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DRIP IRRIGATION IMPACTS ON EVAPOTRANSPIRATION RATES IN CALIFORNIA'S SAN JOAQUIN VALLEY

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ABSTRACT

The acreage irrigated using drip irrigation continues to increase in California and the West. In addition to the increase on orchards and vineyard crops, more and more field crop acreage is coming under drip irrigation due to the increased production that growers are able to achieve with the increased distribution uniformity and improved water and nutrient management possible. When compared to surface irrigation methods, growers are able to increase production with the same, or often less, water applied. Research plot and analytical studies have shown increased evapotranspiration (ET) rates for drip irrigated field crops. Even with less water applied, increased ET rates equal more water consumed. Should the public be concerned about conversion to drip irrigation because water consumption may increase and supplies may be depleted, or should we be advocating conversion to drip/micro because we get more production per unit of water? This study addresses one technical aspect of this question by comparing ET rates over a large area of commercial production agriculture in California's San Joaquin Valley using remotely sensed ET data together with field based land use information.

Using GIS-based crop and irrigation method data and SEBAL ET results, the evapotranspiration rates of populations of selected crop-irrigation method combinations will be compared and contrasted. Statistical tests will be applied to differences in the mean ET rates and within field ET rate variability between selected crop-irrigation method groups. The statistical comparisons will focus on the differences between ET rates of drip irrigation and other irrigation methods.

INTRODUCTION

The cropped area using drip and micro irrigation systems (drip/micro) in California has increased by about thirty-one percent from 1972 to 2001 (Orang, et al., 2008). A corresponding decrease in surface irrigation use has also occurred. These researchers also report an increase in the area planted to orchards and vineyards and a decrease in the area planted to field crops. However, much of the increase in drip/micro irrigation systems results from conversion of surface irrigated orchards and field crops to

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drip/micro. Understanding the effect of this continuing shift in irrigation methods on actual crop evapotranspiration (ET_a) is important for water planning and management.

Numerous researchers have estimated the differences in seasonal ET_a between crops irrigated with drip/micro systems and the same crops irrigated with surface irrigation systems. Burt, et al., (2002) estimated that orchard crop ET_a in the San Joaquin Valley was six to 10 percent higher under drip/micro irrigation compared to surface or sprinkler irrigation. That study estimated the Transpiration (T) and Evaporation (E) components of ET using the FAO 56 (Allen, et al, 1998) dual crop coefficient method for various types of irrigation systems and irrigated areas of California. The study found total ET for furrow, sprinkle, and subsurface drip irrigation (SDI) to be nearly the same. However, the proportions of T and E comprising ET were different depending on the irrigation method, with SDI having the least evaporation of applied irrigation water (4% of seasonal ET_a) and sprinkle irrigation having the most (8% of ET_a). Hsiao et al. (2007) describe a systematic and quantitative approach to improve water use efficiency in agriculture. They describe water use efficiency in agriculture in terms of a chain of efficiencies and discuss the reduction of E as one way to increase transpiration efficiency. In this discussion, they cite Bonachela et al. (2001), who notes that in tree crops, especially those with sparse canopy cover, E reductions achieved by localized irrigation (i.e., drip and micro) can be substantial.

Ward and Pulido-Velazquez (2008) analyze water conservation policies on an integrated, basin-scale linking biophysical, hydrologic, agronomic, economic, policy, and institutional dimensions. Based partly on large ET_a increases ranging from 22 to 29 percent resulting from conversion from surface irrigation to drip irrigation, their results conclude that water conservation subsidies are unlikely to reduce water use. Their study demonstrates the importance of understanding changes in ET_a resulting from conversion from surface to drip/micro irrigation. For example, if ET_a does not increase substantially, and yield increases typically associated with drip/micro irrigation are due to a change in the partitioning of ET into E and T, the above mentioned study's conclusions would not be valid.

Increases in ET_a, or consumptive use of water, as the use of drip/micro increases throughout California could impact future water supplies. The objective of this paper is to further the knowledge and understanding of the changes in ET_a resulting from changes in irrigation methods. This is approached by comparing seasonal ET_a for a range of commercially produced crops irrigated with surface and drip/micro irrigation methods, and the statistical evaluation of the ET_a differences.

Remotely sensed determination of actual ET_a rates developed using a surface energy balance algorithm provide reliable seasonal estimates for individual fields under production conditions (Bastiaanssen et al., 2005). For this analysis, the SEBAL® (Surface Energy Balance Algorithm for Land) model, utilizing satellite-based remotely sensed data together with ground-based weather station data, was used to estimate ET_a across a large area in the San Joaquin Valley of California. The remainder of this paper describes the ET_a estimation method; the methodology for obtaining, comparing, and statistically evaluating the differences between field average seasonal ET_a values for various crops under surface and drip/micro irrigation methods; and the results of the analysis and the conclusions reached.

