Subsurface Drip Irrigation (SDI) on Alfalfa

Technological solutions for the ecological and economic sustainability and stability of California's agriculture and statewide water supply

Important Water Efficacy and Crop Production Solutions for California

- **Water Conservation**
- **Reduced Groundwater Extraction**
- **Nitrates & Other Salinity Management**
- **Increased Yields**

Introduction

Properly designed, installed, and managed subsurface drip irrigation (SDI) in alfalfa is disruptive technology. Unprecedented increases in alfalfa yields compared to actual water use (ETa) were observed on over 1,000 acres of irrigated alfalfa using SDI. These data were collected at six distinct locations across the Central San Joaquin Valley of California. Average yields of 13 tons per acre were achieved with average water applications of 2.8 acre-feet per acre. This places SDI alfalfa water efficacy at 2.6 acre-inches per 1 ton of alfalfa produced compared to the California State average of 6.7 acre-inches per ton. From these results a potential water savings of 61% could be realized using SDI to irrigate alfalfa, along with reductions in nitrates and other salinity.

The 664,318 irrigated alfalfa acres in California currently use 2.524 million acre-ft of water to produce approximately 4.5 million tons of alfalfa. Using disruptive SDI irrigation and agricultural management technologies, the same 4.5 million tons of alfalfa could be produced on 346,153 acres using 0.978 million acre-ft of water.

Producing the same 4.5 million tons of alfalfa on 48% less land using 61% less water combined with a reduction in nitrates and other salinity would truly be transformational. Grower education combined with focused grower incentives to bring about this transformation would be a big win-win for all Californians, California's ecosystems, California Agriculture, better California jobs, and especially everyone concerned about the ecological and economic sustainability and stability of California's agriculture and statewide water supply.

Methodology

The yields on the 1,000 acres mentioned above were easily determined as the summation of the harvest amounts throughout the season. Conversely, the ETa (the actual water use) discussed above is difficult to quantify. Furthermore, it can be quantified only as precisely as are the other 6 components making up the Water Balance Equation (⌂W, I, P, C, R, & D). See Figure 1 on the next page.

On the 1000 acres the applied water (I) was precisely measured. The water content of the soil

