT is fully within the monitored field. For LANDSAT 5, this translates into a field size of about 14 acres. For ASTER, minimum field size is about 8 acres. One can obtain a LANDSAT 5 and ASTER image every16-19 days if there are cloud free conditions. There are, thus, two challenges: to apply satellite-based methods such as SEBAL or METRIC to orchards and vineyards and to assess the ET reductions under RDI. CARDIP experimental plots are too small for satellite based, remote sensing, ET assessment. However, the data for the algorithms used can be obtained from mast-mounted sensors. We propose to collect information on the relevant surface energy balance parameters over small plots, including the large, weighing peach lysimeter field at the Kearney Ag. Center (KAC) in Parlier and ground truth the remote sensing algorithms on this small scale.

The small scale ground truthing will pave the way for upscaling the remote sensing techniques that prove most successful to much larger acreages where satellite imagery can be used. We have a CARDIP site (Site 3, Tehema almonds) that has acreages large enough to use satellite images. Moreover, the Madera pistachios (Site 5) has 3000 continuous acres of mature trees and the grower has agreed to cooperate with us for our remote sensing work there. The remote sensing models described above will be compared with independent ET estimates obtained with sap flow, eddy covariance, and the soil water balance techniques of measuring ET.

Remote Sensing Project Goals

1) Assess ET by:
    a) Application of the METRIC approach to orchards and vineyards for the determination of ET by remote sensing, and
    b) Development of an ET model for orchards and vineyards based on independent calculations of E and T.
    c)
2) Evaluate METRIC and the (E+T) model against actual measurements of orchard ET using eddy covariance techniques in two CARDIP experiments (almond and pistachio) and in the peach lysimeter plot at KAC, using lysimeter and plant based measurements.

3) Apply the methodologies to the evaluation of ET under RDI by:
    a) Using the calibrated ET models to assess the ET reductions in the CARDIP experiments, and
    b) Assessing to what degree full ET conditions exist in an extensive, uniform area of almond production in the San Joaquin Valley as a prerequisite to estimate the potential net water savings resulting from using RDI in almonds.

TECHNICAL/SCIENTIFIC MERIT, FEASIBILITY (including METHODS)

CARDIP

Optimizing RDI Programs and Development of RDI Triggers

Most current RDI management approaches are based on irrigating a certain percentages of estimated ET during stress tolerant periods of the season. This concept works relative well in the mid and later parts of the season, after the soil moisture reservoir has been depleted of winter rainfall. However, early in the season when relatively high soil moisture levels can be found throughout the soil profile and not just in the zones wetted by drippers/microsprinklers, the impact of deficit irrigation on plant stress is buffered. Thus, even though one reduces irrigation, there will likely be a lag in terms of producing the desired plant stress. The duration of the lag depends on the depth of the root zone, soil water holding capacity, effective winter rainfall, and atmospheric evaporative demand. Thus, more precise indicators (triggers) than ET need to be developed especially for early season RDI management. Measuring plant water status directly with a pressure chamber is the current state of the art (Shackel et al., 1997). The development of lightweight, portable, less expensive "pump-up" type instruments in recent years has encouraged

grower adoption of pressure chambers. Other plant sensors are being tested and appear promising in some cases (Goldhamer and Fereres, 2001; Moriana and Fereres, 2002). Opportunities also exist for establishing RDI regimes based on soil moisture measurements. Recent improvements in instruments that continuously monitor soil water status make this approach more feasible than in the past with manually read instruments, such as the neutron probe. A comparison among water stress indicators in peach has provided valuable information on the accuracy and precision of the various indicators (Goldhamer et al., 1999).

Crop-Specific RDI Opportunities That Led To Existing CARDIP Sites

Almonds

While RDI in almonds offer perhaps the greatest opportunity to reduce consumptive use (total acre ft) in California of all crops, there is no consensus on which RDI regime is best. What's known is that when drip/microsprinkler irrigation is used on moderately deep to shallow soils and under high evaporative demand, stress during harvest and in the 6-8 weeks immediately after harvest is extremely detrimental to the following season's fruit load (Goldhamer and Viveros, 2000; Goldhamer and Smith, 1995). One school of thought is that stress during this time significantly reduces fruit set; the evolution of flowers into fruit (Goldhamer and Viveros, 2000). The hypothesis is that since reproductive bud differentiation in almond trees occurs late (Aug.-Sept.) relative to other *Prunus* species (June-July), harvest and postharvest stress may structurally affect the developing flower, hampering either pollination or events subsequent to pollination in the flower that prevents fruit set. The other school of thought is that harvest and postharvest stress restricts vegetative growth required to establish new fruiting positions (Esparza et al., 2001; Klein et al., 2001). Field research into the above issues has been funded by the California Almond Industry and privately by Paramount Farming Company, Inc.

There are two primary yield components in almonds; kernel size and fruit load (number of kernel per tree). Smaller kernels translate into both lower yield (assuming no impact on fruit load) and less valuable kernels as processor prices are related to kernel size. There are approximately 5% differences in kernel value for each of the five or so kernel size categories. Virtually all of the RDI work to date that imposed preharvest stress also reduced harvest kernel size (Goldhamer and Viveros, 2000; Girona et al., 1993; Goldhamer, 1997; Torrecillas et al., 1989). The magnitude of the size reductions was related to the magnitude of the stress. Even with a short term, moderate stress imposed in the first two weeks of July that was found to significantly reduce hull rot, a fungal disease that can kill young shoots and spurs, consistent reductions in harvest kernel size occurred (Teviotdale, 2001). While these reductions of 3-5% usually were not statistically significant relative to fully irrigated trees, they occurred repeatedly. On the other hand, preharvest stress has been found to accelerate the rate of hull split, allowing for an earlier harvest (Goldhamer and Fereres, 2003; Shackel, 2002). Processors usually pay a premium price for nuts delivered early in the season.

There is some disagreement on the impact of preharvest stress on fruit size. One study found that a uniform stress throughout this period imposed by irrigation at 85% ET caused no significant reduction in kernel yield but preharvest stress levels high enough to reduce seasonal consumptive use by 45% for the season decreased harvest kernel size by 15% (Goldhamer,

1997). However, there was no reduction in fruit load. Another study showed that stress imposed during the hull split period (from early July to late July thru harvest, depending on location in the state) had no negative impact on nut (kernel+shell) size (Shackel, 2002). The observation that fruit load could be maintained even with severe preharvest stress and thus, smaller trees, translates into higher fruiting densities (nuts/unit volume of canopy or ground area) and suggests alternative horticultural strategies to exploit this phenomenon. One approach would be to have higher density plantings enabled by the smaller, RDI controlled tree canopies that could produce more nuts per acre while using much less water than fully irrigated trees. For example, if kernel size and value was cumulatively reduced by 20% due to the preharvest stress but planting density was increased by 20%, grower revenue would be unchanged, assuming not influence on fruit load, while much less water would be used.

Preharvest stress in almonds has also resulted in impacts that can be exploited to address serious problems facing the industry. These include the burning of prunings, dust created by the harvesting operations, and bacterial contamination of fruit at harvest. Accelerated hull splitting resulting from preharvest stress allows the kernels to dry more completely on the tree rather than on the ground, as is the current practice (Goldhamer and Fereres, 2003). It's conceivable that the nuts could be dried on the tree to the 3-5% water content achieved while on the ground. Thus, the nuts could be mechanically shaken directly into catching equipment, similar to that now used in pistachio harvests. That would preclude nuts being dried on the orchard floor and the necessity of the current nut sweeping and collection operations, that can produce excessive dust; a health risk. It also eliminates the possibility of fruit contamination from soil-borne bacteria, such as salmonella, and ant damage (Zalom and Bentley, 1985).

The more compact tree canopies resulting from RDI would require less pruning since vegetative growth would be reduced. This would lessen or eliminate most pruning. This change in pruning practices is also supported by recent research that suggest that the current level of pruning used in most of the industry is unnecessary for sustained high productivity (Viveros and Schrader, 2001; Castro and Jimenez, 2001; Edstrom and Krueger, 2000).

There are three almond sites. Two are in the southern San Joaquin Valley (Lost Hills and McFarland) and managed by Goldhamer/Fereres. The other is in Tehema Co and managed by Shackel. The RDI regimes considered optimal based on the current knowledge level by these groups are used. The Tehema site uses stem water potential measurements taken with a pressure chamber to manage the RDI. The West Valley site uses trunk diameter fluctuations, another plant-based stress indicator, in addition to midday shaded leaf water potential and ET estimates to schedule the RDI. Treatments test both normal harvest techniques as well as a direct tree-to-bin approach that utilizes RDI to accelerate hull split that promotes on the tree drying. Site details summarized below.

Citrus

Recent research has shown that early season stress improves harvest fruit quality: peel appearance in certain varieties and/or less granulation (dessication and whitening of the pulp) in others (Holtzhausen, 1981; Goldhamer and Salinas, 2000; Goldhamer, 2003). The former translates into a higher percentage of fruit graded as Fancy (high value) and a lower percentage

as Juice (low value). Fruit drop and fruit load was not negatively affected. Thus, total grower revenue was modestly higher while consumptive use was reduced. Granulation is unwanted by growers, packing houses, marketers, and buyers. Graphical representation of the relationships between yield, revenue, and applied water is shown in Fig. 2.

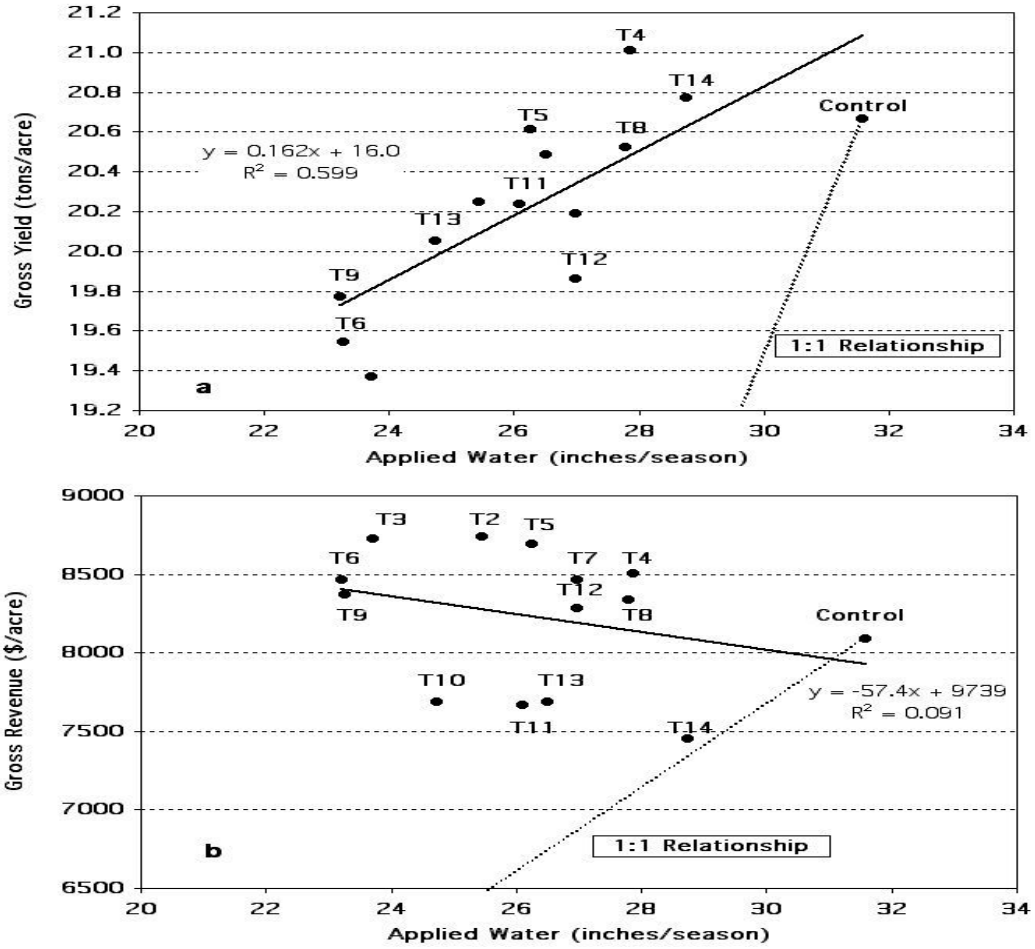


Figure 2. Production (a) and revenue (b) functions for applied water using mean 1998-2000 for navel oranges (Frost Nucellar) in the southern San Joaquin Valley.

We believe that the RDI regimes for citrus can be successful in terms of improving or maintaining grower revenue while significantly reducing consumptive use. Our CARDIP demonstration site is in eastern Tulare Co. and managed by Goldhamer/Fereres. Treatment and site specific details are summarized below.

Pistachio

Mature pistachio trees have the potential to transpire water at an extremely rapid rate (Goldhamer et al., 1985). While pistachio trees are extremely drought tolerant, they are able to withstand severe stress (Goldhamer et al., 1984). During the drought of the late 1980s, we left mature trees unirrigated for three years and they not only survived but produced a small crop. Pistachio production involves many more yield components than the other nut crops and each of

these yield components can be negatively influenced by water stress. However, the unique fruit development pattern of pistachio nuts provides a period where the tree is relatively tolerant of stress: just after full shell size has been attained until the onset of rapid kernel growth. We refer to this as Stage 2 growth and it normally occurs from Mid May thru early July in the southern San Joaquin Valley. Research has shown that irrigation at 50% of potential ET during this period can occur without negative impacts on production (Goldhamer and Beede, 2004). However, the period from the onset of rapid kernel growth thru harvest (Stage 3) is particularly sensitive to stress. Shell splitting (desirable) can be reduced as well as nut removal by mechanical shaking.

In addition to Stage 2, the postharvest period in pistachios has been identified as stress tolerant (Goldhamer et al., 2004). We developed an RDI regime that exploits the Stage 2 and postharvest stress-tolerant periods and reduces applied water by 25% without reducing the yield of marketable product (Goldhamer, 2005). Additionally, we found that mild to moderate stress from leafout to full shell size (Stage 1) can significant improve shell splitting which can sometimes be a major problem for growers. Closed shell nuts are worth much less than split nuts. The downside of Stage 1 stress is that it can reduce nut size. Nevertheless, an ongoing study has found that Stage 1 stress can improve the yield of split nuts by 20% relative to fully irrigated trees. Similar results were obtained when Stage 1 stress was coupled with Stage 2 stress. This treatment reduced applied water by almost 30%.

Our CARDIP site is located in Madera Co. There are four RDI regimes. Site details are summarized below.

Peach

The pioneering RDI work in fruit trees was conducted on late harvest peach (Chalmers et al., 1981). Since the fruit has a double sigmoid development pattern, where a rapid growth first stage is followed by a slower growth second stage, which, in turn, is followed by a rapid growth third stage, the theory was that stress can be imposed during Stage 2 of fruit growth. Researchers in Australia found that with this approach, there was no significant reduction in harvest fruit size, unwanted vegetative growth was reduced (presumably less pruning required), and consumptive use was less (Chalmers et al., 1981). There was no increase in fruit drop. However, we in California and others in Europe have been unable to reproduce these results in late harvest peaches; we usually observe a slight reduction in harvest fruit size (Girona et al., 1993; Goldhamer et al., 2002; Girona et al., 2002). While these size reductions may not be statistically significant relative to fully irrigated trees, the fact that fruit value is so closely tied to fruit size results in significant loss of grower revenue.

This is not the case with early harvest peaches; those harvested in late May-early July (Larson et al., 1988; Johnson et al., 1992). The RDI regimes impose stress only following harvest. Since fresh peach production includes early season thinning of the crop to a desired number, any impact of the previous year's stress on fruit load is negated. However, stress in late Aug.-mid Sept. has been found to increase the percentage of fruit "doubles;" two fruit in varying degrees of completeness attached to one stem (Johnson et al., 1992). This fruit is worthless and can be removed in the thinning process. However, it requires the thinning personnel to be more

watchful, thereby slowing down their work. The fruit double problem can be largely avoided by reintroducing full irrigation in the late Aug.-mid Sept. period.

We will incorporate a new peach site located in eastern Fresno Co. in CARDIP. This site will be managed by Johnson. This site will use border strip irrigation to demonstrate that drip/microsprinklers are not required to successfully use RDI. The RDI regimes will focus on postharvest stress. Tree water status will be monitored throughout the season. All components of the field water balance required to estimate ET on the RDI trees will be measured, including soil water content as the beginning and end of the season (numerous radial measurements in two dimensions from the tree trunks), effective rainfall, and applied water. At harvest, tonnage will be measured and 400-500 fruit per replicate sized in an electronic sorter. Samples of average size fruit will be analyzed for sugar content and firmness.