ET_a ESTIMATION METHOD

Conservation of energy at the Earth's surface denotes a balance between net radiation reaching the Earth's surface from the Sun and the sum of soil, sensible, and latent heat fluxes. Latent heat flux (energy per unit area per unit time) can be easily converted into ET flux (volume of water per unit area per unit time) based on the latent heat of vaporization and density of water. ET flux can be estimated as a closure term from estimates of the remaining fluxes (Equation 1).

$$ET_a = \frac{1}{\lambda \rho_w}\left[R_n - (G + H)\right] \tag{1}$$

where λ is the latent heat of vaporization of water, ρ_w is the density of water, ET_a is the actual ET_a, R_n is the net radiation flux at the Earth's surface, G is the soil heat flux, and H is the sensible heat flux.

Description of SEBAL

The SEBAL model applies radiative, aerodynamic, and energy balance physics in a series of 25 computational steps to estimate ET_a from the energy balance. ET_a is calculated at the pixel-scale using multispectral satellite imagery with a thermal band. The key input data consist of radiances in the visible, near infrared, and thermal infrared regions sensed by earth observing satellites; ground based weather data from agricultural or other weather stations; and land use data describing general vegetation types, when available. Knowledge of specific crop types is not needed to solve the energy balance. SEBAL is internally calibrated for each image to estimate sensible heat flux between the surface and the atmosphere, avoiding the need for absolute calibration of the surface temperature of each pixel. A detailed explanation of the algorithm is provided by Bastiaanssen et al. (1998).

SEBAL has been continually updated over time based on advances in surface energy balance science. These advances include both published and non-published refinements. The 2009 version of SEBAL used for this study includes the following updates from the originally published version of the model:

- Topographic correction of extraterrestrial solar radiation based on actual surface slope and aspect,
- Lapse rate correction of observed surface temperatures prior to calibration of sensible heat flux to normalize for elevation effects on surface temperature,
- Use of spatially distributed weather surfaces from MeteoLook for improved representation of actual surface conditions within the image area,

- Advection correction based on comparison of instantaneous and daily evaporative fractions estimated for a hypothetical grass reference surface assumed to be 0.12 m tall, having a surface resistance of 70 s and an albedo of 0.23 (Allen et. al., 1998) , which is used to compute a theoretical advection correction factor, which is then adjusted based on the actual instantaneous evaporative fraction for each pixel within the image,
- Atmospheric correction and calibration (as needed) of albedo , and
- Improved soil heat flux estimation based on a combination of LAI, and soil moisture.

Validation of SEBAL

SEBAL was developed through 20 years of research and validation. Validation is ongoing due to periodic refinements, sensitivity of model results to analyst judgments related to internal calibration, and interest in further quantifying the accuracy of the approach. The algorithm has been applied in 15 countries, including 11 states mostly in the western United States. Comparisons have been made to six different ET estimation methods for a variety of landscapes including irrigated pasture, sugar beets, riparian vegetation, playas, olives, rice, palm trees, cotton, wheat, sunflower, peaches, almonds, tomatoes, bare soil, grassland and forest.

Recent validations of SEBAL, summarized by Bastiaanssen et al. (2005), have shown seasonal ET_a results generally fall within five percent of seasonal ET_a determined from reliable ground-based measurements. ET_a results from a 2002 SEBAL analysis for the Southern San Joaquin Valley were compared to lysimeter measurements on alfalfa and peaches (Cassel, 2006) and surface renewal measurements on tomatoes (Roberson, 2006). In each comparison, the difference between the SEBAL ET_a and the ground-based estimates was five percent or less (Figure 1).

Additionally, SEBAL estimates of district-wide ET_a for the Imperial Irrigation District were compared to an independent water balance (Thoreson et al. 2009). Annual ET_a was calculated for the 1998 water year (October 1997 – September 1998) based on measured inflows and outflows. Total consumptive use from SEBAL was found to agree with the annual water balance within 1 percent.

Input Data

A combination of satellite, ground-based meteorological, topographic, and land cover classification data are utilized to quantify spatially distributed ET_a. For this study, these datasets were obtained from the U.S. Geological Survey (USGS), CIMIS, and the U.S. Department of Agriculture (USDA). These data are described in greater detail in the following paragraphs.

Satellite Images

Seven Landsat 5TM and one Landsat 7 ETM multispectral images encompassing the period from late March to early November for Path 35/Row 42 were obtained from USGS for 2009 (Table 1). Cloud-free images were selected to achieve a temporal frequency of one image per month for each growing season.