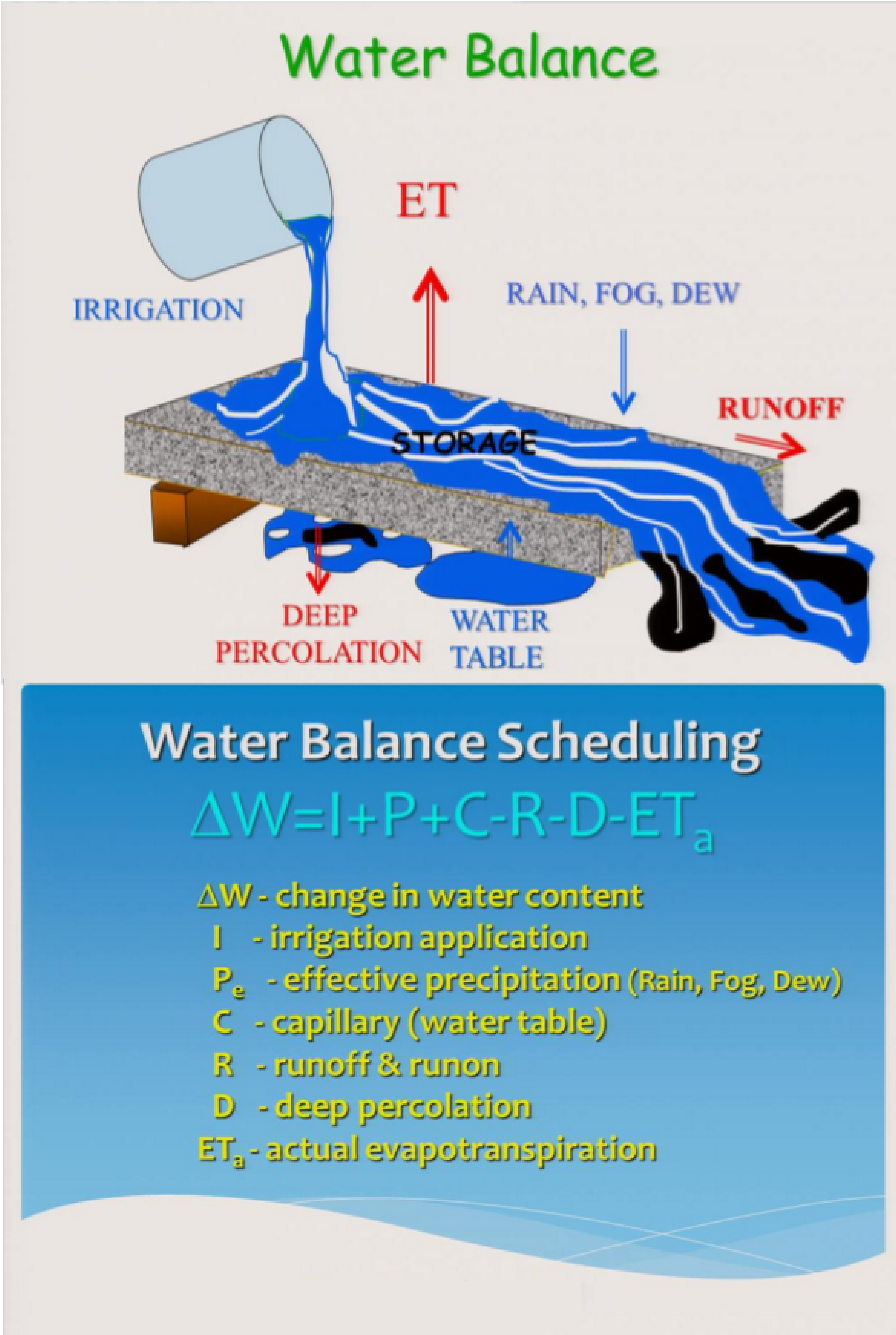

Figure 1. Water Balance (From: The Importance and Limitations of Irrigation Scheduling Using ET Rick Snyder, University of California, Davis, CA)

profile (W) was measured. However, there were limited numbers of measurement sites. Because of precision management practises and the extreme dryness of the 2015 season the profile water content was assumed to be similarly dry at both the beginning and ending of the crop year. Effective precipitation (P) was essentially zero for the 2015 crop year. The most difficult component to determine is the capillary contribution to the crop from a water table (C). Because of the water management control using SDI and the extraordinarily dry 2015 crop year, the assumption is made that C was zero. Net runoff & runon (R) was zero. The deep percolation (D) was also assumed to be zero.

The commercial operations comprising the 1000 acres don't have monitoring and control capabilities typical of university ag research farms. Nevertheless, the management of the 1000 acres of SDI was superb and the data was collected. The results should therefore be indicative of reality. In an effort to refine and expand the results presented and discussed in this paper, work will and must continue to better quantify each of the components in the water balance equation.

The Science

Figure 2 compares two functions defining the traditional linear relationship between Yield (tons) to