Wine Grapes

There is unanimity of opinion that water stress in grapes can improve the quality of the wine produced (Goodwin and Jerie, 1992). In fact, irrigation of wine grapes was against the law until recently in some European countries. While it was recognized that irrigation could increase yields, there was a fear that wine quality would also be reduced. Now it's recognized that irrigation is required to maximize both production (yield) and grower profit. However, there is no agreement on the extent of the stress required to produce the maximum amount of fruit of the best quality for wine making.

It's been thought that the main objective of RDI in wine grapes is to produce a berry that is smaller than when fully irrigated; thus increasing the ratio of skin to pulp (Kennedy et al., 2002; Prichard, 2003). The constituents of the skin are thought to have the primary influence on wine quality. However, reducing berry size also reduces yield, assuming the same fruit load. Some believe that it's not necessary to impose stresses severe enough to reduce berry size in order to produce higher quality wine; that stress-related chemical changes in the fruit are primarily responsible (Matthews et al., 1990). However, there's universal agreement that reduced vegetative growth and thus, smaller canopies, improves grape color by allowing more sunlight to penetrate into the canopies.

Most agree that optimal RDI in wine grapes involves stress prior to veraison (berry color change). Early season stress is usually imposed by delaying irrigation until a desired level of stress occurs in the vines (Prichard, 2003). The triggers used to identify when enough stress has occurred vary. One approach uses plant water stress measured with a pressure chamber; the other is based on irrigating at certain fractions of ET (Prichard, 2003).

There are two CARDIP wine grape sites; one near Paso Robles in San Luis Obispo Co. and the other near Lodi in San Joaquin Co. The Paso Robles site is managed by Battany and the Lodi site by Prichard. Each site contains numerous RDI regimes as well as full ET or grower practice irrigation. Monitoring includes vine water status during the season, grape yield, berry and cluster sizes, and harvest brix and pH. Wine chemistry analysis will include quantifying phenols, monomers, tannins, acid type (malic and tartaric), and anthocynins. Sensory evaluations will also be conducted on a replicated basis.

Coordination of Site Design and Monitoring

A randomized complete block design will be used at each site. It's desirable to have the largest and as many replicates as possible to obtain the most representative, statistically valid data. This must be balanced against practical aspects of logistics and funding. Additionally, field shape and the irrigation system also dictate plot size. For example, with border strip irrigated trees, replicates must include entire rather than partial rows, as is possible with drip/microsprinkler. Nevertheless, one of our goals is to have consistency of design across all plots. Thus, in the orchard sites, we will have at least six replicates of each irrigation treatment and each replicate will have at least 8-10 plants that will be harvested. The addition of border trees will make each replicate 25-30 trees in size. Not all of the trees to be harvested will be used to monitor tree water status. For the wine grapes, each RDI treatment is replicated four times.

Quantifying ET Using the Water Balance Approach

The basic water balance technique is to quantify all sources and sinks of water in the field and calculate ET by difference. One measures applied irrigation water, any rainfall that occurs during the season, and the change is soil moisture in the root zone, which is normally depleted by plant extraction. While deep percolation of water below the root zone can also be part of the balance, it is considered negligible under RDI since applied water during the deficit periods is less than potential ET and irrigation in the non deficit periods just meets potential ET. Moreover, irrigation immediately following the deficit periods into a relatively dry profile, again eliminating potential deep percolation. However, any errors made in determining each component of the water balance are embodied in the ET term. The most difficult and questionably accurate component of the balance is usually the contribution of stored soil moisture to ET.

It's important to recognize that the magnitude of the contribution of stored soil moisture to seasonal ET varies primarily with rooting depth, water application patterns, soil water holding capacity, and winter rainfall. Let's consider two cases. First, a relatively deep root zone of 6 ft., an available soil water holding capacity of 1.2 inches/ft, drip irrigation, and winter rains that entire filled the soil moisture reservoir. Total available soil water would be 7.2 inches (6 ft. x 1.2 inches/ft). If ones assumes that the drip irrigation has a subsurface wetting pattern that wets 25% of the soil moisture reservoir, the remaining 75% of the reservoir is depleted over the season to PWP, and soil water contents in the subsurface zone wetted by the drip are the same at the beginning and end of the season, the contribution of soil moisture to ET would be 5.4 inches (7.2 inches x 0.75). For a crop with seasonal ET of 40 inches, this represents about14% of the total.

On the other hand, a shallow rooted orchard with a 2ft root zone and microsprinkler irrigation that wetted 50% of the subsurface area and the same soil type would have 2.4 inches of available moisture (2 ft. x 1.2 inches/ft) with only 1.2 inches consumed by the trees throughout the year (2.4 inches x 0.50).

It's clear that the accuracy of the water balance method depends on first, accurate assessing soil moisture in the vertical direction and second, accurately estimating how much of the subsurface

area is wetted by irrigation system. We believe that the technique described below addresses these issues and thus, improves upon previously used water balance techniques.

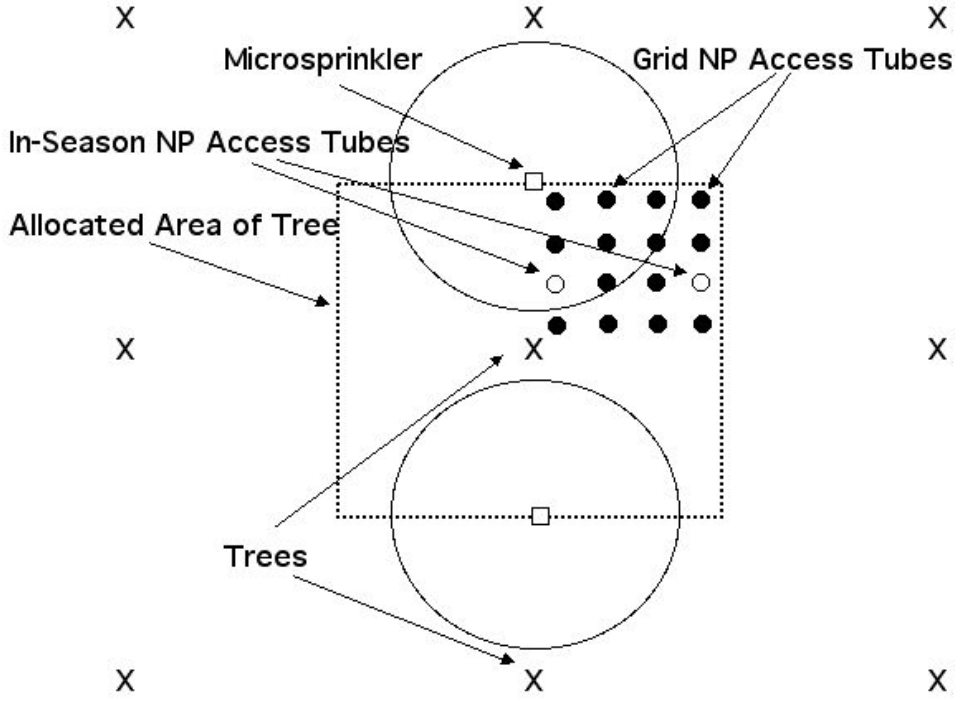


Figure 3. Placement of intensive neutron probe tubes in one tree root zone quadrant.

At each of our experimental sites, we have installed pairs of neutron probe (NP) access tubes on single trees in at least three replications of each irrigation treatment (Fig. 4). One of these tubes is installed in the area wetted by the dripper or microsprinkler ("wet" tube) and the other is located well outside of the wetted surface soil ("dry" tube). These tubes are monitored at the beginning and end of the season to assess soil moisture in addition to be monitored monthly. The goal is to have the "wet" tube describe soil water profiles in the area wetted by the drippers or microsprinklers and the "dry" tubes describe distributions outside of this sphere of influence where extraction occurs over the season. The key to the accuracy of this technique is to quantify what percentages of the soil water reservoir are described by each tube. While is easy to measure the wet and dry surface soil, it's much more difficult in the soil profile.

Our approach is to use a grid of NP access tubes installed in one quadrant of a single tree (Fig. 4) in two irrigation treatments per site; the most severe RDI regime and the Control. We recognize that the former may have a smaller subsurface wetted area than the latter and this approach will bracket the subsurface wetted area found in the intermediate RDI regimes. All quadrants of the tree are identical with respect to the relative distributions of the root zone and applied water. This grid will be monitored at the beginning and end of the season. It will allow us to quantify the percentage of the subsurface areas described by the "wet" and "dry" tubes. We have successfully used this intensive instrumentation of root zone quadrants in walnut ET estimates (Goldhamer et al., 1995).

Summary of Existing CARDIP Experimental Sites, RDI Regimes, and Sampling Protocols

Site 1 Location: Lost Hills, Kern Co
Crop: Almonds. Cooperator: Paramount Farming Co. West Valley Ranch
Description: Goal is to develop water management approaches that offer growers strategies for accelerating hull split and thus, fruit maturation. This offers the potential for drying nuts on the tree rather the ground, reducing dust at harvest as well as allowing for an earlier harvest. There are 4 RDI treatments imposed using truck diameter fluctuations, midday shaded leaf water potential, and CIMIS-based ET estimates. There is a fully irrigated Control.

Treatments:
T1 LVDT-based MDS signal threshold of 2.0 until Aug. 1; ground harvest.
T2 LVDT-based MDS signal threshold of 2.0 until Aug. 1; direct tree-to-bin harvest.
T3 LVDT-based MDS signal threshold of 2.75 until Aug. 1.
T4 LVDT-based MDS signal threshold of 2.75 until Aug. 1; direct tree-to-bin harvest.
T5 Fully irrigated Control

Plot Map: (Appendix D). Plots are 5 rows wide by 7 trees long; interior 15 trees per plot will be used for measurements. Each plot contains 3 cultivars, each of which will be evaluated. Treatments are replicated 6 times. Total experiment size: 10 acres.

Sampling:
Weekly: leaf water potential, hull split
Continuously: applied water, rainfall
Harvest: yield, fruit quality, insect damage, sticktights, harvestibility
Seasonal: Soil moisture with neutron probe (total of 30 access tubes, each to 10 ft deep),

Additional Notes: New microsprinkler system was installed, including controllers, solenoids, mainlines, submains, risers, lateral tubing, pressure regulators, and water meters. Existing filters and booster pump used.

Site 2 Location: McFarland, Kern Co
Crop: Almonds. Cooperator: Paramount Farming Co. East Side ranch.
Description: Goal is to develop water management approaches that offer growers strategies for maintaining or improving fruit yields while increasing water use efficiency. This is accomplished by imposing stress from early May thru just prior to harvest. The RDI is based on a irrigating at a fraction of potential ET. Objective is to improve fruiting density (nuts per unit of canopy volume) and reduce tree size. This would allow for increased planting density while reducing pruning and thus, burning.

Treatments: T1 RDI; 50% ET May 1 to July 31; Oct 16-31, nothing thereafter.
T2 Fully irrigated Control.

Plot Map: Appendix D. Plots are 4 rows wide by 39 trees long; interior 84 trees per plot will be used for measurements. Each plot contains 2 cultivars, each of which will be evaluated.

Treatments are imposed in both adjacent conventional (21 x 24 ft) and high density (18 x 22 ft) orchards. Treatments are replicated 4 times. Total experiment size: 14 acres.

Sampling:
Weekly: leaf water potential
Continuously: applied water, rainfall
Harvest: yield, fruit quality, harvestibility
Seasonal: Soil moisture with neutron probe (total of 32 access tubes, each to 5 ft deep),

Additional Notes: Existing buried drip system modified RDI plots by installing regulator to reduce rate of applied water to 60% of Control. Water meters installed.

Site 3 Location: Orland, Tehema Co.
Crop: Almonds. Cooperator: Lassen Land Co.
Description: Goal is to evaluate a single RDI regime that imposes stress from June through harvest. Objective is to reduce hull rot, a fungal disease, as well as improve water use efficiency. RDI will be compared with fully irrigated Control.

Treatments:
RDI- Moderate Stress during hull split
Control- Irrigated to maintain non-stressed leaf water potential baseline readings

Plot Map: Appendix D. Each plot is 24-30 acres with rectangular shapes. Treatments are replicated 6 times. Total experiment size: 320 acres.

Sampling:
Weekly: stem water potential
Continuously: applied water, rainfall
Harvest: yield, fruit quality
Seasonal: Soil moisture with neutron probe (total of 24 access tubes, each to 10 ft deep),

Additional Notes: Existing microsprinkler required only labeling of main values to identify RDI and Control plots.

Site 4 Location: Strathmore, Tulare Co.
Crop: Citrus. Cooperator: Griffith Farms
Description: Goal is to develop water management approaches that offer growers strategies for improving fruit quality while reducing applied water. RDI regimes test early season stress, that has been shown to reduce peel creasing and thus, the percentage of fruit characterized as "juice." These regimes are based on irrigating at both fractions of ET and midday stem water potential. There is also an RDI regimes based on continuous measurement of fruit size with electronic sensors. All RDI strategies will be compared with fully irrigated Control.

Treatments:
T1 Early season stress by withholding irrigation until end of May. Target is about 16 bars. This is similar to T2 in old McFarland plot. From June 1 on, full irrigation.

T2 Early season stress by irrigating at 25% ET from May 16-July 15. Target is about 20 bars. This is similar to T3 in old McFarland plot. Full irrigation both before and after stress period.

T3 Same as T1 except maintaining mild-moderate stress (4-6 bars less than Control) throughout season

T4 Based on maintaining maximum fruit size. Use signals with similar protocol as was done with MDS at Lost Hills. Threshold; 0.95.

T5 Full irrigation Control

Plot Map: Appendix D. Plots are 4 rows wide by 6 trees long; interior 8 trees per plot will be used for measurements. Treatments are replicated 6 times. Total experiment size: 10 acres.

Sampling:
Weekly: leaf water potential
Continuously: applied water, rainfall
Harvest: yield, fruit quality
Seasonal: Soil moisture with neutron probe (total of 32 access tubes, each to 5 ft deep)

Additional Notes: Fruit evaluation at harvest: These samples will be analyzed for color and granulation. Fruit will also be visually graded by competent packing house personnel to quantify Fancy, Choice, and Juice percentages. Fruit graded as Choice and Juice will be further analyzed to determine the primary reason for non-Fancy designation (peel creasing, insect damage, color, softness, or other).

Site 5 Location: Madera, Madera Co.
Crop: Pistachios. Cooperator: AgriWorld, Inc.
Description: Goal is to develop water management approaches that offer growers strategies for improving fruit quality while reducing applied water. RDI regimes test early season stress, that has been shown to increased shell splitting harvest. There is an additional RDI regime that imposes stress from the attainment of full shell size to the onset of rapid kernel development. These regimes are based on irrigating at both fractions of ET and midday stem water potential. All RDI strategies will be compared with fully irrigated Control.

Treatments:
T1 Early season stress 11 to 14 bars in Stage 1 followed by full irrigation.
T2 Early season stress 14 to 16 bars in Stage 1 followed by 50% ET in Stage 2.
T3 RDI, 50% ET in Stage 2.
T4 Early season stress 11 to 13 bars in Stage 1 followed by full irrigation.
T5 Fully irrigated Control.

Plot Map: Appendix D. Plots are 7 rows wide by 12 trees long; interior 50 trees per plot will be used for measurements. Treatments are replicated 6 times. Total experiment size: 17 acres.

Sampling:
Weekly: leaf water potential
Continuously: Applied Water, rainfall
Harvest: yield, fruit quality
Seasonal: Soil moisture with neutron probe (total of 30 access tubes, each to 5 ft deep),

Additional Notes: Existing microsprinkler system was modified to allow for operation of RDI plots at different frequency than Control, allowing for different levels of applied water.

Site 6 Location: Lodi, San Joaquin Co.
Crop: Syrah Wine Grapes. Cooperator: E and J Gallo/Pacific Agrilands
Description: Goal is to develop water management approaches that offer growers strategies for improving wine grape quality. Leaf water potential is used with different thresholds to determine when to initiate subsequent irrigation based on fractions of potential ET. RDI treatments will be coupled with shoot and cluster thinning treatments. There are a total of 8 treatments, including fully irrigated Control.

Treatments:
1 Full Potential Irrigation, shoot thinning
2 Full Potential Irrigation, cluster thinning
3 13 bar threshold, 40% RDI, shoot thinning
4 13 bar threshold, 40% RDI, cluster thinning
5 17 bar threshold, 50% RDI, Shoot thinning
6 17 bar threshold, 50% RDI, Cluster thinning
7 17 bar threshold, 50% RDI, one bud spur, Shoot Thinning
8 17 bar threshold, 50% RDI, one bud spur, Cluster Thinning

Plot Map: Appendix D. Plots are 3 rows wide by 20 vines long; interior 16 vines per plot will be used for measurements. Treatments are replicated 4 times. Total experiment size: 2.5 acres.