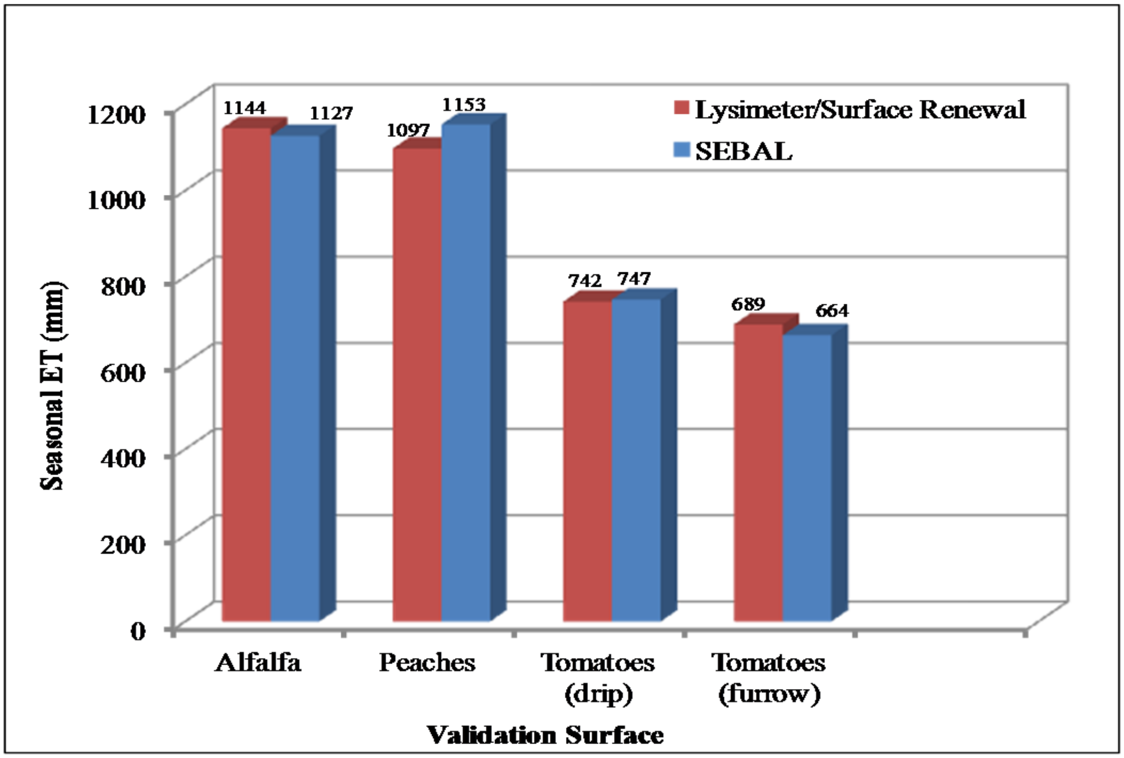

Figure 1. Seasonal SEBAL ET_a Results Compared to Lysimeter and Surface Renewal Results.

Table 1. SEBAL Datasets Used for 2009 Growing Season ET Analysis.

Region	Satellite Platform	Row/ Path	Thermal Resolution	Image Dates	Images
Southern San Joaquin Valley (2009 season)	Landsat 7 ETM	42/35	60 m	3/30/2009	1
Southern San Joaquin Valley (2009 season)	Landsat 5	42/35	120 m	4/23, 5/25, 6/26, 7/28, 8/29, 9/30, 11/1/2009	7

Meteorological Data

Measurements of incoming solar radiation (R_s), relative humidity (RH), air temperature (T_a) and wind speed (WS) were available as hourly averages for the time of image acquisition. Daily (average for the image date), and period (average for the days represented by an individual image) measurements were also available. Eight CIMIS stations falling within or on the edge of the study area were used to develop a spatially varying weather surface prior to the SEBAL image processing. Weather data were quality checked according to the guidelines specified in Appendix-D of the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (Allen et al., 2005).

Weather data were spatially interpolated using MeteoLook, a collection of algorithms developed to interpolate point weather observations based on the surface and terrain characteristics coupled with physically-based models (Voogt, M.P., 2006). Processes that influence surface weather conditions such as elevation, surface roughness, albedo, incoming radiation, land wetness, and distance to water bodies are represented in MeteoLook. This improved spatial distribution of weather data improves the ability to estimate surface conditions influencing the surface energy balance.

