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Evaporation Estimates for Irrigated Agriculture in California

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Background

California's economic and environmental well-being are closely linked to the state's water management. Water conveyance and utilization consume large amounts of energy in the state and water supplies are necessary for industry, agriculture, recreation, and the environment. Policymakers who allocate funds to help balance the water supply and demand require good data on water balances.

All California irrigation districts that receive either federal or state water are now required to prepare Water Conservation Plans. For the first time in the history of most districts, they are developing an elementary water balance. The term "elementary" should be emphasized, because there are significant weaknesses in our knowledge of subsurface flows and some components of Evapotranspiration (ET). Irrigation districts generally use published "typical" values of ET for their water balance computations.

Basic weaknesses with published values for ET include:

1. The values are published as "ET" rather than Evaporation and Transpiration components.
2. Most values only include estimates of ET during the crop-growing season, and ignore ET during the rest of the year and on fallow ground.
3. There is no separation of the evaporation contribution of irrigation, vs. rainfall.
4. Published ET values do not account for differences in irrigation and soil management. Therefore, one cannot estimate the impact of various management practices on the volumes of evaporation that might occur under difference scenarios.

While it is clearly understood that evaporation losses occur, it has been considerably less certain what the values are. Furthermore, the assumption in the irrigation and state planning sectors has typically been that the evaporation values are quite small.

This Paper

This paper presents some of the key findings of a major evaporation research effort conducted at the Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo (Cal Poly). The presentation may appear to be "choppy" as it moves from one topic to another, because each of the topics that were selected for presentation in this paper merits a complete paper of its own. However, the authors felt that The Irrigation Association audience would prefer to learn about a several major points rather than the details of only one single idea.

ITRC research on evaporation was funded by CALFED and the California State University Agricultural Research Initiative. CALFED is financed by both the US and California governments and represents a large effort to resolve major water issues in California.

Two of the logical questions of any large water management and planning effort are:

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1. What is the magnitude of evaporation on irrigated lands in California?
2. Is there anything that can be done to reduce evaporation, if it is significant?

When we began the research that is reported in this paper, we had a general understanding that evaporation on irrigated agricultural lands in California may represent somewhere between 5% and 25% of the total ET_{field} - hardly a precise value. Hence, there was obviously a need to take a closer look at evaporation to estimate its magnitude. The second question of what can be done about evaporation requires further study.

Previous Evaporation Research

One of the first steps in studying California evaporation was to conduct a detailed literature search of previous research on the subject. The literature search was followed by personal and telephone interviews with many of the major researchers. Previous research can be grouped into the following areas:

1. Bare soil evaporation, including field and lysimeter studies. Of particular interest to ITRC were equations that described how the soil dried out with time, as a function of soil type and ETo.
2. Evaporation from soil with various types of mulches.
3. Evaporation from soil with various degrees of plant cover.
4. Evaporation from wet plant canopies.
5. The relationship between increased evaporation and decreased transpiration.

A detailed report on the literature search can be located by accessing the ITRC web page at www.itrc.org. A summary of key literature search results will be published in future papers. For the purposes of this paper, it is sufficient to state that the simulation model that ITRC used in its research (explained below) was able to replicate good research results quite well.

The Simulation Model Used

The FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998) defines a procedure for estimating crop evapotranspiration (ET_{field}). This procedure with some modifications allowed ITRC to compute daily water balances using reference ETo and crop coefficients that account for the impacts of plant stress and wet soil and plant surfaces. Transpiration (T) and evaporation (E) components of ET were separated for both rainfall and irrigation. An EXCEL spreadsheet that was originally developed by Dr. Richard Allen, and which was subsequently modified for this work, is referred to as the "Modified FAO 56 model".