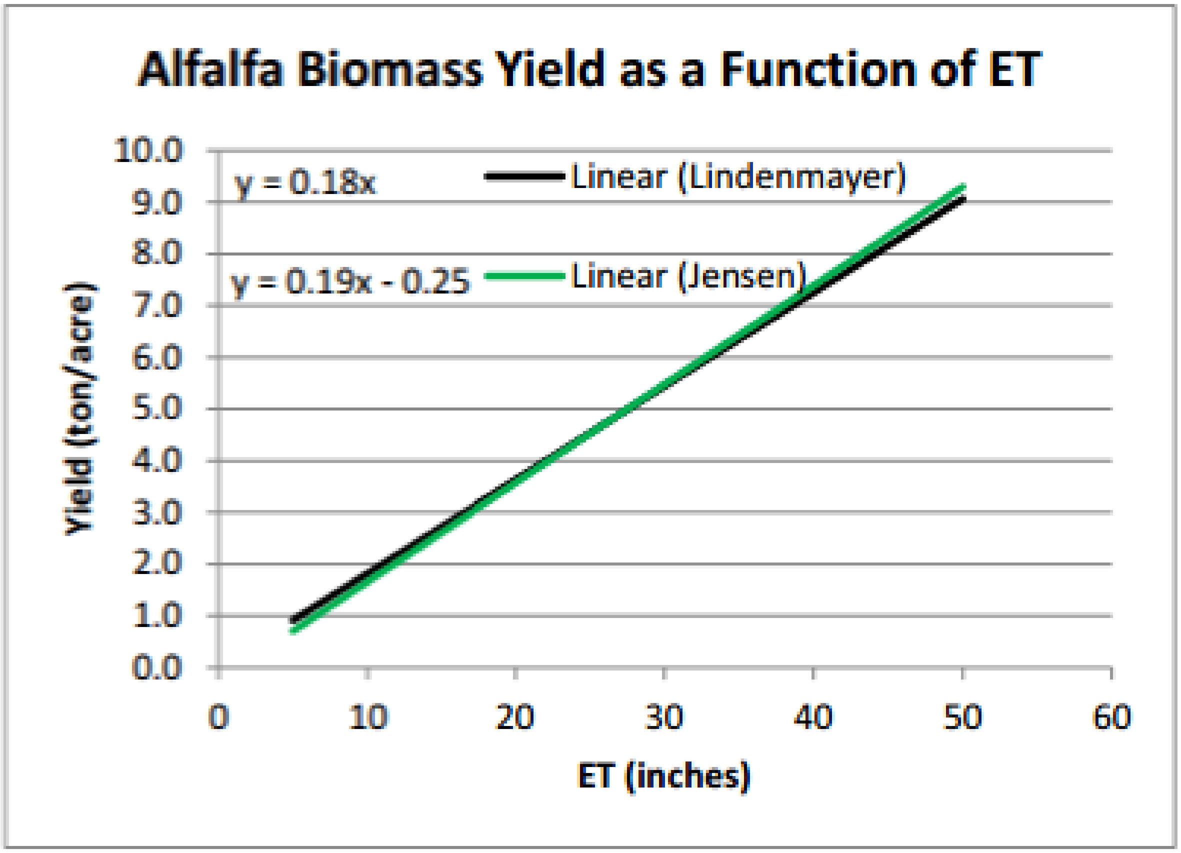

Figure 2. Alfalfa Biomass Yield as a Function of ET - Alfalfa Irrigation and Drought - Glenn E, Shewmaker, Richard G. Allen, and W. Howard Neibling -Kimberly Research and Extension Center, University of Idaho.

ETa (inches). The SDI 13 ton per acre alfalfa yields are off the chart. But, based on the equations, the SDI yields would correspond to 72 inch ETa using Lindenmayor or 70 inch ETa using Jensen. The reality in the field was 33.6 inch ETa, less than half that which is projected by Jensen and Lindenmayor. A clear understanding of why the equations of Figure 2 vastly understate achievable yields per unit of water for properly managed SDI is both critical and revelatory.

The reason why these equations miss SDI biomass produced per ETa inches of water is a combination of at least two factors: 1) SDI eliminates free water from the environment in the vicinity of the plants and 2) with SDI many crop stress factors are mitigated or eliminated altogether. Both of these factors can be significant. Together, they account for the dramatic improvement in plant biomass production and water use efficacy observed on the 1000 SDI acres.

<u>Free Water Yield Reduction and Reduced Water Use Efficacy</u>

One of the approximately 150 State CIMIS stations can be seen in Figure 3 on the following page. Each of these stations provide data to estimate the atmospheric evaporative demand (ETo) which has been correlated to the ET (evapotranspiration) of 12 cm tall cool season grass . ETo is estimated using the Penman Monteith equation also shown in Figure 3. and is strictly valid only at its specific location. ETo is essentially a measure of the available evaporative energy around the station and is independent of crop type, crop development, soil conditions, and irrigation and management practises. ETo is used as a close estimate to schedule irrigations for the areas surrounding a station.

ETc, the maximum potential crop ET is obtained by applying a crop coefficient, Kc, to ETo as shown in Figure 3. ETc can be achieved only when no restrictive conditions exist within the crop environment such as water stress, salinity stress, oxygen stress, pollution stress, fertility stress, or stress from disease. These stress factors are combined into a stress coefficient, Ks. An estimated value for ETa (the actual ET) for the crop is calculated by applying the stress coefficient, Ks, to ETc (the site and crop specific potential evapotranspiration), as shown in Figure 3.

Free water potential yield reductions can best be understood by observing the effects of free water on or about the crop in the form of light rain, dew, or fog as shown in Figure 4. Similarly, when plants and/or soil get wet from irrigation water, they also will dry out as the free water and moisture are evaporated from the vicinity. First, moisture residing on the plants is vaporized and then concurrent with plant transpiration the rest of the environment around the plant such as wet soil, puddles, etc. drys out.

Dr. Richard L. Snyder of the University of California, Davis, CA, states while referring to Figure 4, “The plants get all wet. They may not dry off until noon. The energy that is used to vaporize the water has got to evaporate that water off the surface before it takes it out of the soil. So, its using energy for that and you have less energy available to pull water out of the soil.”