Landuse Data and Digital Elevation Model (DEM*)*

Information describing land use types within the southern San Joaquin Valley was obtained from the statewide land use data provided by the USDA National Agricultural Statistics Service (NASS) (available at datagateway.nrcs.usda.gov) for the year 2009. The NASS land use map utilized is a raster grid derived primarily from multiple satellite images obtained from RESOURCESAT – 1 (IRS – P6) across the 2009 growing season. The NASS land use map was resampled from its original spatial resolution of 56 meters to 30 meters to be consistent with other inputs for SEBAL. This land use data was used to estimate obstacle heights for different surfaces within the study area. These data have been developed by various means including analysis of satellite images along with inspection of aerial photographs and ground-surveys.

A DEM of one arc-second resolution (approximately 30 meters) was obtained from USGS and was used in SEBAL to incorporate the effects of the slope, aspect and elevation of the land into the energy balance.

METHODOLOGY

Two general data sources were utilized in this study. An existing SEBAL dataset provided ET_a estimates at the pixel scale derived from Landsat imagery. Field boundaries, crops and irrigation methods were identified using cropping data from the California Department of Water Resources (DWR) land use survey for east Fresno County for 2009.

Field-scale average seasonal ET_a in inches was calculated for field groups defined based on crop, irrigation method, and estimated fractional canopy cover in the east Fresno County area covered by the DWR land use survey (Figure 2). Field boundaries were buffered inward to identify areas in which ET_a estimates were not affected by heat transfer processes occurring outside of the field (thermal contamination). Then, seasonal ET_a for each pixel within each field of interest was averaged to estimate field-scale seasonal ET_a. The data were filtered to remove fields with low NDVI during critical growth periods (suggesting very young crops or miss-classification) and to group fields based on estimates of fractional ground cover, so that comparisons could be made across fields of similar maturity, canopy structure, and/or cover crop presence. Finally, differences in average field-scale ET_a were compared, and tested for statistical significance.

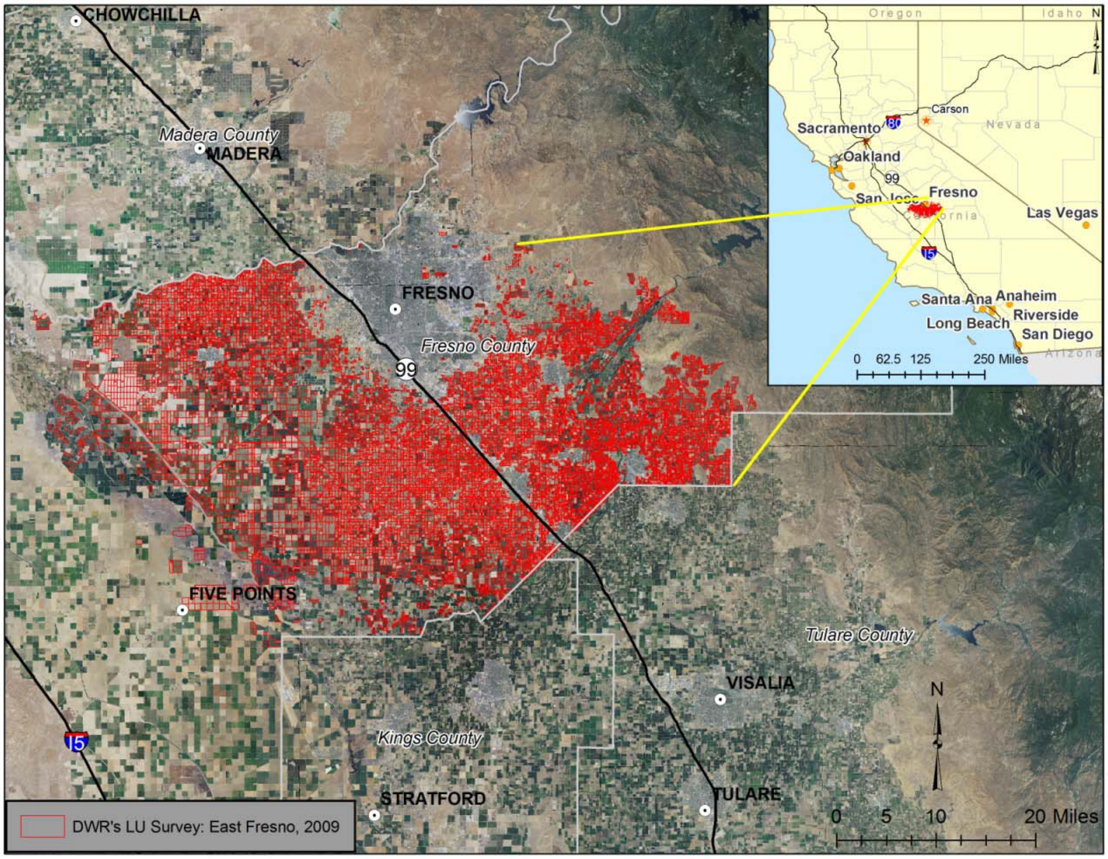

Figure 2. Location of Fields with Land Use Data.