ITRC computed daily soil root zone and plant canopy water balances for 3 years on the major crop rotation patterns in agricultural areas of California. The daily water balance computations required knowledge of common irrigation schedules, the type and distribution of the various irrigation methods, planting dates, harvest dates, normal year rainfall patterns, etc. The computation procedure had the following variables:

a. Irrigated agricultural areas separated by 13 ETo Zones as established by the California Department of Water Resources (DWR). Daily ETo data were obtained from the California Irrigation Management Information Systems (CIMIS) network. Detailed quality control checks of solar radiation and relative humidity were conducted on a representative sample of the station data. Some areas of California were excluded because of their low numbers of irrigated acreage, including the Northern California Coast, east of the Sierra Nevada and Cascade mountains, north of Redding, and parts of the desert in San Bernardino County.
b. Four typical soil types for each ETo Zone. Digitized soil survey data were obtained and were processed in ArcView® GIS, along with crop data.

c. All major crops for each area. Digitized crop acreages for all ETo Zones were obtained through California DWR land use surveys.
d. Three successive years (1997, 1998, 1999) representing normal, wet, and dry years, respectively.
e. Various irrigation methods (drip/micro, sprinkler, and surface; with various subdivisions of each category). The acreages of various irrigation methods used on different crops and soils, by ETo Zone, were obtained from a variety of sources. These included irrigation district surveys, California DWR records as reported by the 1998 annual irrigation survey in the Irrigation Journal, and ITRC experience. Table 1 shows the estimated California irrigated acreage by crop and irrigation methods that were used in this evaluation.

Table1. California crop acreage by irrigation method in the 13 ETo Zones.

Crop	All Furrow	All Border Strip and Basin	Combination Sprinkler/Furrow	All Sprinkler	All Drip/Micro	Total Acreage
Apple, Pear, Cherry, Plum and Prune	17,821	56,111	0	30,930	85,048	189,910
Peach, Nectarine and Apricots	12,537	38,256	0	21,367	55,926	128,085
Almonds	0	211,994	0	94,704	225,211	531,909
Walnuts	17,858	62,346	0	32,192	88,483	200,879
Pistachio	9,687	21,079	0	14,714	35,123	80,603
Misc. Decidous	4,698	13,309	0	7,858	21,631	47,495
Grain and Grain Hay	0	681,963	0	227,321	0	909,284
Rice	0	379,989	0	0	0	379,989
Cotton	714,065	0	143,244	224,428	40,403	1,122,140
Safflower and Sunflower	0	173,096	0	57,699	0	230,795
Corn and Grain Sorghum	381,607	0	72,452	113,515	0	567,574
Beans	61,543	0	17,215	42,615	13,486	134,860
Misc. field crops	103,950	0	35,144	108,687	27,531	275,313
Alfalfa Hay and Clover	37,392	643,093	0	226,828	0	907,312
Pasture and Misc. Grasses	0	357,439	0	119,146	0	476,586
Small Vegetables	310,194	0	109,952	355,057	86,134	861,337
Tomatoes and Peppers	151,737	0	46,141	127,432	36,145	361,454
Potatoes, Sugar beets, Turnip ect.	59,123	0	19,865	61,071	15,562	155,621
Melons, Squash, and Cucumbers	57,139	0	18,567	55,200	14,545	145,451
Onions and Garlic	29,487	0	10,834	36,064	8,487	84,872
Strawberries	0	0	21,362	849	33,317	55,528
Flowers, Nursery and Christmas Tree	1,858	1,486	0	372	33,441	37,157
Citrus (no ground cover)	14,048	11,407	0	2,641	252,865	280,961
Avocado	2,756	2,205	0	551	49,616	55,129
Misc Subtropical	3,073	2,549	0	524	55,316	61,462
Unknown Grapes	202,826	0	0	8,291	633,352	844,469
Idle	186,829	0	0	0	0	186,829
Total	**2,380,226**	**2,656,321**	**494,778**	**1,970,056**	**1,811,622**	**9,313,004**

Crop planting and harvest dates were obtained from farmer interviews and published data available from the University of California, Agricultural Commissioners, and irrigation districts in each Zone. Typical farmer irrigation practices were known from interviews with farmers and from the expertise of ITRC staff.

Evaporation From a Bare Soil Surface

For non-cracking clay soils, evaporation from a wet soils surface is mathematically described as a two-stage function. The first stage occurs when the soil surface is moist (and appears dark to the eye), in which case the evaporation is only limited by ETo, not by the soil moisture content. The second stage has a falling rate of evaporation that decreases as the soil surface moisture content decreases. Figure 1 shows this relationship for a loam soil.

