# SOIL MOISTURE MONITORING IN ALFALFA: DOES IT PAY?

**Blake Sanden, Grant Poole and Blaine Hanson**[1]

## ABSTRACT

Alfalfa yields have been shown to be very responsive to optimal irrigation in past studies. An economic analysis of yields as a function of applied water typical for the San Joaquin Valley showed that reducing alfalfa ET by 6 inches (about 12% of the seasonal requirement) can result in a loss of $96 when hay prices are $120/ton, water cost is $60/ac-ft and irrigation distribution uniformity (DU) is 100%. At a DU of 80% this loss drops to $44 and at a 70% DU drops to $33. Over irrigation by 6 inches is $30 in all cases. However, total net income for optimal ET declines significantly as DU decreases from 100 to 80 to 70%; going from a high of $285 to $211 to $148/ac/year, respectively. (This assumes other base field costs @ $300 and harvest costs about $25/ton.)

A wide variety of technology for soil moisture monitoring has come onto the market in the last 5 to 10 years. The cost of these technologies and the bells and whistles they come with also vary widely. Over the last 4 years, UC farm advisors and specialists have investigated the utility of granular matrix resistance sensors (Watermark® blocks) and inexpensive loggers for tracking soil moisture changes in alfalfa. An 80 acre field can be outfitted with these devices for less than $10/acre. These sensors have performed well in most locations but problems with installation, integrity of some cable connections, soil/field variability and sensor placement and the logistics of irrigation scheduling between cuttings can cause significant problems in gaining the full benefit of this technology to improve net profits.

**Key Words: alfalfa, irrigation, scheduling, distribution uniformity, water-use, soil moisture sensor, net income**

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## INTRODUCTION

Knowing the optimal timing and quantity of water to apply to irrigated crops in the arid southwestern US is without a doubt the foundation stone for profitable farming. In practice, the answer to this question, especially for surface irrigated fields, has often boiled down to “traditional” irrigation schedules that “work pretty good on the average” – once every 7 to 10 days for corn, every 10 to 20 days for cotton and twice per cutting for alfalfa. Simple, right?! And keeping things as simple as possible is of great value to a diversified grower who has to also deal with the complications of regulatory and business problems. Well, every farmer knows that ‘average’ is rarely the exact condition in his field at any given time. This is especially true with insect pests, where one untreated infestation may wipe out your whole crop. So it “pays” to monitor insect pests.

**But what about irrigation? Does it “pay” to check the water status of your crop and soil?** Unlike insect and disease problems, a little too much water or even deficit irrigation almost never causes a crop failure. Growers know good irrigation scheduling helps, but it’s usually not a “make or break” decision. Then, if you want to monitor, you have to ask, “Where should I check in the field? The infiltration is bad on this side. What about weather changes and salinity? What should I check it with? How often do I need to check? Should I be checking both the plant and the soil?"

At the bottom line, the question is a business and logistics decision: "Look, a consultant and/or some equipment to do all this is going to cost me $15 to $25/acre and a bunch of hours over the season to review all the numbers. Besides, I've only got two wells, two irrigators and 10 fields to get across. I have to give the water district my order a week in advance and take the water for 24 hours. We have to crank up a set schedule and keep it going or we won't get across the ranch in time. So is it really going to pay me to monitor soil and/or plant water status?"

Ultimately, only the grower can answer this question for his particular operation. This paper will attempt to give the grower some tools to do this by outlining some of the options for soil moisture monitoring, address concerns over field and instrument variability and offer a few cost benefit scenarios for alfalfa.

***Soil moisture sensing technology:*** For more than a half century, a great deal of work has gone into the development of soil moisture monitoring technologies. Much of this work has been done through bench top testing and field calibration in small plots and lysimeters. These are important activities for developing new technology (and generating scientific papers), but the application and reliability of these technologies is often proven out over decades in the field. Comparisons of heat dissipation blocks, gypsum blocks and tensiometers go back more than 60 years (Cummins and Chandler, 1940). Evaluation of the neutron probe was the hot topic of the 1960's (Van Bavel et al., 1961). Some of the common generalities used for this old standard (i.e. probable error ~ 0.1 inch per reading over a 6 inch depth of soil (Stone, 1960)) still standing today.

With the advent of the silicon revolution and desktop computers, microchips have created an exponential increase in the number of devices for monitoring and recording soil moisture changes. This now makes the sophisticated signal tracking needed for TDR and FDR (Time and Frequency Domain Reflectometry) processing possible in small package equipment. Capacitance changes of soil media due to changing water content have been long documented, but only in the last ten years have the size and expense of these types of sensors become feasible, not cheap – *feasible,* for field use. Papers on the calibration and comparison of these devices were common in the late 1990's (Paltineanu and Starr, 1997).

Growers have been inundated with the presence and promise of high tech offerings for the ag industry; from commodity trading on the internet to GPS driven tractor guidance systems and soil sampling. Whether you want real-time cotton prices, satellite imagery of your operation or web-based access of cell phone up linked weather and/or soil moisture data from automated sensors installed in your field there are lots of vendors to sell you product. An internet search of "soil moisture sensor" returned more than 50,000 references!