Buffering of Field Boundaries

Field boundaries were buffered inward to identify cropped areas that were not affected by thermal contamination. Thermal contamination within field pixels occurs when lower resolution thermal pixels cross the field boundary and are affected by heat transfer processes outside of the field. For such pixels, the thermal radiance represents a weighted average of the radiance of the pixel area outside the field and the pixel area inside the field. To reduce the thermal contamination on field edges to acceptable levels, field boundaries were buffered 30 meters inward, and all fields with an area of less than five acres after buffering were dropped from the analysis.

Seasonal ET_a and June 26, 2009 (mid-season) image NDVI values for each pixel within the buffered areas were extracted and imported to a Microsoft Access database for calculation of field averages.

Filtering of Field Data Based on NDVI

Field ET_a values were filtered prior to the calculation of average seasonal ET_a based on mid-season NDVI. Filters were applied primarily to separate fields of tree and vine crops into fractional cover classes based on NDVI presumably representing similar maturity, canopy structure, and/or cover crop presence.
Threshold NDVI values for the filters were estimated based on a relationship estimating fractional canopy cover from NDVI (Equation 2) after the form of Choudhury et al. (1994):

$$f_c = 1 - \left(\frac{0.8 - NDVI}{0.8 - 0.125} \right)^{0.7} \qquad (2)$$

Threshold NDVI values corresponding to 10 percent incremental changes in fractional cover (f_c) were derived from Equation 2 and are given in Table 2. Fractional cover estimates may also provide insight into the effect of varying ground shading on crop ET. As fractional cover increases, shading increases leading to a decrease in E.

Table 2. Threshold NDVI Values Corresponding to Estimated 10 Percent Fractional Cover Increments from Equation 2.

f_c	*NDVI*	f_c	*NDVI*
0.20	0.310	0.50	0.550
0.30	0.395	0.60	0.618
0.40	0.475	0.70	0.680

RESULTS AND DISCUSSION

Eleven crops in the area bounded by the intersection of the 2009 East Fresno County DWR Land Use Survey and the SEBAL dataset had more than 1,000 acres irrigated by drip/micro irrigation methods (Table 3). Including processing tomatoes, 74 percent of which are irrigated with buried drip systems, these 12 crops accounted for just over 400,000 irrigated acres. Notably 44 percent of the area was irrigated with drip or micro irrigation. When buried drip, sprinklers and other methods are included, 49 percent of the area is irrigated with methods other than the traditional surface irrigation methods of furrow, border strip and basin.

As described previously, a 30 meter buffer was applied to the field boundaries, and pixels impacted by clouds and scan line gaps[4] as well as all remaining fields less than five acres

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[4] Gaps present in the Landsat 7 image acquired March 30th result from a malfunction of the Scan Line Corrector (SLC) that occurred in May 2003 in the ETM+ imaging sensor onboard the satellite. Due to the gaps, approximately 22% of the data is missing from a typical Landsat 7 image. These gaps vary in width from one pixel or less in the center of the image to 14 pixels towards the edges of the image. Despite the gaps in the data, the Landsat 7 image was used in the analysis to provide adequate temporal coverage.

were removed from the analysis. This led to a field data set for consideration for the statistical analysis (Table 4). For the succeeding analyses, crop-irrigation method groups with the number of fields greater than 30 and the total acreage greater than 1,000 acres were included.

Table 3. Crops with Area Irrigated by Drip/Micro Greater Than 1,000 Acres.
Source: East Fresno County DWR Land Use Survey, 2009

Crop	Total Acres	Drip/Micro Irrigation Methods, Acres	Surface Irrigation Methods, Acres	Buried Drip Irrigation Methods, Acres	Sprinklers and Other Irrigation Methods, Acres
Vineyards	202,167	88,250	106,170	215	7,532
Almonds	67,668	29,499	37,404	39	725
Oranges	35,303	29,122	5,802	0	379
Peaches and Nectarines	33,253	3,585	29,128	0	540
Pistachios	18,732	17,222	1,496	0	14
Plums	14,613	2,858	11,554	0	201
Tomatoes (processing)*	10,688	649	968	7,947	1,124
Mixed	6,397	1,293	4,244	583	278
Walnuts	6,183	1,152	4,966	0	65
Miscellaneous deciduous	5,917	2,526	3,023	0	367
Olives	1,329	1,119	210	0	0
Lemons	1,077	1,026	51	0	0
Totals	403,326	178,301	205,015	8,785	11,225
Percent		44%	51%	2%	3%

*Processing tomatoes are included as a crop of interest even though most of the acreage was irrigated with buried drip systems.