Evaporation from Wet Leaves

Sprinkler evaporation from wet canopies (as opposed to losses from droplet evaporation, or evaporation from a wet soil surface) depends upon the type of sprinkler system used, the irrigation frequency and duration, and the time of day of irrigation. Table 2 demonstrates an example of how the irrigation method can affect wet canopy evaporation. The lesson from Table 2 is that there is no "typical" sprinkler system.

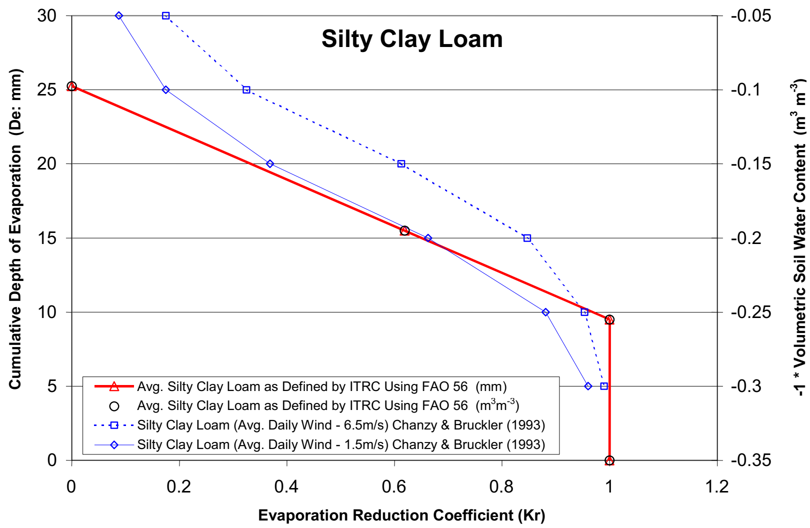

Figure 1. Comparison of the Modified FAO 56 Method results for an ITRC "average loam soil" against measured loam (Avignon, France) relationships derived from data provided by Chanzy and Bruckler (1993).

Table 2. Percentage of time during a 150-day growing season that foliage evaporation occurs for sprinkler irrigation methods that wet the crop canopy.

Irrigation Method	% of California Irrigated Agricultural Land Area	Irrigation Intervals	Leaf Water Contact Assumptions	ITRC Estimated Seasonal Time that Leaves are Wet (hours)	ITRC Estimated Seasonal Time that Leaves are Wet During 12 hours of Daytime (hours)	% of Time in a 150 Day Growing Season that Leaves are Wet
Center pivots, lateral move, and traveler	Combined area <5	55 passes per season at 1.5 day interval	Typical leaf in contact with irrigation water for 15 minutes and being dry after 30 minutes for a daytime irrigation	-	7 / 48 [A]	0.2 / 1.3
Hand move, Side roll/Wheel Line	20, 1.4	6 irrigations per season w/ 24 hours between moves	Typical leaf in contact with irrigation water for a 2 move period	288	144	4
Solid set sprinklers	3	15 **daytime** irrigations with 12 hour sets	Typical leaf in contact with irrigation water for 12 hours	180	180	5
Solid set sprinklers	3	15 **nighttime** irrigations with 12 hour sets	Typical leaf in contact with irrigation water for 12 hours	180	15	0.4

[A] 7 hours represents the amount of daytime that a typical leaf will encounter irrigation water during the season. 48 hours represents the amount of daytime in which the leaves will be undergoing drying after an irrigation and assumes that the water on a typical leaf received from a nighttime irrigation is evaporated in 1 hour after significant evaporation begins.

Drip/Micro Evaporation

A frequently heard argument is that drip irrigation will decrease ET_{field} - or at least decrease the evaporation component of ET. Some limited studies have documented such ET. But there are many forms of "drip" and "micro" irrigation, so research for one case is not necessarily transferable to other situations. The majority of systems in California are placed on the soil surface, with tremendous differences among soil coverage, plant shading, and wetting patterns of various drip and microspray and microsprinkler systems. Even if one focuses on buried drip (subsurface drip irrigation, or SDI), there are huge differences in design and management. Some SDI systems utilize sprinkler or surface irrigation at some times of the year (with the accompanying evaporation), while others completely depend upon the SDI system to wet the soil surface for germination or transplanting.