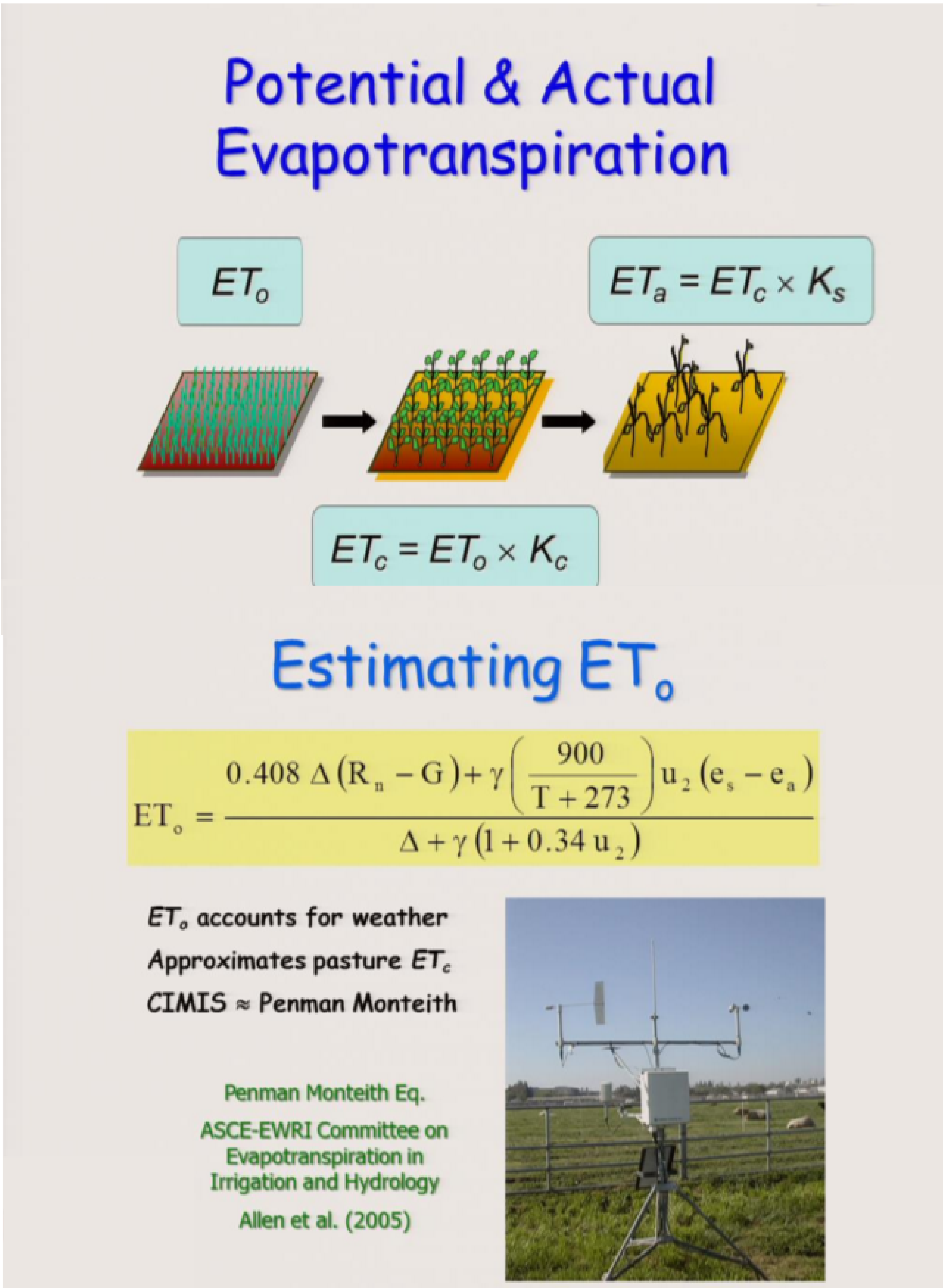

Figure 3. Evapotranspiration dynamics. From: The Importance and Limitations of Irrigation Scheduling Using ET, Rick Snyder, University of California, Davis, CA)