Table 4. Crop-Method Combination Areas Remaining After Buffering, Removing Pixels Impacted by Clouds and Scan Line Gaps (Landsat 7 ETM) and Removing Fields Less Than 5 Acres.

Crop-Method Group	No. of Fields	Acres
Vineyards, drip/micro	1,610	32,391
Vineyards, surface	1,861	31,771
Oranges, drip/micro	761	15,789
Peaches and Nectarines, surface	746	11,172
Almonds, drip/micro	370	8,731
Almonds, surface	423	7,641
Plums, surface	346	4,124
Oranges, surface	194	2,628
Peaches and Nectarines, drip/micro	113	1,447
Plums, drip/micro	88	1,034
Pistachios, surface	18	270
Pistachios, drip/micro	16	236
Tomatoes (processing), drip/micro	11	206
Tomatoes (processing), surface	1	20
Totals	6,558	117,461

The larger areas of drip/micro irrigated almond and orange orchards and vineyards in the lower fractional cover classes indicate a grower preference for drip/micro irrigation compared to surface irrigation (Table 5).

Table 5. Crop-Method Combination Areas and Number of Fields by Fractional Cover Range.

			Drip/micro Irrigation Method		Surface Irrigation Method	
Crop-Method Group	Fractional Cover Class	NDVI Range	No. of Fields	Acres	No. of Fields	Acres
Almonds	< 0.3	< 0.395	112	1,948	96	1,309
Almonds	0.3 - 0.4	0.395 to 0.475	71	1,448	79	1,247
Almonds	0.4 - 0.5	0.475 to 0.55	89	2,195	102	1,852
Almonds	0.5 - 0.6	0.55 to 0.618	81	2,492	114	2,546
Almonds	> 0.6	>0.618	17	648	32	687
Oranges	< 0.3	< 0.395	307	6,109	75	954
Oranges	0.3 - 0.4	0.395 to 0.475	223	4,327	66	1,025
Oranges	0.4 - 0.5	0.475 to 0.55	190	4,522	43	535
Oranges	0.5 - 0.6	0.55 to 0.618	37	788	8	99
Oranges	> 0.6	>0.618	4	43	2	14
Peaches and Nectarines	< 0.3	< 0.395	19	196	66	837
Peaches and Nectarines	0.3 - 0.4	0.395 to 0.475	15	262	77	1,075
Peaches and Nectarines	0.4 - 0.5	0.475 to 0.55	27	333	197	2,934
Peaches and Nectarines	0.5 - 0.6	0.55 to 0.618	38	465	224	3,600
Peaches and Nectarines	> 0.6	>0.618	14	191	182	2,725
Plum	< 0.3	< 0.395	24	241	51	614
Plum	0.3 - 0.4	0.395 to 0.475	12	137	37	432
Plum	0.4 - 0.5	0.475 to 0.55	18	257	85	1,095
Plum	0.5 - 0.6	0.55 to 0.618	23	300	102	1,225
Plum	> 0.6	>0.618	11	99	71	758
Vineyards	< 0.3	< 0.395	866	17,630	842	13,635
Vineyards	0.3 - 0.4	0.395 to 0.475	359	7,585	581	11,138
Vineyards	0.4 - 0.5	0.475 to 0.55	128	2,815	219	3,865
Vineyards	0.5 - 0.6	0.55 to 0.618	82	1,565	123	1,887
Vineyards	> 0.6	>0.618	175	2,796	96	1,246

Average ET_a for surface irrigated fields was greater than the average ET_a for drip or micro irrigated for 21 of 25 crop-irrigation method-fractional cover groups. (Table 6). The 0.4 to 0.5 fractional cover group for oranges and plums had average ET_a of drip or micro fields greater than the average ET_a of surface irrigated fields. The two smallest fractional cover classes for peaches and nectarines were found to have an average ET_a of drip or micro irrigated fields slightly larger than average ET_a of the surface irrigated fields. With the notable exceptions of almonds and peaches and nectarines, the average ET_a of the surface irrigated fields exceeded average ET_a of drip/micro irrigated fields by the greatest amount in the smaller fractional cover groups. This is likely due to greater evaporation from surface irrigation of the younger trees. For all groups, the ET_a difference between surface and drip or micro irrigated fields was less than the standard deviation.