Hsiao of UC Davis (T. Hsiao, personal communication, 2000) is conducting research to determine the potential savings in soil evaporation (E) by using surface drip as opposed to furrow. He notes that drip can reduce evaporation under two conditions:

1. When the crop or tree cover is not complete
2. When the soil is light texture with low water holding capacity. When the texture is light, the required time between furrow irrigations is sometimes reduced to 5 days, resulting in more opportunity for soil evaporation to occur.

Hsiao states that under complete crop cover or when there is a good heavy soil, soil evaporation from surface drip is similar to that under furrow irrigation. The reason is that although the drip wets a smaller area, that area is wet for much of the growing season, whereas with furrow irrigation, more of the surface area is wetted, but it dries, reducing the amount of soil evaporation.

For about 15 years, Westlands Water District has collected district data which indicates 10 – 15% higher ET, part of which is E, for drip on almonds as opposed to other irrigation methods (Westlands Water District Water Management Plan, 1993).

Burt et al. (1997) identified that ET_{field} will be less for a well-watered crop with dry soil and plant surfaces (as can be the case with SDI) than if the crop were irrigated with a method that wets the soil and plant surfaces. A method that wets the soil surface can have both soil evaporation and can also result in more weed development and loss of applied water through weed T. Evett et al. (1995) identified that for treatments with similar canopy development, there is no difference in seasonal ET of drip irrigation and furrow irrigation. Dasberg (1995) found that sprinkler irrigations and micro irrigation that resulted in similar soil surface wetting resulted in similar amounts of the soil evaporation component of ET.

The senior author has consistently maintained that <u>some types</u> of drip/micro system conditions will create at least as much, and probably more, soil evaporation, than will occur under furrow irrigation. The vast majority of drip/micro systems are above ground, and the wetted areas may be quite large with some crops and emitter designs. Those wet soil surface regions are almost continuously wet, contributing to a high soil evaporation loss. This belief can be found in Bresler (1975), Meshkat (2000), and Burt and Styles (1999). When one considers that many drip/micro systems are managed to avoid plant stress, it is apparent that the transpiration under drip/micro is often higher than the transpiration under sprinkler and surface irrigation methods. When one combines possible higher evaporation with almost certain higher transpiration, the overall ET_{field} can be expected to be higher under drip/micro than for surface and sprinkler methods in many cases.

Again, it must be emphasized that it is impossible to say that "drip/micro" can be compared to "sprinkler" because each has so many variations. ITRC used the modified FAO 56 procedure to theoretically compute the evaporation and transpiration in a variety of comparison situations. Table 3 shows the results for a specific example – cotton on the west side of the central San Joaquin Valley. This is an arid area, and cotton is a predominate crop for the area.

Table 3. Components of ET_{field} for typical irrigation methods in ETo Zone 15. Values are in inches per year. Considers the complete year.

Irrigation Method	E_{irr}	E_{ppt}	T	ET_{field}
Furrow	2.5	5.4	29.1	37.0
Hand Move Sprinkler	2.9	5.4	29.4	37.6
Drip (SDI) 10" burial depth	1.5	5.4	30.4	37.3

Table 3 shows that there is almost no difference in annual ET_{field} between irrigation methods, but that the distribution between E and T is different. The majority of the irrigation water E for the SDI was generated during pre-irrigation, which was assumed to be with hand move sprinklers. However, even if sprinklers are not used for pre-irrigation, the soil surface must somehow be wet so that seeds will germinate. Surface drip was not used as an example, because the drip systems used on cotton are almost all SDI.

The amount of evaporation with drip/micro is heavily dependent upon the percent of the soil surface that is wet. The importance of this also depends upon the amount of crop cover, and the frequency of irrigation. Figure 2 shows a comparison of evaporation under different conditions with almonds on the western side of the central San Joaquin Valley.