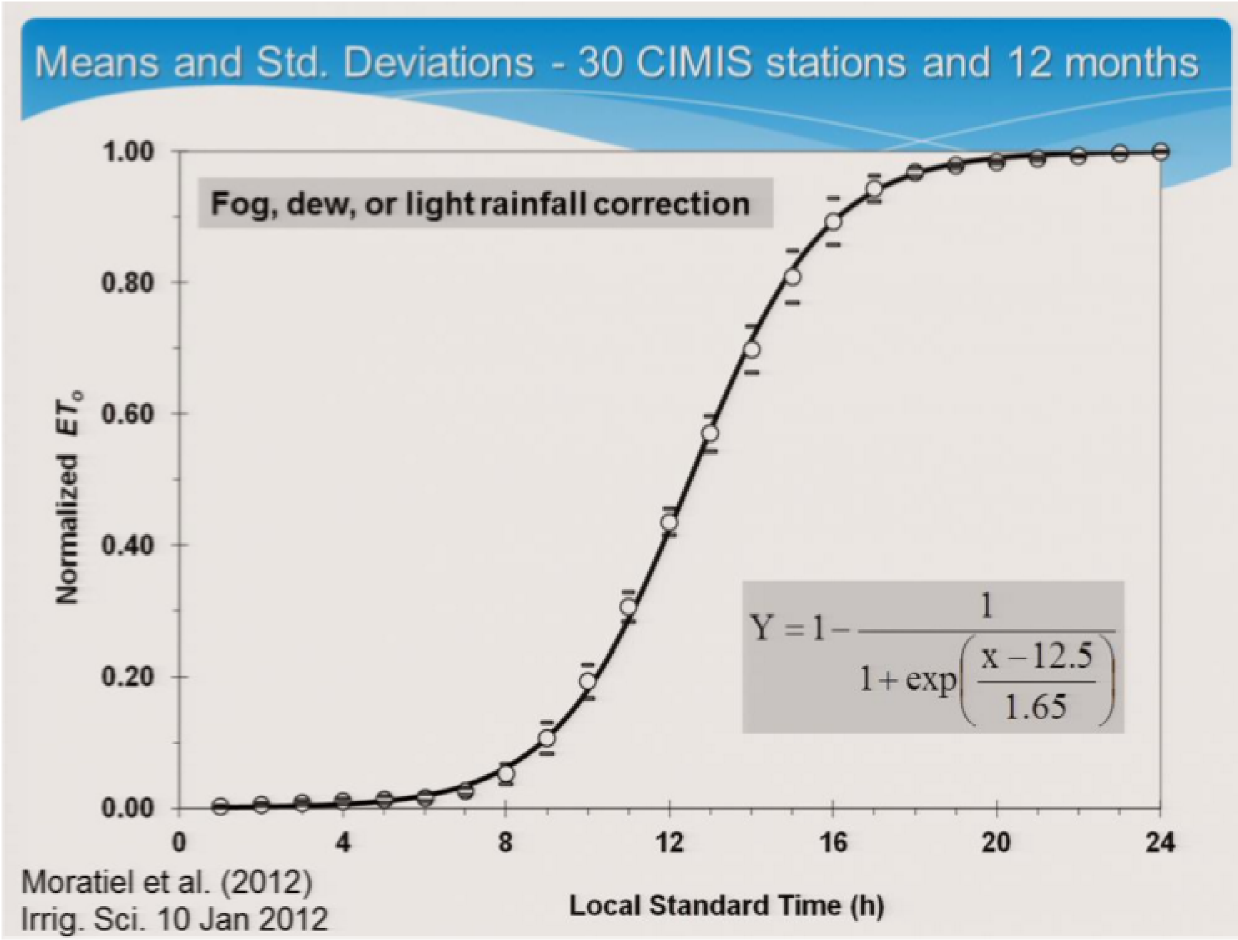

Figure 4. Evapotranspiration correction.

Water/nutrient take-up into the plant from the soil is driven by the matric potential differential in the plant as water vaporization takes place in the plant and is expelled out of the stomata and carbon dioxide is drawn in during the photosynthesis/transpiration process. This builds biomass and is subsequently manifest as crop yield.

Free water hijacks a portion of the available energy away from transpiration with a corresponding decrease in biomass production. This reduces plant water and nutrient uptake from the soil because of diminished photosynthesis/transpiration. A careful look at Figure 4 shows that easily 20% - 60% of potential crop ET (ETc) can be consumed evaporating free water before things dry out. This is significant in so many ways.

Yield Reductions Related to stress factors (Ks)

Environmental stress factors diminish crop yields because ETc can be achieved only when no restrictive conditions exist within the crop environment.

Flood and sprinkler irrigation water has to be stopped ahead of each cutting in order to dry down for equipment to get into the field. Watering cannot resume until the harvest is complete. This brings about plant water stress. SDI mitigates this effect because the irrigation stoppage period is much reduced and can be resumed instantaneously.