Table 6. Crop-Method Combination Average Et_a and Standard Deviation by Fractional Cover Range.

	Fractional		Drip/micro Irrigation Method		Surface Irrigation Method		Surface - Drip
Crop-Method Group	Cover Class	NDVI Range	Avg. ETa, in	StdDev, in	Avg. ETa, in	StdDev, in	Avg. ETa, in
Almonds	< 0.3	< 0.395	16.6	4.2	18.2	4.2	1.6
Almonds	0.3 - 0.4	0.395 to 0.475	34.0	4.7	35.7	4.7	1.8
Almonds	0.4 - 0.5	0.475 to 0.55	41.9	5.1	43.7	5.3	1.7
Almonds	0.5 - 0.6	0.55 to 0.618	47.6	5.5	49.6	4.9	2.0
Almonds	> 0.6	>0.618	54.0	4.4	55.9	4.3	1.9
Oranges	< 0.3	< 0.395	16.5	4.1	19.6	3.8	3.1
Oranges	0.3 - 0.4	0.395 to 0.475	32.4	4.7	34.8	4.5	2.4
Oranges	0.4 - 0.5	0.475 to 0.55	38.3	4.6	38.1	4.7	-0.2
Oranges	0.5 - 0.6	0.55 to 0.618	42.4	4.2	44.1	4.8	1.6
Oranges	> 0.6	>0.618	42.9	3.7	45.0	4.0	2.1
Peaches and Nectarines	< 0.3	< 0.395	22.1	5.0	19.6	4.9	-2.5
Peaches and Nectarines	0.3 - 0.4	0.395 to 0.475	31.8	6.2	31.5	5.5	-0.3
Peaches and Nectarines	0.4 - 0.5	0.475 to 0.55	35.4	5.5	38.8	4.7	3.3
Peaches and Nectarines	0.5 - 0.6	0.55 to 0.618	39.6	5.2	43.6	4.1	4.0
Peaches and Nectarines	> 0.6	>0.618	45.5	4.7	48.8	3.9	3.3
Plum	< 0.3	< 0.395	16.1	4.8	18.1	5.1	2.1
Plum	0.3 - 0.4	0.395 to 0.475	27.5	5.7	31.0	4.8	3.6
Plum	0.4 - 0.5	0.475 to 0.55	37.9	4.2	37.2	4.6	-0.7
Plum	0.5 - 0.6	0.55 to 0.618	42.2	3.8	43.0	4.6	0.8
Plum	> 0.6	>0.618	47.7	5.2	48.5	3.6	0.8
Vineyards	< 0.3	< 0.395	13.6	3.6	17.0	4.3	3.4
Vineyards	0.3 - 0.4	0.395 to 0.475	21.1	3.6	25.0	4.4	3.9
Vineyards	0.4 - 0.5	0.475 to 0.55	29.2	4.1	30.9	3.9	1.6
Vineyards	0.5 - 0.6	0.55 to 0.618	35.6	3.7	35.9	3.3	0.3
Vineyards	> 0.6	>0.618	41.0	3.1	42.4	3.0	1.4

Statistical hypotheses were tested regarding the differences of the means of each group. Walpole and Myers (1978) define a statistical hypothesis as “an assumption or statement which may or may not be true, concerning one or more populations.” For the fifty populations considered in this study, a statistical hypothesis that the mean ET_a of surface irrigated fields was equal to the mean ET_a of drip/micro irrigated fields for each crop fractional cover category was formulated and tested as to whether it should be rejected at the $\alpha = 0.05$ level of confidence. This hypothesis is called the null hypothesis (H_0). The rejection of this hypothesis leads to the acceptance of the alternative hypothesis (H_1) that the means are not equal. This null hypothesis was rejected for four of the five crop-method-fractional cover groups for almonds and vineyards, the two crops with the greatest area and number of fields (Table 7). Overall all 25 crop-method-fractional cover groups, the null hypothesis was rejected for 13 groups accounting for 98,411 acres and accepted for 12 groups accounting for 18,318 acres. The null hypothesis that the means were equal was not rejected for all five groups of plums, the crop with the smallest area in the study.

Table 7. Crop-Method Combination Test Statistic and Statistical Hypothesis Test Results.