Sampling:
Weekly: leaf water potential
Monthly: shoot growth
Continuously: applied water
Harvest: yield, grape quality, wine chemistry, wine sensory evaluation
Seasonal: Soil moisture with neutron probe (total of 50 access tubes, each to 10 ft deep), rainfall, pruning weights

Additional Notes: New microsprinkler system was installed, including controllers, solenoids, mainlines, submains, risers, lateral tubing, pressure regulators, and water meters. Existing filters and booster pump used.

Site 7 Location: Paso Robles, San Luis Obispo Co.
Crop: Cabernet Sauvignon and Syrah Wine Grapes. Cooperator: J. Lohr Vineyards

Description: Goal is to develop water management approaches that offer growers strategies for improving wine grape quality. Treatments are imposed based on irrigating at different fractions of potential ET.

Treatments:

1. 75% ET Set-Version; 75% ET Veraison-Harvest
2. 60% ET Set-Version; 60% ET Veraison-Harvest
3. 45% ET Set-Version; 45% ET Veraison-Harvest
4. 45% ET Set-Version; 30% ET Veraison-Harvest
5. Grower Practice

Plot Map: Appendix D. Plots are 3 rows wide by 16 vines long; interior 14 vines per plot will be used for measurements. Treatments are replicated 4 times. Total experiment size: 2.5 acres.

Sampling:
Weekly: leaf water potential, stomatal conductance, leaf chlorophyll
Monthly: photosynthesis
Continuously: applied water, sap flow (Syrah), leaf temperature, rainfall
Harvest: yield, grape quality, wine chemistry
Seasonal: Soil moisture with neutron probe (total of 30 access tubes, each to 5 ft deep),

Remote Sensing to Quantify ET

<u>Development of approaches measure the ET of orchards and vineyards</u>.

Models to calculate orchard ET will be developed. One approach will independently model E and T losses (Testi et al., 2004b). Evaporation from orchard soils under microirrigation will be obtained with the model of Bonachela et al., (2001) that calculates separately E from the dry and wet soil areas, obtaining the E with a modified Penman-FAO equation for stage-one evaporation, and the model of Ritchie (1972) for the soil-limited evaporation stage. For the wetted area, microadvection effects are taken into account (Bonachela et al., 2001)

The transpiration model will use the Penman-Monteith equation using a specific bulk canopy conductance (G_c) model (Testi et al., 2004b,c). This model is conceptually based on the proportionality of G_c to carbon assimilation, A, and on a function of vapour pressure D (Leuning, 1995). Radiation interception by tree canopies will be calculated following approaches developed for olive orchards by Villalobos et al., (1995) and Mariscal et al., (2000) and parameterised for the species in question.

An alternative approach to calculate orchard ET will be based on the use of METRIC (Mapping Evapotranspiration at high Resolution and with Internalized Calibration), a remote sensing, energy balance procedure (Allen et al., 2003). METRIC is an image-processing model for calculating ET as a residual of the surface energy balance. METRIC has successfully predicted ET based on validation with lysimeter data (Fig. 5). METRIC is a variant of SEBAL, an important energy balance model developed in the Netherlands by Bastiaanssen, and was

extended to provide tighter integration with ground-based reference ET. There are important scientific and technical differences between METRIC and SEBAL, which are outlined in Appendix E. At a seminar at UC Davis on October 29, 2004, Dr. Bastinaanssen stated that it's not possible to currently use SEBAL to accurately estimate ET in California's orchards and vineyards.

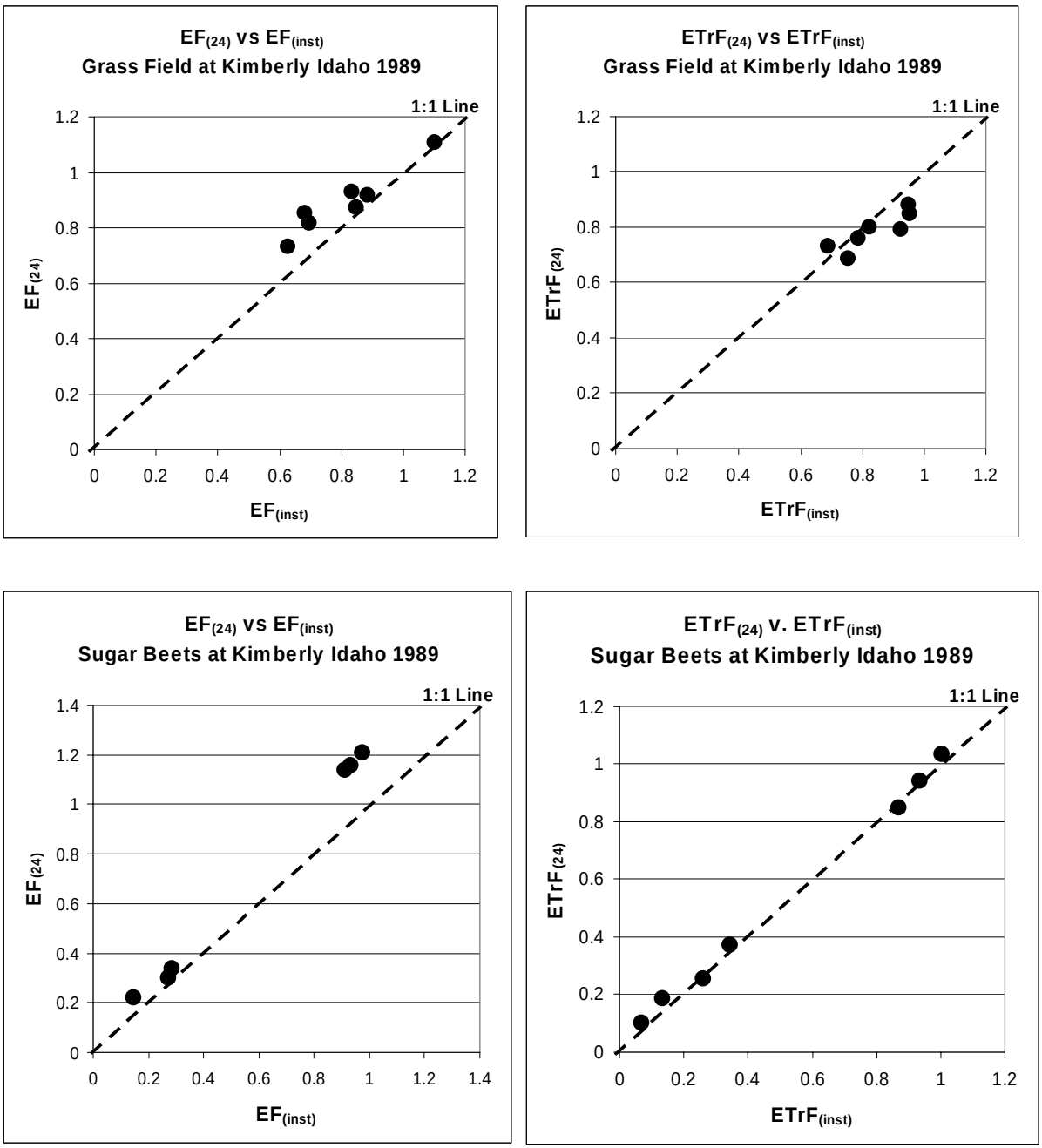


Figure 4. Comparison of lysimeter and METRIC ET for field crops over 24-h periods with the same parameter computed at the satellite time (*inst*) for LANDSAT 5 image days at Kimberly, Idaho during 1989 (Lysimeter data were from J.L. Wright, USDA-ARS).

METRIC has been applied with LANDSAT images in southern Idaho, Imperial Valley of California, and along the Middle Rio Grande of New Mexico to predict monthly and seasonal ET for water rights accounting and in Idaho for operation of ground water models. METRIC uses digital image data collected by LANDSAT or other remote-sensing satellites that record thermal infrared radiation in addition to visible and near-infrared radiation. ET is computed on a pixel-by-pixel basis for the instantaneous time of the satellite image. The process is based on a complete energy balance for each pixel, where ET is predicted from the residual amount of energy remaining from the classical energy balance, where ET = net radiation – heat to the soil – heat to the air. Details are presented in Bastiaanssen et al. 1998, Bastiaanssen 2000, Bastiaanssen et al. 2002, Allen et al., 2004, and Tasumi et al. 2004.

Why the METRIC Model Is Desirable For Use With RDI

1) METRIC calculates actual ET rather than potential ET and does not require knowledge of specific crop type (no satellite-based crop classification is needed),
2) METRIC relies heavily on theoretical and physical relationships, but provides for the introduction and automated calibration of empirical coefficients and relationships to make the process operational and accurate,
3) The use of reference ET (ET_r) in calibration of METRIC and the use of the fraction of ET_r (ET_rF) in extrapolation to daily ET provides general equivalency and congruency with ET as estimated using the traditional K_c ET_r (or K_c ET_o) approach. This is valuable for use of ET generated by METRIC in conjunction with water rights management. This approach of METRIC (using weather-based reference ET to calibrate and to extrapolate) contrasts with SEBAL, which generally calibrates by assuming that ET is equal to net radiation less soil heat flux when the surface temperature equals that of a local water body, and where SEBAL uses the evaporative fraction (EF) to extrapolate to daily ET, where $EF = ET/(R_n-G)$ where R_n is net radiation and G is soil heat flux. METRIC extrapolates using $ET_rF = ET/ET_r$ where ET_r is the reference ET for full-cover alfalfa. Again, Appendix E provides a detailed analysis of the differences that exist between the METRIC and SEBAL approaches to calculate ET.
4) METRIC is auto-calibrated for each image using ground-based calculations of ET_r (made using hourly weather data). We have confidence in the ET_r computation (based on the recently standardized ASCE Penman-Monteith equation), where accuracy of the ET_r estimate has been established by lysimetric and other measurement methods, and
5) Internal calibration of the sensible heat computation within METRIC eliminates the need for atmospheric correction of surface temperature (T_s) or reflectance (albedo) measurements using radiation transfer models (Tasumi et al. 2004a). The internal calibration also reduces impacts of any biases in estimation of aerodynamic stability correction or surface roughness.

While the absolute calculations of ET by METRIC (or any other satellite-based method) have some potential to be biased (either high or low), relative differences in ET (by stress vs. nonstress fields) can have much higher accuracy. In application to trees and vines, there is some question, in regard to the application of METRIC (and related remote sensing algorithms such as SEBAL), concerning the appropriate aerodynamic roughness to use during the calculation of sensible heat flux to the air and consequently the calculation of ET. In energy balance algorithms, such as are employed in METRIC and SEBAL, ET is solved by subtracting sensible

heat flux (H) from available energy (R_n and G). The calculation of H is based on the aerodynamic roughness of the specific vegetation, along with surface temperature and mean wind speed. As roughness is increased, H increases, and the estimate for ET decreases. The question of best estimation and parameterization of roughness for tree and vine crops will be addressed during the first two years of this project.

Validation of METRIC Using Eddy Covariance Measurements

The models will be tested by taking measurements of eddy covariance ET in the CARDIP pistachio orchard in Madera Co. and the CARIP almond site in Tehama Co. The orchard plots will have the minimum size needed for the appropriate use of this technique and the measurements will be performed during at least three 10-14 day periods during the first year. The time periods will be chosen to obtain ET measurements under stressed (pre-harvest) and non stressed conditions. The equipment needed will be, in part, brought to California from Spain and complemented with equipment that will purchased in California. Measurements necessary to parameterize the METRIC and the T model will be taken during the measurement periods. Recent developments in techniques to correct eddy covariance measurements for energy balance closure error (Twine et al. 2000, Wilson et al., 2002), along with other necessary corrections (Villalobos, 1997) will be applied.

The METRIC model will be applied using only ground-based data during Years 1 and 2 to increase the number of observations available for calibration and validation (LANDSAT observations are available only every 16-19 days at best whereas METRIC can be applied continually using intensive ground-based measurements). In Year 3, METRIC will be applied using only satellite data supplemented by CIMIS weather data. Measurements during Years 1 and 2 necessary to apply METRIC include the measurement of total hemispherical radiation (short wave and long wave) reflected and emitted upward from the CARDIP plot using a stationary and mobile (human held) radiometer, surface temperature (using both stationary and mobile infrared transducers), soil heat flux averaged from six or more locations in the CARDIP plot, and friction velocity derived from the eddy covariance measurements. Associated hourly weather data from a nearby CIMIS (for example, Parlier or Orange Cove) or other electronic weather station will be utilized. The application of METRIC with ground-based data will require the infrared temperature instrumentation of a bare soil area and a grassed area (for hot and cold pixel determination).

Ground Truthing METRIC With Lysimetry, Sap Flow, and Energy Balance Measurements

Intensive energy balance measurements via METRIC for the calculation of ET will be conducted at the KAC peach lysimeter beginning in Year 2. Additionally, sap flow sensors, and the radiometric measurements described above for calculating ET will be correlated with the lysimeter measurements of potential ET. The peach lysimeter plot is too small for eddy covariance measurements; however, the actual Lysimeter ET measurements can be used to test the METRIC and the T measurements and models if all the relevant energy balance parameters are measured during short time periods over the lysimeter plots. This test of METRIC at a small scale will be critical for its extension to larger, satellite based, scales and for the assessment of the impact of RDI on the ET of the CARDIP plots. There will be also an opportunity in the

lysimeter orchard to test the use of sap flow sensors (in trees outside the lysimeter) to estimate tree T independently of other estimates, thus offering an alternative method to soil water balance and to METRIC to obtain tree T in the RDI plots of CARDIP.

Testing METRIC and Other ET Models On CARDIP Sites and Validation of METRIC ET Derived From LANDSAT 5 Images

The METRIC and the E+T model will be used to estimate ET under stress and non-stress conditions at CARDIP Sites 1, 3, 5, and 6 beginning in Year 3. Remote sensing techniques (satellite-based METRIC) will be applied to an area of about 40,000 acres of predominant almond production in the San Joaquin Valley using five LANDSAT images to assess to what degree full ET conditions exist. By combining vegetation indices with thermal images during periods of potential water deficits and by applying METRIC to these large, uniform areas, it will be possible to evaluate the potential net water savings through the use of the prescribed RDI programs for almond irrigation.

Work (Task) Requirements

CARDIP

Task1. Site Establishment and Equipment Installation (February-April, 2006). This is for Fresno Co. peach site only, all other sites have been established and will have completed two years operation by the start of 2006.

- Layout and flag plot. Color code and number monitored trees for treatment, replicate.
- Design irrigation system modifications.
- Procure soil moisture monitoring equipment, including neutron probe access tubes or electrical resistance blocks.
- Install soil moisture monitoring equipment.
- Measure initial trunk or primary scaffold circumference.

Task 2. In Season Monitoring (March-December/February, each year)
- Adjust irrigation scheduling (daily-weekly).
- Monitor soil moisture (monthly) with neutron probes calibrated for each site.
- Monitor tree/vine water status (at least weekly).
- Monitor species-specific fruit maturation processes, such as hull split in almonds.
- Check irrigation systems for operation, leaks, and emitter clogging. Repair and/or replace (daily-weekly).
- Flush irrigation system (monthly).
- Monitor trees/vines for diseases, pests, and nutrient deficiencies/toxicities expressed by leaf symptoms (monthly).

Task 3. Harvest (August-December/January, each year)
- Arrange for portable field scales for weighing harvest bins.
- Coordinate operations with cooperator and field personnel, arrange for harvest crews.

- Brief harvest crew leaders on harvest protocols.
- Insure that harvest crew leaders train pickers/equipment operators on protocols.
- Measure gross harvest weights.
- Collect fruit samples and store properly.
- Transport required fruit and samples to cold storage or processing facilities.
- Conduct required fruit size determinations. This can be done with automated, electronic sorters with peach but must be done manually with calipers with other crops.
- Measure fresh and dry fruit weights. When necessary, measure fruit component weights, such as hull, shell, and kernel with almonds.
- For grapes, measure pH and brix.
- For grapes, chemical analysis of the wine.
- Conduct wine sensory evaluations.

Task 4. A yearly meeting will be held with the steering committee comprised of representatives from agricultural and scientific peers to discuss the results from the previous year.

Task 5. Data Analysis and Report Compilation.

- Data from each site will be compiled, analyzed, and presented to the funding agency as a yearly and final report at the end of the contract period. These data will include impacts of RDI on yield and yield components, applied water, estimates of consumptive use (ET), and water productivity (gals/lb product).