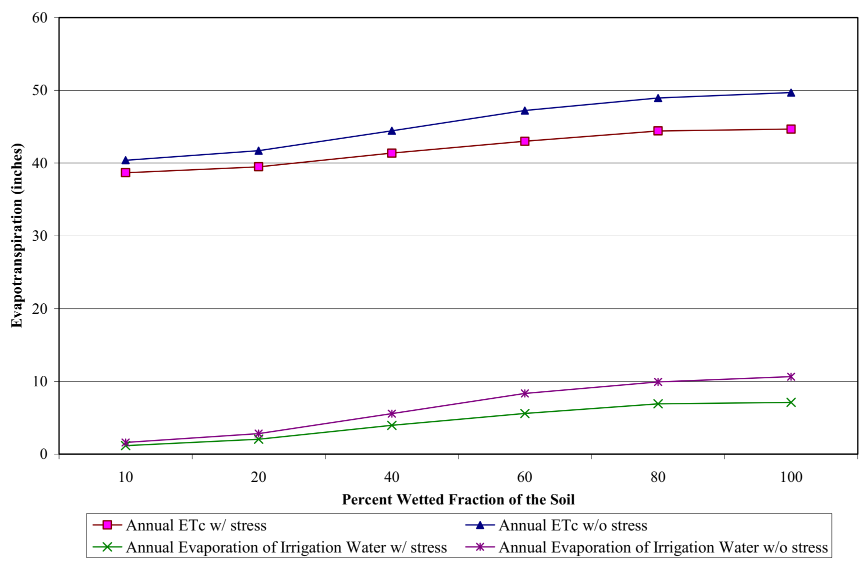

Figure 2. Field evaporation and evapotranspiration as influenced by the fraction of soil surface wetted area. No cover crop. Almonds. Arid area.

It is clear from Figure 2 that there is significantly more evaporation from microsprayers with a large wetted area than there would be from a single line of drip hose. But in recent years, most drip systems on almonds now use a double line of closely spaced emitters. Furthermore, the almond tree plant spacings have narrowed over the years, so the percent surface wetted area can be very large even under drip irrigation (as well as under microspray).

Overall Results

ITRC examined the ET_{field} for the complete calendar year, not just during the growing season. Overall results are presented in Table 4.

Many reports of "ET" are limited to the time period between planting and harvest; considerable evaporation of irrigated water (stored in the soil) and rainfall can occur between those two dates. Therefore, ITRC's ET_{field} numbers will be larger than those found in most published reports. For the purposes of CALFED, the annual ET values are needed because various CALFED and irrigation district studies are addressing water destinations during the complete year.

Table 4. Estimated annual Evaporation (E) and Transpiration (T) for irrigated agriculture land in California, acre-feet.

	1997 (normal)	1998 (wet)	1999 (dry)
E_{ppt} - E from Precipitation (AF)	3,912,000	6,226,000	3,989,000
E_{irr} - E from Irrigation (AF)	2,301,000	1,794,000	2,295,000
T_{ppt} - T from Precipitation (AF)	518,000	2,708,000	440,000
T_{irr} – T from Irrigation (AF)	19,029,000	14,219,000	18,219,000
Total ET_{field} (AF)	25,759,000	24,947,000	24,944,000
Total Precipitation (AF)	10,294,700	31,130,000	7,526,400
Total ET_{irr} (AF)	21,329,000	16,014,000	20,514,000
% of Precipitation that Evaporates	38%	20%	53%
% of Precipitation used for ET_{ppt}	43%	29%	59%
E_{irr}, as a % of ET_{irrig}	11%	11%	11%

Key points from Table 4 are:

1. Although ET_{field} may remain relatively constant in California between years, the relative amounts of E vs. T can change significantly.
2. The majority of evaporation in California originates as precipitation, rather than irrigation water.
3. The percentage of ET_{irr} that is E is about the same, regardless of the year.
4. The percentage of precipitation that is destined for ET varies from 29% to 53% (averaged over all crops and ETo Zones)

Conclusions

This paper provides a summary of key points regarding evaporation on California's irrigated lands. Key points include:

1. California acreages by irrigation method, soil, and climate have been compiled. This information should prove useful to a wide variety of studies.
2. The two-stage soil surface drying (via evaporation) function used in FAO56 matches results found in the literature search.
3. There is no such thing as a "typical" sprinkler system when one discusses evaporation. Conditions of duration and hardware must be specified before discussing sprinkler evaporation.
4. There is no such thing as a "typical" drip/micro system because of the wide variation in wetted soil percentage and canopy cover, as well as the possibility of cover crops for some micro methods.
5. Drip/micro ET_{field} can be greater than ET_{field} with sprinkler or furrow irrigation.

6. Although ET_{field} does not vary tremendously from wet to dry years, the ET_{irr} does change appreciably.
7. Evaporation (E) represents about 11% of the annual ET_{irr}, regardless of the year.

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