Oxygen stress can virtually be eliminated by air injection possible with SDI but impossible with flood or sprinklers. Also, each time a field is flood irrigated, oxygen stress is exacerbated because of complete soil saturation. For several days each season the crop is restricted from full robust growth as the gravity water drains away out of the larger pores to allow oxygenation of the roots.

Crop stress from disease is dramatically reduced using SDI because irrigation water never wets the crop or the soil surface. The same is true for weed pressure. The soil crust is dry with SDI, therefore weeds have difficulty establishing themselves. This has multiple benefits:

1. Reduces or eliminates herbicides and/or other weed eradication measures
2. Retains water for the alfalfa that normally would supply the weeds
3. Eliminates the need for GMO alfalfa seed
4. Increases the harvest quality.

<u>SDI and Nitrates and Other Salts</u>

Free water evaporation takes place in the environment outside of the plants themselves. Nitrates and other salts are left to concentrate in the environment by nutrient enriched irrigation water lost to free water evaporation. These nitrates and other salts are not taken up by the plant because the opportunity to become part of the plant through transpiration was lost. This multiplies leaching requirements and denigrates long term sustainability. This issue is mitigated with SDI.

Conclusion

The method for irrigating alfalfa along with its management is of utmost importance. With SDI, Yield to ETa ratios are dramatically increased. Applied irrigation water never wets the plant nor the soil surface. All of the irrigation water, nutrients, and air are deposited uniformly in the root zone. The very top of the soil remains dry with a hydraulic conductivity that approaches zero. Many crop stress factors are mitigated or eliminated altogether as also herbicides and the need for GMO seed. Nitrates and other salt concentrations due to free water evaporation are eliminated.

It is clear from the results on the 1000 acres of SDI alfalfa presented in this paper that action must be taken. To do so will yield high dividends for all the people of California and indeed the rest of the United States and the World.

- Millions of acre-ft of water will be conserved while achieving and even exceeding current production levels.
- Groundwater extraction will be dramatically reduced.
- Current levels of nitrates and other salinity will be mitigated and herbicide use reduced.

Grower education combined with focused grower incentives to bring about this transformation would be a big win-win for all Californians, California's ecosystems, California Agriculture, better California jobs, and especially everyone concerned about the ecological and economic sustainability and stability of California's agriculture and statewide water supply.

The economic value of millions of acre-ft of water and the mitigating effect of SDI for groundwater conservation along with nitrate and other salinity management is staggering. But, of even greater value would be the greater peace of mind for all Californians because of the reality of a more sustainable and stable statewide water supply and a state agricultural sector with a more vibrant workforce and brighter future.

Acknowledgements

Special thanks to Western Alfalfa Sciences, Inc. for their foresight and technical abilities to promote, design, install, and manage the 1000 acres of SDI on alfalfa presented in the paper.

Thanks to all the researches, associates, university facilities, experimental farms, laborers, and growers that have been instrumental over so many years to bring about the current understanding and state of the art of ET (evapotranspiration).

Particular thanks to Dr. Richard L. Snyder of the University of California, Davis, CA for a lifetime of work on ET, to Dr. Charles E. Burt, the irrigation guru at Cal Poly San Luis Obispo for contributions in California Agriculture beyond what anyone will ever understand, and Dr. Ken Solomon who was instrumental in making the Center of Irrigation Technology at Fresno State University what it is today and where much early work on SDI was conceived and tested.

Author credentials

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- Mr. Allred is currently working with Western Alfalfa Sciences, Inc. to promote the widespread benefits of SDI generally, and SDI in alfalfa in particular.
- Mr. Allred has a BS in Civil & Environmental Engineering and a MS in Irrigation Engineering from Utah State University where he learned from and associated with both Dr. Burt and Dr. Solomon and was tutored by the one and only Dr. Jack Keller.
- Mr. Allred has 1 year of work toward a PhD in Biological & Irrigation Engineering at Texas A&M University.
- Mr. Allred presented papers at the 1980 and 1981 ASAE Summer Meetings on "Stress Level Irrigation Scheduling".

- Mr. Allred pioneered irrigation scheduling in the late 1970’s and early 1980’s as the irrigation scheduling manager over 9000 acres of permanent crops for the old Superior Farming Company of Bakersfield, CA.
- Mr. Allred was a pioneer in line source drip irrigation on vegetables primarily in Mexico over a period of 25 years.
- Mr. Allred has been a pioneer in local natural Controlled Environment Agriculture (CEA) and urban agricultural food production for the past 8 years.