<u>Remote Sensing To Quantify ET</u>

Task 1. Measurements and Models of orchard ET. (February 2006-November 2007).
- Shipment and installation of eddy covariance and sap flow equipment in the pistachio orchard in Madera (Feb-April 2006).
- ET data collection in the pistachio orchard
- Measurements of canopy architecture and radiation interception features in pistachio and almond (April-Sept.2006)
- Development of a model of radiation interception and of a E+T model for almond and pistachio trees (Oct.2006-February 2007)
- Equipment installation (sap flow, radiation, temperature, and other sensors) in the peach lysimeter plot at KAC (March 2007)
- Data collection and processing from the peach lysimeter plot (short runs between April and November 2007)

Task 2 Development and tests of METRIC for determining the ET of orchards (February 2006-December 2007).

- Data collection on short and long-wave -reflected and emitted-radiation, surface temperatures, soil heat flux and related parameters for the RS model in the pistachio orchard, including surface temperatures of a hot and a cold pixel (April-October, 2006).
- Data collection of same parameters in the peach lysimeter plot (April- November 2007)

- Parameterization of METRIC, including the aerodynamic roughness, for orchards using available datasets (Feb.-Sept.2006)
- Tests of METRIC estimates against available measurements and recalibration of the method (Sept.2006-December 2007)

Task 3 Use of METRIC to estimate orchard ET under non-stress and stress conditions (Dec 2006-Dec 2008)

- Satellite data collection of CARDIP sites (Feb - Nov 2007)
- Satellite data collection of the 40,000 acre test area (March-October2008)
- Estimation of the ET by METRIC of CARDIP sites where possible (Nov 2007-Feb 2008)
- Estimation of Almond ET by METRIC over the test area (Aug-Dec 2008)

Task 4 Data Analysis and Report Compilation.

Data from every experiment will be compiled, analyzed, and presented to the funding agency as a yearly and final report at the end of the contract period.

Deliverables

CARDIP

1) Eight replicated, established demonstration/research sites involving almond, citrus, pistachio, peach, and wine grapes that will provide data on long term impacts of RDI on production and consumptive use.
2) A final report detailing results from each site for the five year (2004-2008, inclusive) duration of this study (three years with the peach site). The report will address success or failure of RDI and offer suggestions for future demonstration/research efforts.
3) Educational information on RDI will be extended to growers in the form of either field days or seminars by each of the UC team members for each of their sites. These presentations would ideally take place at the end of the study but may occur earlier depending when the optimal presentation forum (short courses, ET.) occurs.
4) A publication entitled "Regulated Deficit Irrigation Management for Orchards and Vineyards" will be developed and published by the University of California (Appendix F). This will cover all aspects of RDI management, including plant response to water stress, use of different RDI triggers, impacts of RDI on salinity and diseases, and specific RDI strategies for peach, plum, nectarine, prunes, almonds, pistachio, citrus, olives, red wine grapes, and white wine grapes. A draft of this publication will be delivered to the funding agency by the end of the contract. Due to review and editing, actual publication may occur after the contract terminates.

Remote Sensing to Quantify ET

1) A generic model for calculating the water requirements of orchards as the sum of E and T which will represent an improvement over existing models now used in irrigation scheduling.

2) A dataset on ET measurements methods with a comparison with actual ET data obtained in the peach lysimeter.
3) A new approach at estimating the ET of orchards and vineyards using remote sensing techniques which will be tested at two scales .
4) An estimation of the potential ET reduction via RDI in almond orchards.
5) A report with all information gathered throughout the study period.
6) A method for calculating orchard water requirements based on a simple model derived from Deliverable 1. This method will be available to growers in the State at the end of the project.

MONITORING AND ASSESSMENT

Methodologies to quantify ET in both CARDIP and the Remote Sensing components of this project have been detailed in previous sections. However, we include the following discussion concerning extrapolation of experimental results to large scale application.

Quantifying RDI water use savings statewide

Uncertainties

We believe that consumptive use of water in California's orchards and wine grape vineyards could be reduced by about 1 million AF of water if RDI were adopted on a wide scale (Table 1). The data that was used to develop these potential estimates is summarized in Table 2. Our estimates are based on RDI studies published in peer reviewed journals and our own research and experience.

Table 2. Estimates of potential ET, current actual ET, and consumptive use savings with RDI.

	Potential ET*	Actual ET**	Consumptive Use Reductions	Consumptive Use ET
	(inches)	(inches)	(inches)	(inches)
Almonds	42	40	8	32
Wingegrapes	27	23	8	15
Citrus	35	35	6	29
Pistachios	44	42	10	32
Prunes	39	37	6	31
Peaches	39	37	4	33
Olives	41	41	6	35
Apples and Pears	40	40	4	36

*Based on CIMIS ETo Maps, locations of major growing areas in state, and published Kcs.
**Estimated by Goldhamer and Fereres from our experience.

We believe the primary uncertainty these data involved the current actual ET. There is no way of accurately knowing exactly how much water growers are applying and how much of this is actually being used in ET. There is also some uncertainty in the potential ET data as newer

estimates of ETo in some areas are higher than those originally published (Snyder and Pruitt, 1989).

Grower Adoption of RDI and Likely Consumptive Use Reductions

In addition to the uncertainties cited above, the question of determining how much consumptive use savings are likely depends on grower adoption. We believe that growers are motivated by two primary forces: profit and regulation. It growers believe that a new technology or approach to irrigation will increase their profits, adoption is much more likely. For this reason, we are highly focused on identifying positive horticultural aspects of RDI, such as improved fruit quality. While consumptive use reductions require lower amounts of applied irrigation water and this reduces irrigation costs, the fact of the matter is that water costs in California are generally low and savings of 8-12 inches are not normally considered as major reductions in operational expenses. Moreover, purposely imposing stress with RDI is considered a risk by most growers and the rewards must balance this risk. Again, water costs savings are not generally considered as reward enough for adopting RDI.

We recognize that implementing RDI is easiest when drip and microsprinkler irrigation is used. While these forms are rapidly replacing traditional surface and impact sprinkler systems in California, we need to document that RDI is possible with the conventional systems. This is why Site 8 was added to CARDIP.

Incentives for Grower Adoption

We believe that in the future, it's likely that growers will be compensated for actually reducing consumptive use by agencies that supply water. The scenario is that agencies that meet the growing demand from the urban sector due to an expanding population and environmental sectors will offer to pay growers for water that they currently apply to crops. Growers will be forced to consider whether the highest profit will be achieved by having their plants consume the water or selling it. If growers recognize that 8-10 inches can be saved using RDI without negatively impacting production and this water can add to their profit by being used elsewhere, RDI adoption is likely. We are not implying that all "saved" water will be sold. To the contrary, the growers will decide how they can better use this water by planting more acreage, for example.

Because estimates of consumptive use will be required in the above scenarios, we believe that remote sensing techniques that measure ET will be not only desirable but required in the future. Agencies such as NASA are currently working on aerial platforms could monitor surface energy much more frequently than the current 16-19 days with LANDSAT 5, making the use of remote sensing models of ET much more feasible. Thus, knowledge of how RDI impacts production, potential reductions in consumptive use, and developing remote sensing techniques to measure this on the farm will be of paramount importance in not only irrigation management of California's orchards and vineyards in the future but overall allocation to all water consuming sectors. This is why we are submitting our proposal that couples both RDI and remote sensing for Prop. 50 funding.

QUALIFICATIONS OF APPLICANTS AND COOPERATORS

Applicants

We believe that the objectives CARDIP can best be achieved with a coordinated effort by a team of University of California personnel comprised of faculty, Extension Specialists, and Farm Advisors plus recognized experts in remote sensing for determining ET on a tree, orchard, and regional scale. The team has published a total of 400+ water related publications in scientific journals. Resumes and selected relevant publications within the two page limit are shown in Appendix G. Each CARDIP has identified appropriate cooperators in the geographic region identified for their site. All members of this team have agreed on fundamental aspects of the field site development and operation, thus providing full coordination consistent with the freedom of the researchers to explore crop and site specific issues when needed.

The team is:
Dr. Richard Allen, Professor, University of Idaho, Moscow, assisted by Dr. Tasumi and graduate students
Mr. Mark Battany, Grape Farm Advisor, Cooperative Extension, San Luis Obispo Co.
Dr. Elias Fereres, Professor, IAS-CSIC and University of Cordoba, Spain, assisted by Dr. Francisco Villalobos, Luca Testi, and I. Lorite.
Dr. David A. Goldhamer, Water Management Extension Specialist, Kearney Ag. Center, Parlier
Dr. Scott Johnson, Pomology Extension Specialist, Kearney Ag. Center, Parlier
Mr. Terry Prichard, Water Management Specialist, Dept. of LAWR, San Joaquin Co.
Dr. Ken Shackel, Professor, Pomology Dept., UCD

Dr. Allen is an internationally recognized authority on ET and remote sensing. He was the senior author for the update of UN FAO 24, "Reference Evapotranspiration Factors" originally written by Doorenbos and Pruitt. Dr. Fereres has a team of colleagues and students in Spain that have wide experience in directly measuring ET on a tree, orchard, and regional scale. Both Drs. Allen and Fereres have been senior researchers on numerous water use and irrigation management projects, including those funded by Federal, State, and the EU.

Dr. Shackel has pioneered work in using stem water potential in irrigation management. His work with California's prune growers is well known. He developed a hand-held, "pump-up" type pressure chamber that is currently being manufactured by PMS Instrument Co., Corvallis, OR. Dr. Johnson built and manages the large weighing peach lysimeter at KAC that is vital for the remote sensing work we propose. He also is a well respected researcher in water use and management in peach, plum, and nectarines. Dr. Goldhamer is best known for his work on RDI in California's orchards. He also developed the ET (crop coefficients) values for walnut, pistachio, olive, and figs in California. Mr. Prichard has conducted a large part of the wine grape RDI work in California and is recognized as an expert in this field. Drs. Shackel, Johnson, Goldhamer, and Mr. Prichard have conducted numerous irrigation-related studies funded by Federal, State and commodity groups, including the peach, prune, citrus, fig, pistachio, olive, walnut, and wine grapes group in California.

Cooperators

Each of the grower/cooperators has agreed to allow the demonstration/research plots in their orchards/vineyards for the duration of the study. This is no small commitment. The cooperators not only provide land and services to us but take the production risk of potential negative impacts of stress on fruit yields and quality. Demonstration/research plots must be treated differently in terms of many farming practices, including irrigation and harvests. It's imperative that the cooperators avoid doing anything in the plots that would comprise the integrity of the experiments. Good communications with the researchers is a must. For example, if the grower is going to apply fertilizer through the drip/microsprinkler system, he must tell the researcher so that the experimental system is adjusted to insure that equal fertilizer in applied to all the irrigation treatments. The 2004 season has proved that our cooperators are committed to the project by their actions and excellent communication.

The grower/cooperators donate a variety of services, most notable those associated with the harvests. We estimate that this value is $ 6,000 to $15,000 per site. For example, our experimental plots are usually portions of tree/vine rows and thus, must be harvested separately from the bulk of the orchard/vineyard. This often involves harvested individual plants, taking gross weights, and fruit samples. This slows the harvesting process considerably. Moreover, the RDI treatments can influence crop maturity and thus, the experimental harvests occur outside the time when the grower normally has harvesting equipment/personnel in the field. After harvest, many of the cooperators arrange for industry-type analysis of the samples from each replication. This provides data that growers can directly understand.

Past projects have shown that if industry leaders adopt new technologies, the remainder of the industry is like to follow suit. Agreeing who cooperate with us shows that our cooperator/growers are interested in RDI and if its shown to be successful, will likely be the early adopters. We are fortunate to have some notable cooperators. CARDIP Sites 1 and 2 (almonds) are done in cooperation with Paramount Farming Co., Inc., the largest grower of almonds and pistachios in the US, likely the world. CARDIP Sites 6 and 7 (wine grapes) are with E. and J. Gallo and J. Lohr, two respected names in the wine industry. CARDIP Site 5 is with AgriWorld, Inc., as is the largest contiguous mature pistachio acreage (3500 acres) in the US, likely the world.

INNOVATION

We believe that the innovative demonstration/research aspects of our project have been adequately detailed in the above sections.

References

See Appendix H

Appendix A; Project Information Form

Appendix B; Signature Page

Appendix C-1; Budget

Appendix D; Existing CARDIP Site Plot Maps

Appendix E; Significant differences between SEBAL and METRIC

Appendix F; Regulated Deficit Irrigation Management for Orchards and Vineyards Draft Table of Contents

Appendix G; Resumes and Relevant Publication of Applicants

Appendix H; References

2004 Water Use Efficiency Proposal Solicitation Package
APPENDIX A: Project Information Form

Applying for: ☐ Urban ☒ Agricultural

1. (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: _____

2. (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): Dr. David A. Goldhamer, University of California, Davis

4. Project Title: California Regulated Deficit Irrigation Program and Remote Sensing to Quantify Evapotranspiration

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

Name, title	David A. Goldhamer Irrigation Management Specialist
Mailing address	University of California Kearney Agricultural Center 9240 South Riverbend Avenue Parlier, CA 93648
Telephone	559-646-6500
Fax.	559-646-6593
E-mail	dagoldhamer@ucdavis.edu

6. . Contact person (if different):

Name, title	
Mailing address	
Telephone	
Fax.	
E-mail	

7. Grant funds requested (dollar amount): *(from Table C-1, column VI)*	1,432,398
8. Applicant funds pledged (dollar amount):	1,453,600
9. Total project costs (dollar amount): *(from Table C-1, column IV, row n)*	2,885,998
10. Percent of State share requested (%) *(from Table C-1)*	49.6%
11. Percent of local share as match (%) *(from Table C-1)*	50.4%

1. 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?

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.

☐ (a) yes

☒ (b) no

12. Duration of project (month/year to month/year): **12/1/05 through 12/1/08**

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

Site 1 – District 30 – Parra
Site 2 – District 32 – McCarthy
Site 3 – District 2 – LaMalfa
Site 4 – District 34 – Maze
Site 5 – District 25 – Cogdill
Site 6 – District 10 – Nakanishi
Site 7 – District 33 - Blakeslee

14. State Senate District where the project is to be conducted:	**Site 1 – District 16 – Florez** **Site 3 – District 4 – Aanestaal** **Site 5 – District 14 –Poochigian** **Site 7 – District 15 - Maldonado**	**Site 2 – District 18 – Ashburn** **Site 4 – District 18 – Ashburn** **Site 6 – District 1 – Cox**
15. Congressional district(s) where the project is to be conducted:	**Site 1 – District 20 – Costa** **Site 3 – District 2 – Herger** **Site 5 – District 21 – Nunes** **Site 7 – District 22 – Thomas**	**Site 2 – District 22 – Thomas** **Site 4 – District 21 – Nunes** **Site 6 – District 11 – Pombo**

16. County where the project is to be conducted: **Kern, Fresno, Tulare, Madera, San Luis Obispo, San Joaquin, Tehama**

17. Location of project (longitude and latitude)

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

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

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

2004 Water Use Efficiency Proposal Solicitation Package
APPENDIX B: Signature Page

By signing below, the official declares the following:

The truthfulness of all representations in the proposal;

The individual signing the form has the legal authority to submit the proposal on behalf of the applicant;

There is no pending litigation that may impact the financial condition of the applicant or its ability to complete the proposed project;

The individual signing the form read and understood the conflict of interest and confidentiality section and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant;

The applicant will comply with all terms and conditions identified in this PSP if selected for funding; and

The applicant has legal authority to enter into a contract with the State.