Crop-Method Group	Fractional Cover Class	NDVI Range	Surface - Drip Avg. ETa, in	Z test Statisitic	$Z_{0.05/2}$	Reject Null Hypothesis (Alpha = 0.05)
Almonds	< 0.3	< 0.395	1.6	2.732	1.96	**Yes**
Almonds	0.3 - 0.4	0.395 to 0.475	1.8	2.283	1.96	**Yes**
Almonds	0.4 - 0.5	0.475 to 0.55	1.7	2.288	1.96	**Yes**
Almonds	0.5 - 0.6	0.55 to 0.618	2.0	2.594	1.96	**Yes**
Almonds	> 0.6	>0.618	1.9	1.428	1.96	**No**
Oranges	< 0.3	< 0.395	3.1	6.215	1.96	**Yes**
Oranges	0.3 - 0.4	0.395 to 0.475	2.4	3.840	1.96	**Yes**
Oranges	0.4 - 0.5	0.475 to 0.55	-0.2	-0.269	-1.96	**No**
Oranges	0.5 - 0.6	0.55 to 0.618	1.6	0.898	1.96	**No**
Oranges	> 0.6	>0.618	2.1	0.618	1.96	**No**
Peaches and Nectarines	< 0.3	< 0.395	-2.5	-1.950	-1.96	**No**
Peaches and Nectarines	0.3 - 0.4	0.395 to 0.475	-0.3	-0.178	-1.96	**No**
Peaches and Nectarines	0.4 - 0.5	0.475 to 0.55	3.3	3.011	1.96	**Yes**
Peaches and Nectarines	0.5 - 0.6	0.55 to 0.618	4.0	4.510	1.96	**Yes**
Peaches and Nectarines	> 0.6	>0.618	3.3	2.562	1.96	**Yes**
Plum	< 0.3	< 0.395	2.1	1.697	1.96	**No**
Plum	0.3 - 0.4	0.395 to 0.475	3.6	1.946	1.96	**No**
Plum	0.4 - 0.5	0.475 to 0.55	-0.7	-0.588	-1.96	**No**
Plum	0.5 - 0.6	0.55 to 0.618	0.8	0.918	1.96	**No**
Plum	> 0.6	>0.618	0.8	0.484	1.96	**No**
Vineyards	< 0.3	< 0.395	3.4	17.382	1.96	**Yes**
Vineyards	0.3 - 0.4	0.395 to 0.475	3.9	14.802	1.96	**Yes**
Vineyards	0.4 - 0.5	0.475 to 0.55	1.6	3.590	1.96	**Yes**
Vineyards	0.5 - 0.6	0.55 to 0.618	0.3	0.612	1.96	**No**
Vineyards	> 0.6	>0.618	1.4	3.709	1.96	**Yes**

These results contradict the increased ET_a attributed to drip/micro irrigation reported by other investigators (Burt, 2002 and Ward, 2008). Four possible reasons for this are:

1. The more precise irrigation management possible on drip/micro irrigated fields provides increased opportunities to practice irrigation management strategies that result in lower ET_a.
    a. Vineyards on drip/micro are more likely to be deficit irrigated resulting in reduced ET_a,

   b. Almonds irrigated with drip/micro systems are more likely to be managed utilizing Regulated Deficit Irrigation (RDI) (Goldhammer, 2005) practices with irrigation restricted during certain growth periods leading to reduced ET_a
2. A reduction in E resulting from conversion to drip or micro, without an offsetting increase in T (T may increase, but not as much as E decreases).
3. Differences in the practice of using cover crops in orchards depending on the use of drip/micro or surface irrigation methods.
4. If surface systems tend to occur in surface water areas with relatively abundant supplies and drip/micro tends to occur in GW areas or water short areas in general, it is possible that differences in water supply source explain the outcome that drip ET_a is not greater than surface ET_a.

CONCLUSION

Mean ET_a from production fields irrigated with surface irrigation methods was found to be greater than mean ET_a from fields irrigated with drip/micro for 13 of 25 crop-irrigation method-fractional cover groups. This result is surprising given the conventional wisdom supported by findings of some researchers that ET_a from drip/micro irrigated fields is more than that from surface irrigation. To obtain the increased yield reported from the drip/micro irrigated fields, it is likely that the partitioning of E and T has changed with the volume of E from drip/micro irrigated fields being less than the E from surface irrigated fields. Additional research into seasonal ET_a for drip/micro and surface irrigated fields is necessary to confirm or refute this preliminary conclusion. However, if proven to hold true by additional research, this indicates that conversion to drip/micro irrigation on orchard crops in the San Joaquin Valley of California is not substantially increasing the consumptive use of water. Thus, installation of drip/micro irrigation may, in many cases, increase transpiration efficiency by reducing the volume of evaporation without increasing overall ET_a. Other changes resulting from installation of drip/micro irrigation systems may include reduction of deep percolation. Future studies are required to evaluate differences in ET_a from surface irrigated and drip/micro irrigated field crops such as tomatoes and alfalfa.

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