_____	David A. Goldhamer, Irrigation Management Specialist	1/9/05
Signature	Name and title	Date

Table C-1. Project Costs

California Regulated Deficit Irrigation Program (CARDIP)

	Project Costs Yr. 1	Applicant Share Yr 1	State Share Yr. 1	Project Costs Yr. 2	Applicant Share Yr. 2	State Share Yr. 2	Project Costs Yr. 3	Applicant Share Yr. 3	State Share Yr. 3	Project Costs Total	Applicant Share Total	State Share Total
Salaries, Wages	**$312,000**	**204,000**	**108,000**	**316,000**	**204,000**	**112,000**	**320,000**	**204000**	**116,000**	**948,000**	**612,000**	**336,000**
Fringe Benefits	**124,800**	**81,600**	**43,200**	**126,400**	**81,600**	**44,800**	**128,000**	**81,600**	**46,400**	**379,200**	**244,800**	**134,400**
Supplies	**24,000**		**24,000**	**25,600**		**25,600**	**27,200**		**27,200**	**76,800**		**76,800**
Equipment	**49,000**	**41,000**	**8,000**	**8,000**		**8,000**	**8,000**		**8,000**	**65,000**	**41,000**	**24,000**
Grower/Cooperator In-Kind	**80,000**	**80,000**		**80,000**	**80,000**		**80,000**	**80,000**		**264,000**	**240,000**	**24,000**
Travel	**24,000**		**24,000**	**25,600**		**25,600**	**27,200**		**27,200**	**76,800**		**76,800**
Steering Committee	**6,000**		**6,000**	**6,000**		**6,000**	**6,000**		**6,000**	**18,000**		**18,000**
UC RDI Publication							**55,000**	**41,000**	**14,000**	**55,000**	**41,000**	**14,000**
UC Overhead (22%)	**45,144**		**45,144**	**47,080**		**47,080**	**52,096**		**52,096**	**144,320**		**144,320**
Total	**664,944**	**406,600**	**258,344**	**634,680**	**365,600**	**269,080**	**703,496**	**406,600**	**296,896**	**2,027,120**	**1,178,800**	**824,320**
Cost Share Percentage		**61.1**	**38.9**		**57.6**	**42.4**		**57.8**	**42.2**		**58.2**	**40.7**

Table C-1. Project Costs (continued)

Remote Sensing To Quantify ET

Salaries, Wages	28,000	10,000	18,000	28,000	10,000	18,000	28,000	10,000	18,000	54,000		54,000
Salaries, Wages**	62,280	30,000	32,280	63,960	30,000	33,960	58,785	30,000	28,785	185,025	90,000	95,025
Salaries, Wages***	68,560	26,000	42,560	68,560	26,000	42,560	68,560	26,000	42,560	205,680	78,000	127,680
Total Salaries	**158,840**	**66,000**	**92,840**	**160,520**	**66,000**	**94,520**	**155,345**	**66,000**	**89,345**	**474,705**	**198,000**	**276,705**
Fringe Benefits	11,200	4000	7,200	11,200	4000	7,200	11,200	4000	7,200	21,600		21,600
Fringe Benefits**	33,500	12,000	21,500	34,625	12,000	22,625	31,175	12,000	19,175	99,300	36,000	63,300
Fringe Benefits***	25,300	9,600	15,700	25,300	9,600	15,700	25,300	9,600	15,700	75,900	28,800	47,100
Total Benefits	**70,000**	**25,600**	**44,400**	**71,125**	**25,600**	**45,525**	**67,675**	**25,600**	**42,075**	**208,800**	**76,800**	**132,000**
LANDSAT Images									**25,000**	**25,000**		**25,000**
Supplies	**6,000**		**6,000**	**4,000**		**4,000**	**4,000**		**4,000**	**14,000**		**14,000**
Equipment**	20,940		20,940							20,940		20,940
Equipment***	11,180		11,180							11,180		11,180
Total Equipment	**32,120**		**32,120**							**32,120**		**32,120**
Travel	3,000		3,000	3,000		3,000	3,000		3,000	9,000		9,000
Travel**	3,000		3,000	3,000		3,000	1,800		1,800	7,800		7,800
Travel***	3,300		3,300	4,400		4,400	4,400		4,400	12,100		12,100
Total Travel	**9,300**		**9,300**	**10,400**		**10,400**	**9,200**		**9,200**	**28,900**		**28,900**
Overhead (22%)	**33,559**		**33,559**	**33,978**		**33,978**	**31,816**		**31,816**	**99,353**		**99,353**
Total	**309,819**	**91,600**	**218,219**	**280,023**	**91,600**	**188,423**	**293,036**	**91,600**	**201,436**	**882,878**	**274,800**	**608,078**
Cost Share Percentage		**29.6**	**70.4**		**32.7**	**67.3**		**31.3**	**68.7**		**31.1**	**68.9**

**Univ. of Idaho, including Dr. Allen for 1.5-2.5 months/yr.
***CSIC (Spain), including Dr. Fereres for 2 months/yr.

Table C-1. Project Costs (continued)

Overall Total Budget

Salaries,Wages	**470,840**	**270,000**	**200,840**	**476,520**	**270,000**	**206,520**	**475,345**	**270,000**	**205,345**	**1,422,705**	**810,000**	**612,705**
Fringe Benefits	**194,800**	**107,200**	**87,600**	**197,525**	**107,200**	**90,325**	**195,675**	**107,200**	**88,475**	**588,000**	**321,600**	**266,400**
Supplies	**30,000**		**30,000**	**29,600**		**29,600**	**31,200**		**31,200**	**90,800**		**90,800**
Equipment	**81,120**	**41,000**	**40,120**	**8,000**		**8,000**	**8,000**		**8,000**	**97,120**	**41,000**	**56,120**
Grower/Cooperator In-Kind	**80,000**	**80,000**		**80,000**	**80,000**		**80,000**	**80,000**		**240,000**	**240,000**	
Travel	**33,300**		**33,300**	**36,000**		**36,000**	**36,400**		**36,400**	**105,700**		**105,700**
Steering Committee	**6,000**		**6,000**	**6,000**		**6,000**	**6,000**		**6,000**	**18,000**		**18,000**
UC RDI Publication							**55,000**	**41,000**	**14,000**	**55,000**	**41,000**	**14,000**
UC Overhead (22%)	**78,703**		**78,703**	**81,058**		**81,058**	**83,912**		**83,912**	**243,673**		**243,673**
Total	**974,763**	**498,200**	**476,563**	**914,703**	**457,200**	**457,503**	**996,532**	**498,200**	**498,332**	**2,885,998**	**1,453,600**	**1,432,398**
Cost Share Percentage		**51.1**	**48.9**		**50.0**	**50.0**		**50.0**	**50.0**		**50.4**	**49.6**

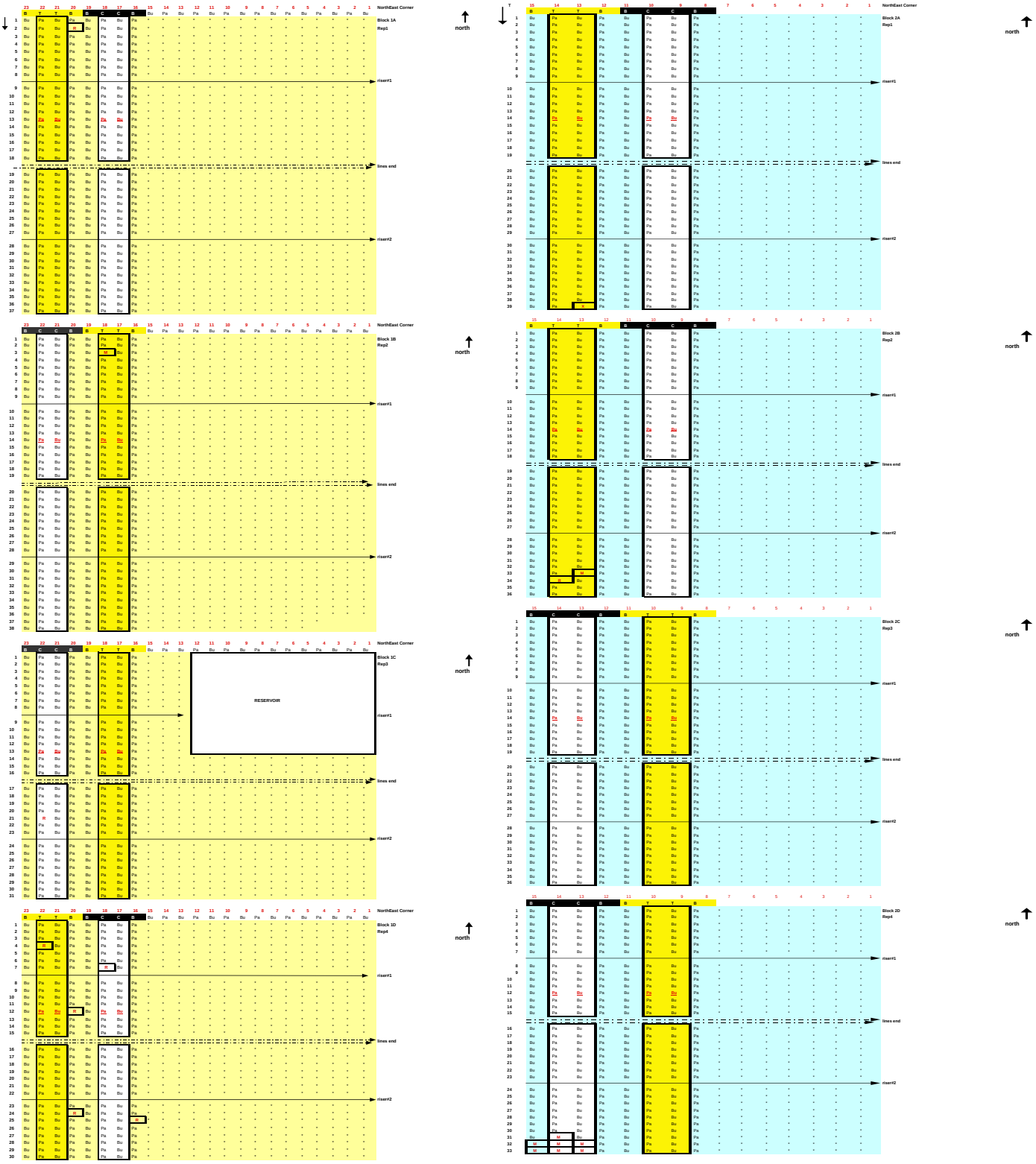
2004 Water Use Efficiency Proposal Solicitation Package
Appendix D; Existing CARDIP Site Plot Maps

Site1: West Valley Ranch Almond Experiment, Lost Hills, Kern Co. 2004 Plot Lay out

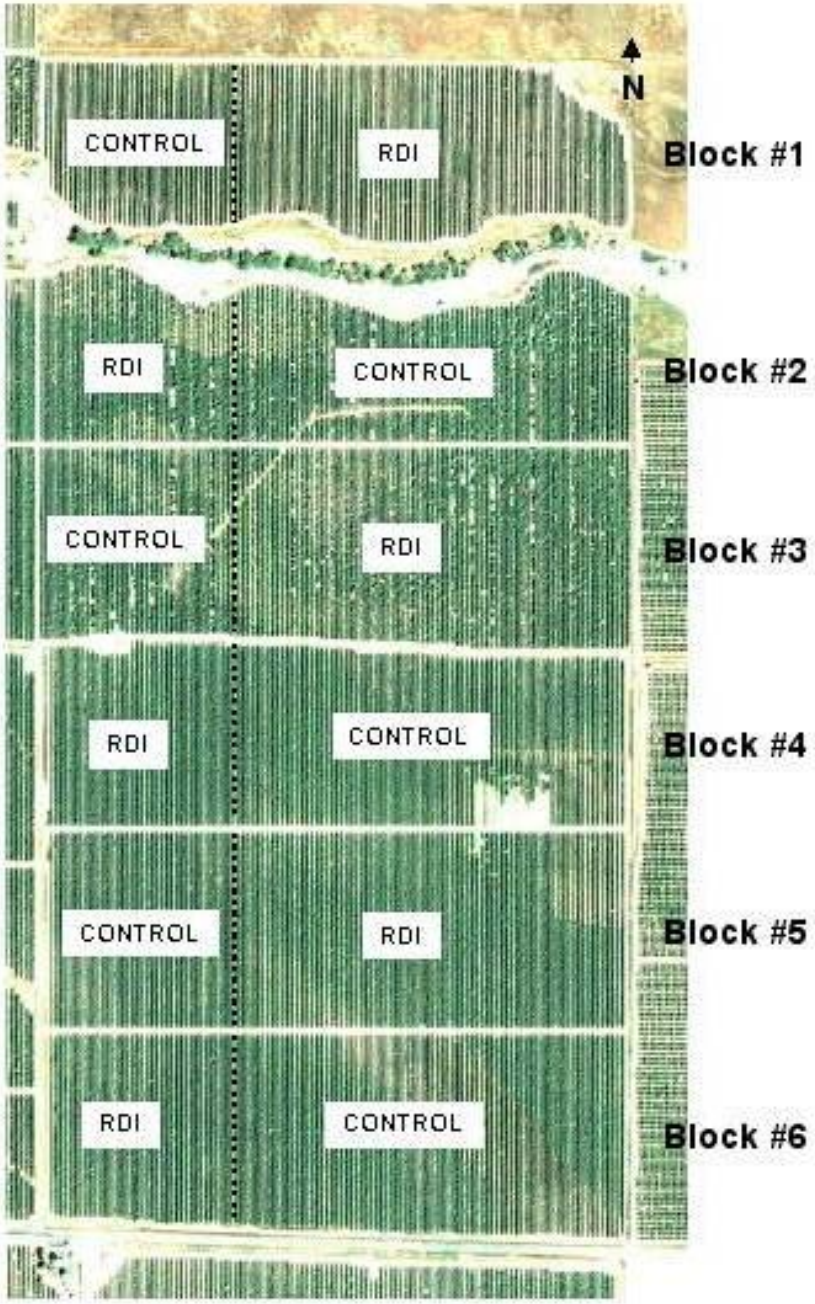
Site 2: High Density Almond Experiment, 2004 Plot Layout, Parmount Farming Co. McFarland, CA.

Low Density
21 x 24

High Density
18 x 22



Site 3:



Magnum Ranch, Lassen Land

Treatments:

Control – close to non-stressed baseline all season

RDI – moderate stress during hull split

Site 4: Strathmore RDI Citrus Plot layout 2004

	1	2	3	4	5	6	7	8	9	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	
	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
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	*	*	*	*	*	*							T	3			CT	RL			T	1			T	4			T	2		Rep. 1
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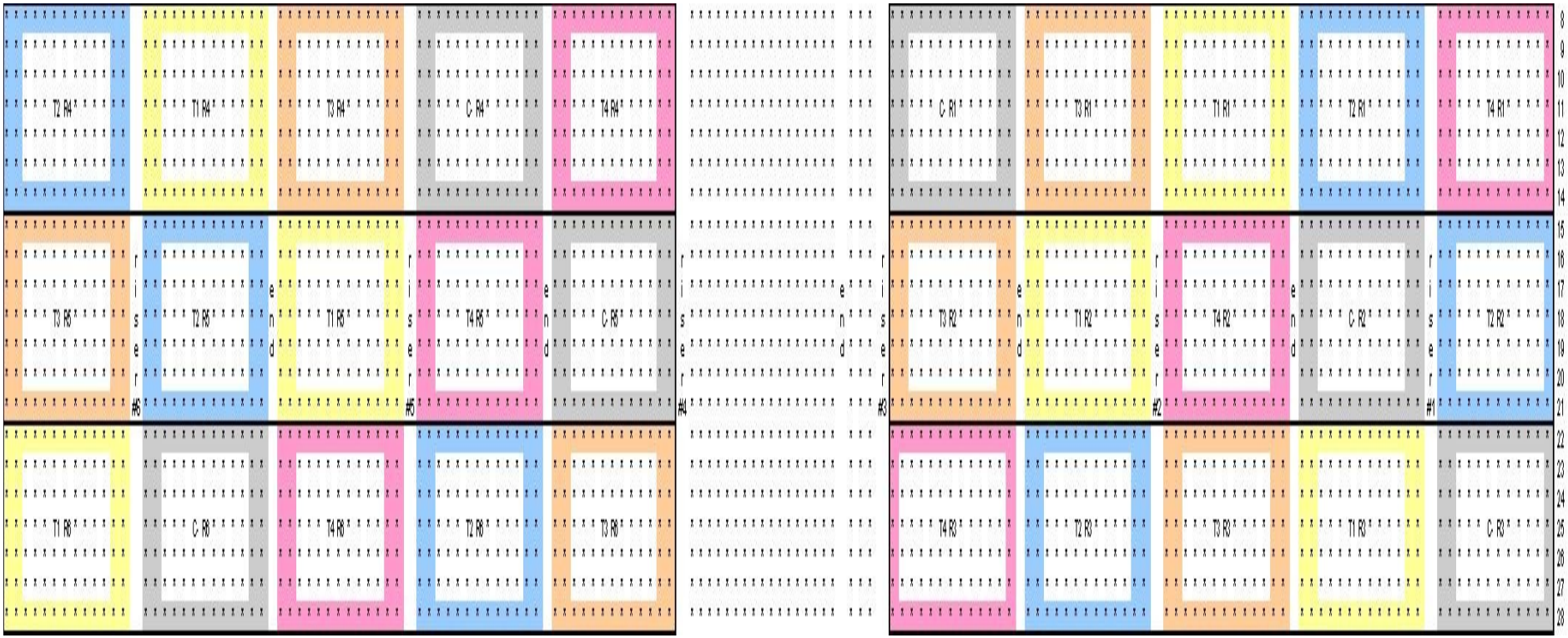
Site 5: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riser #5
riser #4
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riser #2
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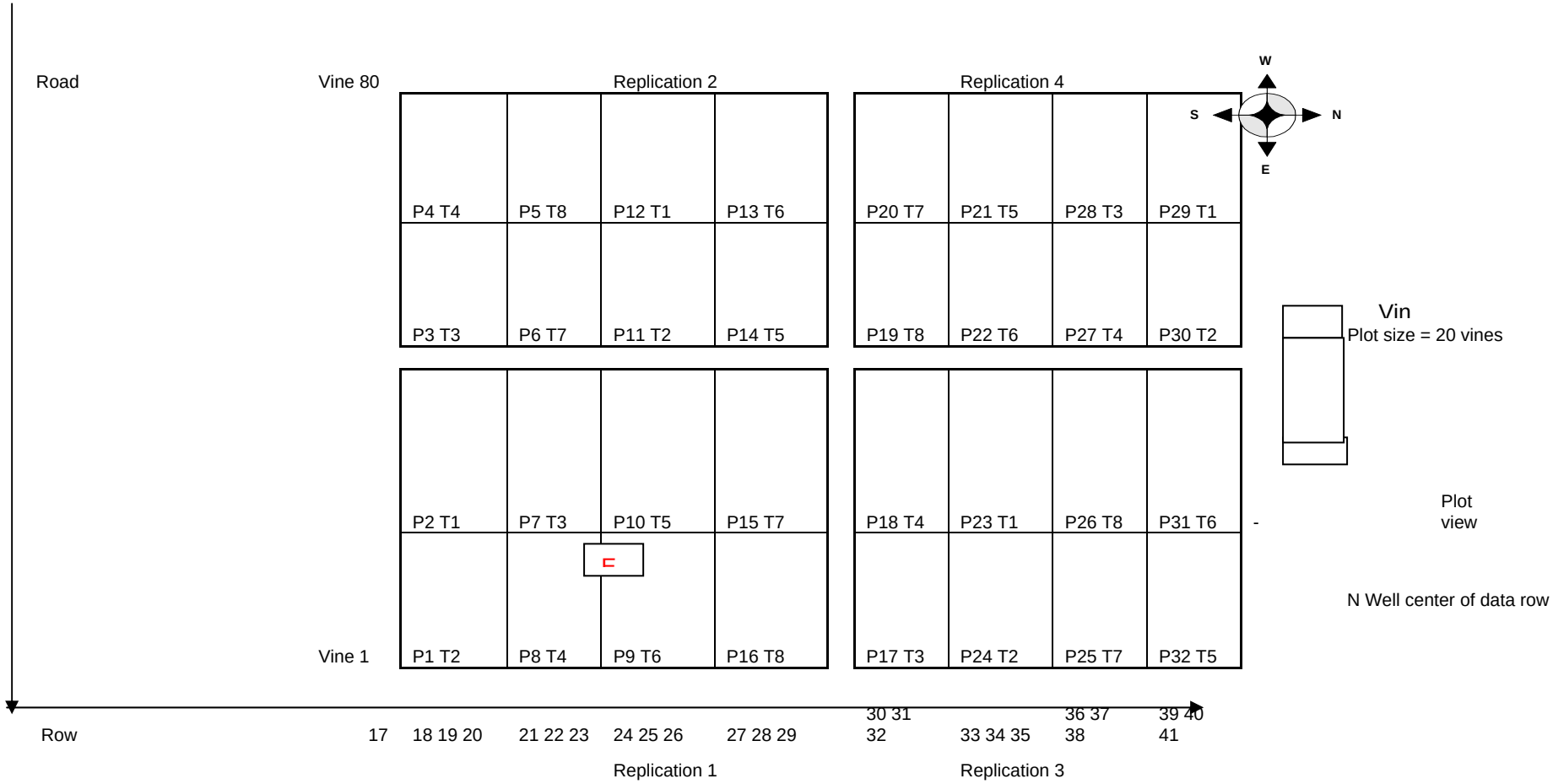
Site 6

Syrah 2004

4/27/2008



Road

		Treatment	Irrigation	Cluster	Shoot	Buds/spur	In Words Treatments
		1	1		x	2	Full Potential Irrigation, Shoot Thinning
Vine Sacing	5 ft	2	1	x		2	Full Potential Irrigation, Cluster Thinning
Row Spacing	11ft	3	2		x	2	-13 Threshold, 40% RDI, Shoot Thinning
		4	2	x		2	-13 Threshold, 40%RDI, Cluster Thinning
Emitter flow	.52 gph	5	3		x	2	-17 Threshold, 50% RDI, Shoot Thinning
2 emitters per vine		6	3	x		2	-17 Threshold, 50% RDI, Cluster Thinning
		7	3		x	1	-17 Threshold, 50% RDI, one bud spur,Shoot Thinning
		8	3	x		1	-17 Threshold, 50% RDI, one bud spur,Cluster Thinning

Site 7

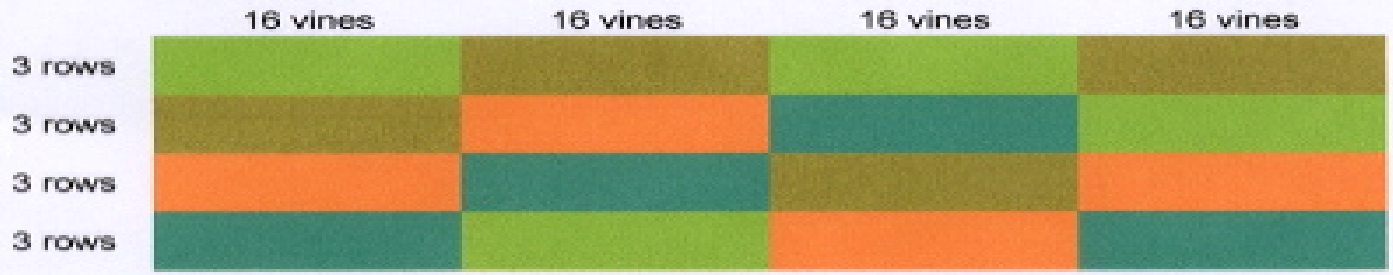
CARDIP Plot Design – Paso Robles Winegrapes

Location: J. Lohr Vineyard, just north of the Paso Robles Airport, near the intersection of Airport Road and Tower Road.

Description: Trial will be done in two blocks, one in Cabernet Sauvignon and one in Syrah, both on same rootstock. Vines are five years old and in full production. Both blocks are drip irrigated with the same source and schedule; a weather station is on site to determine local ETo.

Additional Funding: Research in the Syrah block is funded by a grant from the American Vineyard Foundation to study "Syrah Disorder", a physiological problem that may be related to excessive deficit irrigation. Research equipment purchased under this grant (porometer, chlorophyll meter, etc.) will be shared between blocks. Additional funding from AVF will be used to study canopy temperatures relative to water stress in the Cabernet Sauvignon block.

Block layout for each variety:



	Set-Veraison	Veraison-Harvest
Treatment 1:	75% ETc	75% ETc
Treatment 2:	60% ETc	60% ETc
Treatment 3:	45% ETc	45% ETc
Treatment 4:	45% ETc	~30% ETc

Sampling:

Weekly	Continuously	Monthly	Harvest
Leaf W.P. (diurnal)	Sap flow (Syrah)	Photosynthesis	Fruit ripening
Porometer (diurnal)	Leaf temperature		Fruit quality
Leaf Chlorophyll	Soil moisture		Juice analysis
Tissue nutrients	Irrigation operation		

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Appendix E: On the differences between the METRIC and SEBAL procedures for the assessment of ET via remote sensing.

Various theoretical and computational approaches of SEBAL and METRIC™ are described in Bastiaanssen et al., (1998), Bastiaanssen (2000), Morse et al., (2000) and Tasumi et al. (2004). By using an energy balance at the surface, energy consumed by the ET process is calculated as a residual of the surface energy equation:

$$LE = R_n - G - H \qquad (1)$$

where LE is the latent energy consumed by ET, R_n is net radiation (sum of all incoming and outgoing shortwave and longwave radiation at the surface), G is sensible heat flux conducted into the ground, and H is sensible heat flux convected into the air. The utility of using energy balance is that actual ET rather than potential ET (based on amount of vegetation) is estimated, so that reductions in ET caused by shortage of soil moisture are captured. Of course, the estimate of LE is only as accurate as the estimates of R_n, G, and H. The algorithms used in METRIC™ for R_n and G are similar to those described for SEBAL by Bastiaanssen et al. (1998) and the reader is referred there and to Tasumi et al. (2004) for detail. Basically, R_n is computed from satellite-measured broad-band reflectances and surface temperature, G is estimated from R_n, surface temperature, and vegetation indices, and H is estimated from surface temperature ranges, surface roughness, and wind speed using buoyancy corrections.

METRIC™ differs from SEBAL principally in how the "H function" is calibrated for each specific satellite image. In both METRIC™ and SEBAL, H is predicted from an aerodynamic function where:

$$H = \rho C_p \frac{dT}{r_{ah}} \qquad (2)$$

where ρ is air density, C_p is specific heat of air at constant pressure, and r_{ah} is aerodynamic resistance between two near surface heights (generally 0.1 and 2 m) computed as a function of estimated aerodynamic roughness of the particular pixel and using wind speed extrapolated to some blending height above the ground surface (typically 100 to 200 m), with an iterative stability correction scheme based on the Monin-Obhukov functions. The dT parameter represents the near surface temperature difference between the two near surface heights. Because of the difficulties in estimating surface temperature (T_s) accurately from satellite due to uncertainties in atmospheric attenuation and contamination and radiometric calibration of the sensor, dT is estimated as a relatively simple linear function of T_s:

$$dT = a + b\,T_s \qquad (3)$$

Bastiaanssen (1995) and Bastiaanssen et al. (2004) provide rationale and empirical evidence for using the linear relation between dT and T_s. The application of (3) appears to extend well across

a range of surface roughnesses, because as roughness increases and r_{ah} reduces, given the same H, dT reduces due to more efficient transfer of H, and T_s reduces for the same reason.

In most applications of SEBAL (Bastiaanssen et al., 1998), parameters a and b in (3) are computed by setting dT = 0 when T_s is at the surface temperature of a local water body (or in its absense, a well vegetated field) where H is expected to be zero, and by setting $dT = (H\ r_{ah})/(\rho\ C_p)$ at T_s of a "hot" pixel that is dry enough that one can assume that LE = 0. From (1) and (2), $dT = ((R_n\text{-}G)\ r_{ah})/(\rho\ C_p)$ at the "hot" calibration pixel. In METRIC™, the same approach and assumptions are made for the hot pixel as in SEBAL, although a daily surface soil water balance is run for the hot pixel to confirm that ET = 0 there or to supply a nonzero value for ET for the hot pixel for calibration of (3). For the lower calibration point of dT in METRIC™, a well vegetated pixel having relatively cool temperature is selected and dT at that pixel is calculated as:

$$dT = \frac{(R_n - G - k\ ET_r)\ r_{ah}}{\rho C_p} \qquad (4)$$

The a and b coefficients are determined using the two values for dT paired with the associated values for T_s. With Landsat images, fields of alfalfa or other high leaf area vegetation can generally be identified that are close to or at full cover, so that the ET from these fields can be expected to be near the value of "reference ET" (ET_r) computed for an alfalfa reference. In METRIC™, we use the standardized ASCE Penman-Monteith equation for alfalfa reference (ASCE-EWRI 2002), which is typically 20 to 30 percent greater than grass reference ET (ET_o). The k factor in (4) is set to 1.05 because we assume that a viewed field having high vegetation and colder than average temperature, as compared to other high vegetation fields, will have ET that is about 5% greater than ET_r due to higher surface wetness or merely due to its rank within the population of alfalfa fields (or other highly vegetated areas). Generally, METRIC™ is applied without crop classification, so that specific crop type is generally not known.

The aerodynamic resistance, r_{ah}, varies with the value assigned to aerodynamic roughness for heat transport, z_{oh}. In classical applications of SEBAL, z_{oh} is predicted for all surfaces as a function of vegetation index derived from the satellite image. In METRIC, z_{oh} is predicted for agricultural crops as a function of vegetation index or, in some situations, as a function of the ratio of vegetation index to albedo (reflectance) to create more separation among types of vegetation. The vegetation index basis for z_{oh} is used to keep METRIC (and SEBAL) crop classification-free, as routine crop classification can be expensive. METRIC generally distinguishes trees during assignment of z_{oh}, and assigns a value representing the average roughness expected for a particular tree species. Definition of tree species is based on a land use map showing general spatial distribution of tree species. For application of METRIC to orchard and vine crops under this study, locations of specific orchards and vineyards of interest will be identified and nominal tree or vine spacing, ground-cover fraction and height documented using field observations. This will enable field specific values of z_{oh} to be assigned using standardized relations (of spacing, ground-cover and height) from the literature. These relations will be

adjusted according to the experimental results from years 1 and 2 as a means to calibrate METRIC for routine application to orchards and vineyards in California.

METRIC™ and SEBAL, when applied with Landsat images, differ in how ET for the adjoining 24-h period is estimated. With satellite-based remote sensing, 24-h ET must be estimated using the instantaneous ET calculated at the time of the satellite image (generally during late morning). In SEBAL, the evaporative fraction (EF), defined as the ratio of ET to (R_n-G), is assumed to be the same at both the observation time and for the 24-h period. The assumption of constant EF can underpredict 24-h ET in arid climates where afternoon advection of hot, dry air into irrigated areas can occur and where wind speeds may increase during afternoon. Both of these effects increase ET for the 24-h period relative to R_n-G. In METRIC™, the extrapolation from observation time to the 24-h period is done using the fraction of reference ET (ET_rF) rather than EF. ET_rF is defined as the ratio of ET to ET_r (in the case of METRIC™, we use an alfalfa reference for ET_r), and is essentially the same concept as the well-known crop coefficient, K_c, method. The assumption of constant ET_rF during a day may be better able to capture impacts of advection and changing wind and humidity conditions during the day, since these impacts are expressed in the ET_r calculation (which is done hourly and summed daily).

Trezza (2002) and Romero (2004) demonstrated the general validity of constant ET_rF during a day using lysimeter data from Kimberly. Example plots of both EF and ET_rF for 24-h periods vs. EF and ET_rF for the instantaneous satellite time are shown in Figure 1 for clipped fescue grass and sugar beet crops grown at Kimberly, Idaho during 1989. The days shown are days having Landsat 5 images. The comparisons show more consistency between ET_rF_{24} and ET_rF_{inst} (i.e., $ET_rF_{24} \approx ET_rF_{inst}$), especially for the sugar beet crop, whereas, often, $EF_{24} > ET_{inst}$ due to the impacts of advection during afternoon.

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APPENDIX F: Regulated Deficit Irrigation Management for Orchards and Vineyards Draft Table of Contents

Regulated Deficit Irrigation Management for Orchard and Winegrape Crops

I. History of RDI

II. Tree Physiology in Relation to Water Use

- A. Crop Responses to Stress.
- B. Water Use.
- C. Root Volume Effects.
- D. Fruit Quality Effects.

III. Irrigation Management Under RDI.

- A. RDI Triggers
  1. Atmospheric.
  2. Soil Based.
  3. Plant Based.
- B. Adjusting RDI to Environmental Conditions and Irrigation Methods.
- C. Effects of RDI on salinity and water tables.
- D. Effects of RDI on Pests and Diseases.

IV. RDI Strategies for Specific Crops

- A. Peach, Plum, and Nectarine.
- B. Prunes.
- C. Apples.
- D. Pears.
- E. Almonds.

F. Pistachio.

G. Walnuts.

H. Citrus.

I. Olives.

J. Red Grape Varieties.

K. White Grape Varieties.

2004 Water Use Efficiency Proposal Solicitation Package
Appendix G: Resumes and Relevant Publication of Applicants

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AREAS OF SPECIALIZATION:
Hydrology and Water Resources – Surface and Subsurface Systems, Remote Sensing
Evapotranspiration –Prediction, Measurement, Wetlands, Crop Water Requirements
Irrigation – Water Management, Demands, System Design, Electronic Instrumentation

DEGREES:
B.S. Agricultural Engineering, Iowa State University, November 1974
M.S. Agricultural Engineering, University of Idaho, June 1977
Ph.D. Civil Engineering, University Idaho, May 1984

PROFESSIONAL REGISTRATION:
Civil Engineer, State of Idaho, #4351, July 1981

PROFESSIONAL POSITIONS:
Professor of Civil Engineering and Biological and Agricultural Engineering, December 1998 to Present. University of Idaho.
Professor of Biological and Irrigation Engineering, May 1998 to December 1998. Utah State University.
Assistant/Associate Professor of Biological and Irrigation Engineering, January 1986 to April 1998. Utah State University.
Assistant Professor of Civil Engineering, January 1984 to December 1985. Iowa State University, Ames, IA.
Research Associate, May 1977 to December 1983. University of Idaho, Kimberly Research and Extension Center.

PROFESSIONAL ORGANIZATIONS:
American Society of Civil Engineers:
Evapotranspiration Technical Committee
International Commission on Irrigation and Drainage
U.S. Representative to the Working Group on Sustainable Crops and Water Use
U.S. Committee on Irrigation and Drainage
Ex-officio Member of the National Board of Directors
American Geophysical Union
Irrigation Association - ***Water Management Committee***

PUBLICATIONS

Hargreaves, G.H. and R.G. Allen. 2003. History and evaluation of the Hargreaves evapotranspiration equation. *J. Irrig. and Drain. Engrg.*, ASCE. 129(1):53-63.

Allen, R.G. 2003. Crop Coefficients. Chapter in the Water Encyclopedia. Dekker. 10 p.

Irmak, S., A. Irmak, J. Jones, T.A. Howell, J. Jacobs, R.G. Allen, A. Hoogenboom. 2003. Predicting Daily Net Radiation Using Minimum Climatological Data. *J. Irrig. and Drain. Engrg*., ASCE. 129(4):256-269.

Irmak, S., A. Irmak, R.G. Allen, and J. Jones. 2003. Solar and Net radiation-Based Equations to Estimate Reference Evapotranspiration in Humid Climates. *J. Irrig. and Drain. Engrg*., ASCE. 129(5):336-347.

Irmak, S., R.G. Allen, and E. B. Whitty. 2003. Daily Grass and Alfalfa-Reference Evapotranspiration Estimates and Alfalfa-to-Grass Evapotranspiration Ratios in Florida. *J. Irrig. and Drain. Engrg*., ASCE. 129(5):360-370.

Itenfisu, D. R.L. Elliott, R.G. Allen, I.A. Walter. 2003. Comparison of Reference Evapotranspiration Calculations as a Part of the ASCE Standardization Effort. *J. Irrig. and Drain. Engrg.*, ASCE. 129(6):440-448.

Payero, J.O., C.M.U. Neale, J.L. Wright, and R.G. Allen. 2003. Guidelines for validating Bowen ratio data. *Trans. ASAE* 46(4): 1051-1060.

Allen, R.G. 2003. Soil Physics and Hydrology: Penman-Monteith Equation. Chapter entry in the Water Encyclopedia (manuscript no. 399). Elsevier Science, London. 17 p (accepted for publication)

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Allen, R.G., Clemmens, A.J., Burt, C.M., Solomon, K., and O'Halloran, T. 2004. Prediction Accuracy for Project-wide Evapotranspiration using Crop Coefficients and Reference Evapotranspiration. *J. Irrig. and Drain. Engrg,* ASCE (accepted for publication).

Mutziger, A.J., C.M. Burt, D.J. Howes, and R.G. Allen. 2004. Comparison of Measured and FAO-56 Modeled Evaporation from Bare Soil. *J. Irrig. and Drain. Engrg,* ASCE (accepted for publication).

Montague, T. R. Kjelgren, and R. Allen. 2004. Water Loss Estimates for Five Newly Transplanted Landscape Tree Species in an Arid Climate. *J. Amer. Soc. Hort. Sci.*. (accepted for publication)

Bastiaanssen , W.G.M., E.J.M. Noordman , H. Pelgrum, G. Davids, B.P. Thoreson and R.G. Allen. 2004. Use of SEBAL model with remotely sensed data to improve water resources management under actual field conditions. *J. Irrig. and Drain. Engrg,* ASCE (accepted for publication).

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UNIVERSITY EDUCATION

Master of Science, University of California at Davis**,** 1997; Major in **Hydrologic Sciences**.
Thesis Title: *Rainfall simulator development and use to determine the runoff and erosion characteristics of a hillside vineyard.*
Bachelor of Science, Colorado State University, 1994; Major in **Agronomy**, Minor in **Spanish**.

ACADEMIC HONORS

Fulbright Fellowship
National Defense Science and Engineering Graduate Fellowship
Graduated Summa Cum Laude, Colorado State University
Colorado State University President's Scholarship, three awards
Tucker, Steinwald, and DeRicqles Memorial Scholarships, Colorado State University
Outstanding Junior and Senior in Agronomy, Colorado State University

WORK EXPERIENCE

Farm Advisor, Viticulture/Soils
University of California Cooperative Extension, San Luis Obispo, CA. Aug. 2001- present
Farm Advisor for 50,000 acres of grapes in San Luis Obispo and Santa Barbara Counties.

Technical Representative
Adcon Telemetry, Santa Rosa, CA. 2000-2001
Advised clients on weather station hardware, software, irrigation & disease modeling.

Research Scientist/Fulbright Scholar
Institute of Sustainable Agriculture, Cordoba, Spain. 1998- 2000
Conducted olive grove rainfall-runoff investigations, focusing on development of field research equipment, and modeled the olive grove water budget as affected by cover crops.

Teaching Assistant
Principles of Hydrologic Science, UC Davis. 1995- 1996
Irrigation Principles and Management, UC Davis. 1995- 1996
General Genetics, Colorado State Univ. 1993- 1994
Assisted teaching lab classes, graded coursework, and tutored students.

Research Technician
Dept. of Agronomy, Colorado State University. 1992- 1993
Sampled soils for nitrogen studies, maintained greenhouse plants for genetic studies.
AgriPro Seeds Winter Wheat Division, Berthoud, CO. 1991
Conducted disease resistance trials, harvested regional test plots.

Farm Worker
Dexter Farm, Boulder, CO. 1988- 1990
Raised fresh market vegetables and greenhouse crops.

Squadleader
United States Marine Corps, 1984-1988

ELIAS FERERES
Instituto de Agricultura Sostenible (CSIC)
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ELIAS FERERES is Professor of Agronomy in the School of Agricultural and Forestry Engineering, University of Córdoba, Spain, and Researcher at the Institute of Sustainable Agriculture, Scientific Research Council of Spain (IAS-CSIC), Cordoba, Spain.

He was trained as an agricultural engineer (University of Madrid, 1969; doctoral degree, 1977) and has a Master degree (Irrigation, 1974) and a Ph. D. (Ecology, 1976) from the University of California, Davis. From 1976 to 1982 he was a Lecturer at the Department of Land, Air and Water Resources, University of California, Davis, and Irrigation and Surface Water Specialist in Cooperative Extension, working on statewide extension programs on agricultural water management and conservation. In 1982 he returned to Spain as Professor of Agronomy at the University of Cordoba, Spain. Between 1983 and 1991, he collaborated with the Ministry of Education and Science on various tasks related to the evaluation of research performance. In 1991, he was appointed President of the Higher Council of Scientific Research (CSIC), the largest research organization of Spain. In 1992, he was promoted to Secretary of State for Universities and Research of the Government of Spain where he worked until September of 1994. He was Director of the Institute of Sustainable Agriculture, 1996-2000 (CSIC, Cordoba, Spain). In 1998, he was appointed member of the Technical Advisory Committee of the Consultative Group of International Agricultural Research (CGIAR), until 2003. He has been President of the European Society of Agronomy (2000-2002) and President (1995-2003) of the Spanish Royal Academy of Engineering, of which he is a founding member. He is also a member of the Academia Europaea.

His areas of expertise relate to the role of water in agricultural systems. Mayor activities in private consulting for national and international agencies have been on agronomy, water and the environment, irrigation engineering, agricultural water requirements, water management and conservation and on irrigation scheduling. Current research interests are focused on the sustainability of water-limited agriculture and include topics such as soil and water conservation, irrigation water management, use of plant sensors and simulation models for irrigation scheduling, deficit irrigation strategies for horticultural crops, adaptation of plants to water deficits, and efficient use of limited water supplies in drought situations. He has taught graduate and post-graduate courses on agricultural systems, irrigation and crop ecology and has directed 27 doctoral theses. He has published over 150 papers in refereed journals and book chapters, including chapters in both the American Society of Agronomy and the American Society of Agricultural Engineering irrigation monographs, and over 200 publications on technical issues and reports.

PUBLICATIONS LIST

FERERES, E. and A. KASSAM. 2003. Water and the CGIAR: A Strategic Framework. Water International 28(1):122-129.

FERERES, E., D.A. GOLDHAMER and L.R. PARSONS. 2003. Irrigation Water Management of Horticultural Crops. Historical Review Compiled for the American Society of Horticultural Science's 100th Anniversary. HortScience 38(5):1036-1042.

GOLDHAMER, D.A., and E. FERERES. 2003. The Promise of Regulated Deficit Irrigation in California's orchards and Vineyards. Water Conservation News, April 2003:6-9.

GOLDHAMER, D.A., E. FERERES and M. SALINAS. 2003. Can almond trees directly dictate their irrigation needs?. California Agriculture 57(4):138-144

GÓMEZ, J.A., M . BATTANY, C.S RENSCHLER and E. FERERES. 2003. Evaluating the impact of soil management on soil loss in olive orchards. Soil Use and Management 19:127-134.

LORITE, I., L. MATEOS y E. FERERES. 2003. Aplicación de un modelo de simulación a la evaluación de una zona regable. Ingeniería del agua, 10(4):517-525.

MORIANA, A., F. ORGAZ, M. PASTOR and E. FERERES. 2003. Yield Responses of Mature Olive Orchard to Water Deficits. Journal of the American Society for Horticultural Science 123(3):425-431.

SORIANO, M.A., and E. FERERES. 2003. Use of crops for *in situ* phytoremediation of polluted soils following a toxic flood from a mine spill. Plant and Soil 256:253-264.

FERERES, E., and D.J. CONNOR. 2004. Sustainable water management in agriculture. In: Challenges of the New Water Policies for the XXI Century. (Eds. E.Cabrera and R. Cobacho) pp:157-170. A.A. Balkema Publishers, Lisse, The Netherlands.

GOLDHAMER, D.A., and E. FERERES. 2004. Irrigation scheduling of almond trees with trunk diameter sensors. Irrigation Science, 23:11-19.

LORITE, I., L. MATEOS and E. FERERES. 2004. Evaluating irrigation performance in a Mediterranean environment. I. Model and general assessment of an irrigation scheme. Irrigation Science, 23:77-84.

LORITE, I., L. MATEOS and E. FERERES. 2004. Evaluating irrigation performance in a Mediterranean environment. II. Variability among crops and farmers. Irrigation Science, 23:85-92.

LORITE, I., L. MATEOS and E. FERERES. 2004. Impact of spatial and temporal aggregation of input parameters on the assessment of irrigation scheme performance. Journal of Hydrology, **In press**

MORIANA, A., and E. FERERES. 2004. Establishing Reference Values of Trunk Diameter Fluctuations and Stem Water Potential for Irrigation Scheduling of Olive Trees. Acta Horticulturae 537:293-297.

KASSAM, A.H., H.M. GREGERSEN, E. FERERES, E.Q. JAVIER, R.R. HARWOOD, A. DE JANVRY and M.M. CERNEA. 2004. A framework for enhancing and guarding the relevance and quality of science: The case of the CGIAR. Expl. Agric, 40:1-21.

FERERES, E. 2004. Water Limited Agriculture: Introduction. Guest Editor of a Special Issue. European Journal of Agronomy, 21:399-401.

SORIANO, M.A., F. ORGAZ, F. VILLALOBOS and E. FERERES. 2004. Efficiency of water use of early planting of sunflower. European Journal of Agronomy, 21:465-476.

CONNOR D.J., and E. FERERES. 2005 The Physiology of Adaptation and Yield Expression in Olive. In: Horticultural Reviews (31). (Eds. R. Darnell, I.B. Ferguson and S.C. Hokanson) pp:155-229. John Wiley & Sons, New Jersey.

ORGAZ, F., M.D. FERNANDEZ, S. BONACHELA, M. GALLARDO and E. FERERES. 2005. Evapotranspiration of horticultural crops in an unheated plastic greenhouse. Agricultural Water Management, (in press).

Curriculum vitae

Name: David Goldhamer

Title: Water Management Specialist
Department of Land, Air, and Water Resources
University of California, Davis

Contact Information: Kearney Agricultural Center
9240 South Riverbend Avenue
Parlier, CA 93648
Phone: 559-646-6575
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Degrees: B.S., Soil and Water Science, UC Davis, 1971
M.S., Water Science, UC Davis, 1974
Ph.D., Soil Science, UC Davis, 1980

Research Statement:
There continues to be high demand for information on optimizing irrigation for California's tree fruit and nut orchards. It's clear that while weather-induced droughts will continue to be a periodic problem for tree and vine growers, institutional-related droughts due to demand from municipal and environmental interests must also be addressed. My applied research program deals with developing information on regulated deficit irrigation (RDI). This technique purposely stresses trees at stress-tolerant periods of the season in order to both save water and not lessen but rather possibly enhance grower profit by improved fruit quality. It is a true savings of water (reduced consumptive use). Additionally, I'm working on plant-based electronic sensors that detect water stress in order that RDI be more precisely imposed.

International Experience:

TURKMENISTAN
1998 Flood Irrigation/Water Control/Water Users Groups. Charchow, Turkmenistan, USAID/ACDI.
Part of a two-man team charges with improving cotton irrigation practices in the Charchow area. Assignment included meeting with local irrigation district personnel and farm water managers, discussing current practices and developing strategies for improvement, organized and presented a field day on how to assess soil moisture and manage furrow irrigation most efficiently. Field day included regional governor and other political officials.

MACEDONIA
1994 Potential of Drip Irrigation in Macedonia. Skopje, Macedonia, USAID/ACDI.
1996 Adoption of Drip Irrigation in Macedonia. Bitola, Macedonia, USAID/ACDI.
Completed 3 week assignment for Volunteers in Overseas Cooperative Assistance (VOCA) providing expertise in drip irrigation. Assignment was to address poor irrigation practices

on tree fruit. Established drip irrigated test plot in apple orchard to test both effectiveness of technique and usefulness of "dirty water" emitter manufactured in U.S. to overcome clogging problem due to high iron content in the water. Returned to site two years later as part of another VOCA assignment to evaluate effectiveness of the plot.

PUBLICATIONS

M. Cohen, D. A. Goldhamer, E. Fereres, J. Girona, and M. Mata. 2001. Assessment of peach tree responses to irrigation water deficits by continuous monitoring of trunk diameter changes. J. Hort. Sci. and Biotech 76(1):55-60.

Goldhamer, D. A. and E. Fereres. 2001. Irrigation scheduling protocols using continuously recorded trunk diameter measurements. Irrig. Sci. 20:115-125.

Girona, J, M. Mata, E. Fereres, D. A. Goldhamer, and M. Cohen. 2002. Evapotranspiration and soil water dynamics of peach trees under water deficits. Agricultural Water Management 54:107-122.

Goldhamer, D.A., T.J. Michailides, and D.P. Morgan. 2002. Buried drip irrigation reduces fungal disease in pistachio orchards. California Agriculture 56(4):133-138.

Goldhamer, D.A., M. Salinas, C. Crisosto, K.R. Day, M. Soler, and A. Moriana. 2002. Effects of regulated deficit irrigation and partial root zone drying on late harvest peach tree performance in Proceedings of the 5th International Society on Peach. Acta Hort 592, p. 343-350.

Fereres, E. and D.A. Goldhamer, D. A. 2003. Suitability of stem diameter variations and water potential as indicators for irrigation scheduling of almond trees. J. Hort Sci and Biotech. 78(2):139-144.

Goldhamer, D.A., E. Fereres, and M. Salinas. 2003. Can almond trees directly dictate their irrigation needs? California Agriculture 57(4):138-144.

Goldhamer, D.A. 2003. Irrigation Scheduling with Plant Indicators: Field Applications in Encyclopedia of Water Science. Marcel Dekker, Inc. pp. 512-518.

Goldhamer, D.A. 2003. Irrigation Scheduling with Plant Indicators: Measurement in Encyclopedia of Water Science. Marcel Dekker, Inc. pp. 519-522.

Fereres, E., D. A. Goldhamer, L. R. Parsons. 2003. Irrigation water management of horticultural crops. HortSci. 38(5): 1036-1042.

Goldhamer, D.A. and E. Fereres. 2004. Irrigation scheduling of almond trees with trunk diameter sensors. Irrigation Science 23:11-19.

Goldhamer, D. A. and R.H. Beede. 2004. Regulated deficit irrigation effects on yield, nut quality and water-use efficiency of mature pistachio trees. J. Hort. Sci. and Biotech. 79(4):538-545.

Goldhamer, D.A., M. Viveros, and M. Salinas. 2004. Regulated deficit irrigation in almonds: effects of variations in irrigation amounts and in stress timing on yield and yield components. (In Press)

Goldhamer, D.A. and Beede, R.H. Effects of water stress on olive tree performance in Olive Production Manual, UC-DANR Publication 3353. S. Sibbett and L. Ferguson (eds.) (In Press)

Beede, R.H. and D.A. Goldhamer. Olive Irrigation Management in Olive Production Manual, UC-DANR Publication 3353. S. Sibbett and L. Ferguson (eds.) (In Press)

Goldhamer, D.A. 2005. Irrigation management in Pistachio Production Manual. L. Ferguson (ed.). (Accepted)

Goldhamer, D.A. and B. Faber. 2005. Irrigation in Citrus Production Manual. L. Ferguson (ed.). (Accepted)

R. Scott Johnson
Pomologist

Personal Data: Date of Birth: March 26, 1953
Place of Birth: Salt Lake City, Utah
Marital Status: Married, 4 children

Office Address: U. C. Kearney Agricultural Center
9240 S. Riverbend Avenue
Parlier, California 93648
Phone: 559/646-6547
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Education: B.S., Biology, 1977, University of Utah
Ph.D., Pomology, 1982, Cornell University

Experiences:

1982-1988	Associate Extension Specialist University of California, Davis at Kearney Agricultural Center
1988-present	Extension Specialist University of California, Davis at Kearney Agricultural Center

Research Interests

Research interests include field projects on irrigation, nutrition, thinning, rootstocks and training systems of peaches, plums, nectarines, apples and kiwifruit. The emphasis has been on developing cultural practices which improve fruit size and yield efficiency, enhance fruit quality and are environmentally sound.

PUBLICATIONS RELEVANT TO
IRRIGATION AND WATER MANAGEMENT

1. Larson, K.D., T.M. DeJong, and R.S. Johnson. 1988. Physiological and growth responses of mature peach trees to postharvest water stress. Journal of the American Society for Horticultural Science 113(3):296-300.

2. Johnson, R.S., D.F. Handley, and T.M. DeJong. 1992. Long-term response of early maturing peach trees to postharvest water deficits. J. Amer. Soc. Hort. Sci. 117(6):881-886.

3. Girona, J., M. Mata, D.A. Goldhamer, R.S. Johnson, and T.M. DeJong. 1993. Patterns of soil and tree water status and leaf functioning during regulated deficit irrigation scheduling in peach. J. Amer. Soc. Hort. Sci. 118(5):580-586.

4. Johnson, R. Scott, D.F. Handley, and K.R. Day. 1994. Postharvest water stress of an early maturing plum. Journal of Horticultural Science 69(6):1035-1041.

5. Crisosto, Carlos H., R. Scott Johnson, Juvenal G. Luza, and Gayle H. Crisosto. 1994. Irrigation regimes affect fruit soluble solids concentration and rate of water loss of 'O' Henry' peaches. HortScience 29(10):1169-1171.

6. Mata, Merce, Joan Girona, David Goldhamer, Elias Fereres, Moshe Cohen, and Scott Johnson. 1999. Water relations of lysimeter-grown peach trees are sensitive to deficit irrigation. California Agriculture 53(4):17-21.

7. Johnson, Scott, R. and Dale F. Handley. 2000. Using water stress to control vegetative growth and productivity of temperate fruit trees. HortScience 35(6):1048-1050.

8. Handley, Dale F. and R. Scott Johnson. 2000. Late summer irrigation of water-stressed peach trees reduces fruit doubles and deep sutures. HortScience 35(4):771.

9. Ayers, J.E., R.S. Johnson, C.J. Phene, T.J. Trout, D.A. Clark and R.M. Mead. 2003. Water use by drip-irrigated late season peaches. Irrigation Science 22(4):187-194.

10. Bryla, David R., Thomas J. Trout, James E. Ayars and R. Scott Johnson. 2003. Growth and production of young peach trees irrigated by furrow, microjet, surface drip, or subsurface drip systems. HortScience 38(6):1112-1116.

TERRY L. PRICHARD

Water Management Specialist
Department of Land, Air and Water Resources/Hydrology
University of California, Davis, California 95616
Telephone (209) 468-9496; Fax (209) 462-5181; e-mail: tlprichard@ucdavis.edu

Degrees:

B.S. Polytechnic State University, San Luis Obispo, 1973
M.S. University of California, Davis, 1976

Academic Experience:

1975-1977 System-wide UC CE Farm Advisor
1977 Department of Land, Air and Water Resources, University of California, Davis.
Water Management Specialist,
Asst. Spec., 1977
Assoc. Sepc., 1982
Full CE Specialist, 1990
Lecturer, 1989 – present

Research Interests:

Understanding changes in soil-water-plant relationships under environmental stress and developing management strategies to maximize crop quality, resource use and minimize environmental impact.

Current Research Projects

Effects of regulated deficit irrigation on winegrape
Orchard management influences on water infiltration characteristics.
Optimizing irrigation to maintain productivity and minimize environmental impacts.
Irrigation management influence on the incedence of Phytopthera in Walnut
Deficit irrigation of walnut
Irrigation Education and Training Program for Leaching Ground Water Protection Areas in CA (Writing Training Materials and Coordinating Program)
Irrigation of Quality Winegrapes using deficit irrigation techniques (writing manual)

PROFESSIONAL ACTIVITIES (2000-2004)

I have been an active member in several professional societies including ASA, ASAE, and ASEV. I am a committee chair of the American Society of Enology and Viticulture (ASEV). I have also reviewed manuscripts from ASEV (2), *Journal of Irrigation and Drainage* (1), *Journal of Horticultural Science* (1), *Journal of the Science of Food and Agriculture* (1), *California Agriculture* (2), and UC Agriculture and Natural Resources (ANR) publications (2). I have reviewed 63 project proposals from a variety of granting agencies including American Vineyard Foundation (both East and West Sections), Lodi-Woodbridge Winegrape

Commission, and ANR Special Grants Program, Dry Bean Commission, Walnut Marketing Board, and the Nickles Trust

.

In 2000, I was awarded the ANR Distinguished Service Award for Outstanding Teaching as a Specialist. This award is given to one specialist in ANR each year. During this review period, I received a total of $340,000 as principal investigator covering 15 extramural grants from the following: commodity groups: American Vineyard Foundation, Lodi-Woodbridge Winegrape Commission, Walnut Commission; Federal Agencies: Viticulture Consortium (USDA); State Agencies: California Department of Pesticide Regulation; and Public Agencies: Stockton East Water District. As a co-principal investigator, I participated in an additional total of $340,000 in funding from numerous grants.

I have participated as a member of non-UC committees in the areas of water quality and non-point pollution. They include the Interagency Delta Water Use Committee, cooperating with DWR, USGS, and USBR and the Interagency Land Use Subcommittee of the California Water Use Coordination Committee. Additionally I serve on the Cal-Fed Bay Delta Water Quality Technical Advisory Committee and the CA Dept of Pesticide Regulation Chemigation Technical Task Force.

SELECTED PUBLICATIONS

Prichard, T.L. 2001. Vineyard irrigation systems, Varietal Winegrape Production Short Course, February 6-8, 2001.

Prichard, T.L. 2001. Winegrape water use and the effects of water deficits, Varietal Winegrape Production Short Course, February 6-8, 2001.

Prichard, T.L., G. Browne, L. Schwankl, K. Shackel. 2001. Irrigation management and the incidence of phytophthora root rot in young walnut trees, Project Report to Walnut Marketing Board.

Prichard, T., B. Hanson, L. Schwankl, P. Verdegaal, R. Smith. 2001. Irrigation of quality winegrapes using micro-irrigation techniques, Winegrape Irrigation Short Course, June 5, 6, 11, 2001.

Prichard, T.L., R. Smith, E. Lundquist. 2001. Development of irrigation management strategies to improve fruit quality, Comprehensive Project Report to Viticulture Consortium.

Prichard, T.L., P.S. Verdegaal. 2001. Effects of water deficits upon winegrape yield and quality, Varietal Winegrape Production Short Course, February 6-8, 2001.

Prichard, T.L., P.S. Verdegaal. 2001. Irrigation of quality winegrapes, Varietal Winegrape Production Short Course, February 6-8, 2001.

Prichard, T.L., S. Wulfert, D. Cummings, M. Canadas. 2001. Irrigation management and the incidence of mold in walnut, Project Report to Walnut Marketing Board.

Schwankl, L., T. Prichard. 2001. Chemigation in tree and vine microirrigation systems. University of California ANR Publication 21599.

Prichard, T., J. Troiano, M. Canevari. 2004. Pond water infiltration as a source of ground water contamination from pre-emergence herbicide application to a cracking-clay soil. Jour. Env. Qual.

Schwankl, L., S. Johnson, T. Prichard. 2004. Irrigation of deciduous trees, chapter in Growing Deciduous Fruit and Nut Trees in the Home Garden, Irrigation. ANR publication in press.

CURRICULUM VITAE

KENNETH ANDREW SHACKEL

Mailing address:	Department of Pomology, University of California, Davis, California 95616-8683.
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Citizenship:	US
Birth date:	June 11, 1950

EDUCATION/ACADEMIC RECORD

2000 - Present	Full Professor/Pomologist, Department of Pomology, University of California, Davis. Research emphasis on the water relations of fruit and nut crops.
1992 - 2000	Associate Professor/Pomologist, Department of Pomology, University of California, Davis. Research emphasis on the water relations of fruit and nut crops.
1986 - 1992	Assistant Professor/Pomologist, Department of Pomology, University of California, Davis. Research emphasis on the water relations of fruit and nut crops.
1984 - 1986	Postdoctoral Researcher with Drs. J. Morrison and M.A. Matthews, Department of Viticulture and Enology, UC Davis. Used the pressure probe technique to demonstrate the dynamic relationship of cellular turgor to leaf growth in grape (Vitis vinifera).
1982 - 1984	Postdoctoral Researcher with Professor E.-D. Schulze, University of Bayreuth, West Germany, including two months in the laboratories of U. Zimmermann and E. Steudle (Julich, West Germany) learning the pressure probe technique. Developed a system for in situ measurement of epidermal cell turgor and osmotic potential, leaf water potential and gas exchange in Tradescantia virginiana. Obtained and reported the first direct evidence for the occurrence of transpirationally induced within leaf water potential gradients and the sensitivity of epidermal cell turgor to changes in atmospheric humidity.
1979 - 1982	Ph.D. program in Plant Physiology (environmental physiology with emphasis in water relations) at UC Riverside. Major Professor, Dr. Anthony E. Hall. Dissertation entitled, "Genotypic Differences in Osmotic Potential and Water Relations for Sorghum and Cowpea under Field Conditions," accepted July 1982.
1976 - 1979	Master's program in Plant Science at UC Riverside. Major Professor, Dr. Anthony E. Hall. Thesis entitled, "The Effects of Drought on Leaflet Orientation by Cowpea (Vigna unguiculata (L.) Walp.)," accepted December 1978.
1972 - 1973	Lower division science and mathematics courses at Fullerton Jr. College, Fullerton, CA.
1968 - 1972	Undergraduate at St. Mary's College of California in the Integral Liberal Arts Program (program emphasized historical/classical approach to all fields).

Research: Water, and the physiology of plant responses to water availability, is the focus of my research and that conducted by the students and postdoctoral associates in my lab. Our research program includes two main areas of focus: (1) tree responses to water stress and Regulated Deficit Irrigation (RDI) under field conditions, and (2) fruit growth and pre- and postharvest fruit water relations. My research program is also strongly focused on methodology development, particularly the use of the micro-pressure probe for cell water relations and other studies.

Selected publications on water relations and irrigation:

Shackel, K, R. Gross. 2002. Using midday stem water potential to assess irrigation needs of landscape valley oaks. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184, pp397-402.

Lampinen, B.D, K.A. Shackel, S.M. Southwick, W.H. Olson, 2001. Deficit irrigation strategies using midday stem water potential in prune. Irrig. Sci. 20:47-54.

Fulton A., R. Buchner, B. Olson, L. Schwankl, C, Giles, N. Bertagnia, J. Walton, K. Shackel. 2001. Rapid equilibration of leaf and stem water potential under field conditions an almonds, walnuts and prunes. HortTechnology. 11:609-615.

Shackel, K., B. Lampinen, S. Southwick, D. Goldhamer, W. Olson, S. Sibbett, W. Keueger, J. Yeager. 2000, Deficit irrigation in prunes: Maintaining productivity with less water. HortSci.35:30-33.

Shackel, K.A.,. N.C. Turner. 2000. Seed coat cell turgor in chickpea is independent of changes in plant and pod water potential. J. Exp. Bot. 51:895-900

Turner, N.C., K.A. Shackel, I.F. LeCoultre. 2000. Leaf-cutter psychrometers: a cautionary note. Agron. J. 92:538-541.

Shackel, K., B. Lampinen, S. Sibbett, W. Olson. 2000. The relation of midday stem water potential to the growth and physiology of fruit trees under water limited conditions. Acta Hort. 537:425-430.

Shackel, K., B. Lampinen, S. Southwick, D. Goldhamer, W. Olson, S. Sibbett, W. Keueger, J. Yeager, D. Goldhamer. 2000, Deficit irrigation in prunes: Maintaining productivity with less water. HortSci.35:30-33.

Shackel, K.A., Ahmadi, H., Biasi, W., Buchner, R., Goldhamer, D., Gurusinghe, S. Hasey, J., Kester, D., Krueger, B., Lampinen, B., McGourty, G., Micke, W., Mitcham, E., Olson, B., Pelletrau, K., Philips, H. Ramos, D., Schwankl, L., Sibbett, S., Snyder, R., Southwick, S., Stevenson, M., Thorpe, M., Weinbaum, S., Yeager, J. 1997. Plant Water Status as an Index of Irrigation Need in Deciduous Fruit Trees. HortTechnology 7:23-29.

Lampinen, B.D., K.A. Shackel, S.M. Southwick, B. Olson, J.T. Yeager, D. Goldhamer. 1995. Sensitivity of yield and fruit quality of french prune to water deprivation at different growth stages. J. Amer. Soc. Hort. Sci. 120:139-147.

Ramos, D.E., S.A. Weinbaum, K.A.Shackel, L.J. Schwankl, E.J. Mitcham, F.G. Mitchell, R.G. Snyder, G. Mayer, G. McGourity. 1994. Influence of tree water status and canopy position on fruit size and quality of bartlett pears. Acta. Hort. 367:192-200.

Greenspan, M.D., K.A. Shackel, M.A. Matthews. 1994. Developmental changes in the diurnal water budget of the grape berry exposed to water deficits. Plant Cell Env., 17:811-820.

2004 Water Use Efficiency Proposal Solicitation Package
Appendix H: References

Allen R, L.S. Pereira, D. Raes, M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO. Rome, Italy, 300p.

Allen, R.G., A. Morse, and M.Tasumi. 2003. Application of SEBAL for Western US Water Rights Regulation and Planning. Proc. Int. Workshop on Use of Remote Sensing of Crop Evapotranspiration for Large Regions. 54th IEC Meeting of the International Commission on Irrigation and Drainage (ICID), Montpellier, France, Wednesday, 17 September, 2003. 13 pages. On web at: http://www.kimberly.uidaho.edu/water/montpellier/index.html

Allen, R.G., M. Tasumi, A. Morse, and R. Trezza. 2004. A Landsat-based Energy Balance and Evapotranspiration Model in Western US Water Rights Regulation and Planning. J. of Irrig. and Drain. Sys. (accepted).

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag. 1998. A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. J. Hydrology 212-213, p. 198-212.

Bastiaanssen, W.G.M. 2000. SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. J. Hydrology 229:87-100.

Bastiaanssen W.G.M., D. Ahmad, and Y. Chemin. 2002. Satellite surveillance of evaporative depletion across the Indus Basin, Water Resources Research, vol. 38, no. 2: 1273

Boland, A.M, P.H. Jerie, P.D. Mitchell, and I. Goodwin. 2000. Long-term effects of restricted root volume and regulated deficit irrigation on peach: II. Productivity and water use. J. Amer. Soc. Hort. Sci. 125(1):143-148.

Bonachela, S., F. Orgaz, F.J. Villalobos, and E. Fereres. 2001. Soil evaporation from drip-irrigated olive orchards. Irri. Sci. 20(2):65-71.

Bradford, K.J. and T.C. Hsiao. 1982. Physiological responses to moderate water stress, p. 264-312. *In*: O. L. Lange, P.S. Nobel, C.B. Osmond and H. Ziegler (eds.). Physiological Ecology II Encyclopedia of Plant Physiology (N. S. vol. 12B). Springer-Verlag, NY.

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