The physics and complexity of tracking irrigation, drainage and crop water use can be intimidating for the most educated of farmers. When you throw in this dizzying area of technology, most growers see the exercise of "real-time irrigation scheduling/soil moisture/plant stress monitoring" not becoming easier, but actually becoming a bigger problem and expense than it's worth. A continuation of the old calendar scheduling approach means ranch logistics are not complicated with changing water schedules. Especially in the San Joaquin Valley, where we have no summer rain and May through August potential ETo does not vary significantly, a calendar driven irrigation schedule, especially with low-volume micro systems, can work very well. Grower's are not always convinced that there is a significant payback for adding additional monitoring into their decision making and farming expense. Table 1 provides a brief comparison of the different types of technology used to monitor soil moisture.

Table 1. Comparison of different soil moisture measurement technologies.

| DEVICE | MODE OF OPERATION | ADVANTAGES | COST |
|---|---|---|---|
| **Steel rod depth probe** | 3/8" x 4 to 5 ' rod with handle and "acorn shape" tip is pushed into soil following irrigation to determine depth of wetting. | CHEAP!! Most rapid probe technique to find depth of penetration to 4'. | $2-4 (you make) |
| **Open faced push probe** | 3' commercial probe with ~ 7/8" bit and 12" open half pipe for retrieving soil sample as deep as 3'. Models available for hand push, foot-jack assist or slide hammer. "Hand-feel" moisture. | Quickest method for retrieving a soil sample to a 3' depth. See profile, hand-feel moisture estimate or oven dry sample. | $150-400 |
| **Auger** | Bucket shape with opposing teeth, screws onto extensions for desired depth. Auger is twisted into soil, cuts about a 2 to 3" depth at a time which must then be extracted and knocked out of the bit to continue cutting. "Hand-feel". | Holes from 2 to 4" in diameter can be cut to secure larger sample than above. Can probe to about 8' in 20 minutes. Easier on the back than push probe. | $100 – 250 |
| **Tensiometer** | Water filled tube with a porous ceramic tip attached to a vacuum gauge. Tip contacts surrounding soil; measures soil moisture 'tension' (matric potential). Monitors one site all season. | Easy install up to a 4' depth, no holes to dig the rest of season. Good for veg crops and most trees and vines. Stress thresholds known. | $50 |
| **Resistance Block** | Often called a gypsum block or Watermark®. Uses changes in electrical resistance to estimate changes in soil moisture. Requires special meter to read. Intimate contact with soil essential. Readings often related to soil moisture tension. Can be a problem on course or cracking soils. | No maintenance required after install. Produces electrical signal so can be hooked up to a data logger for frequent monitoring. Data loggers run from $250 to 5,000. Hand held meter for spot reading $100 – 200. | $12 – 29 |
| **Neutron Probe** | 2 to 2.5" hole is augured into monitoring site. PVC or aluminum pipe is installed. Radioactive source lowered into access tube, scatters neutrons into soil profile. 'Slowed' neutrons are counted by a detector and are directly proportional to soil water content. (Radiation License required.) | Largest sampling volume of all probes (basketball size). Usually most accurate, yielding quantitative water content when calibrated to site. Probe to any depth. Can do hundreds of sites with one probe. Cost of PVC tube very small to measure multiple depths/site. | $2 PVC tube.<br>$6,000 probe |
| **Capacitance Probes** | The "dielectric constant" of soil changes mostly in response to changing water content. These probes, from a buried sensor or strip to probes inserted in access tubes, measure the frequency change of a radio signal and use this to estimate actual water content or a relative 0 to 100 reading. Very small sampling volume. | Most can be installed once and then checked over the season without additional digging. Some can be sensitive to very small changes in water content. Requires hand-held meter or, most often, a data logger to read. | $60 (single sensor) to $13,000 system |
| **Time Domain Reflectometry** | TDR uses the time delay of a reflected voltage pulse between two electrodes to measure the "dielectric constant" of the soil. Uses either buried sensors or access tubes. | Bigger sample volume than capacitance but electronics and power requirements more. Requires hand-held meter or, most often, a data logger to read. | $150 (sensor) to $15,000 |

Many orchard, vineyard and vegetable growers have tried using tensiometers. The appeal is that the device is simple to install/maintain and the principal of operation easy to understand. For about $150 you can install two of them at one location to give you an estimate of soil moisture "tension" at the 18 and 36 inch depths. Those who are convinced that this effort increased their profits usually continue using the device, but even many of them get busy in the middle of the season and do not maintain a sufficient internal water level and/or lose track of the record of readings. A small minority of growers (mostly winegrape growers and some orchards) know that they don't have the inclination or expertise to mess with monitoring and they will hire an irrigation consulting service for $15 to $20/acre (San Joaquin Valley). A neutron probe monitoring service is about $800/site. Some devices, like liquid filled tensiometers, pose a problem for monitoring in alfalfa because the top of the instrument must stick out of the soil and will be damaged when cutting.

More recently a more reliable variation of the old gypsum block, a "granular matrix" modified electrical resistance block made by Irrometer called the Watermark® has gained popularity with some growers and consultants as in inexpensive and "maintenance free" alternative to the tensiometer. At about $30 each, these sensors are currently the least expensive on the market. Recognizing the potential acceptance and value of these simpler devices some university ag extensionists have continued to examine the accuracy of the tensiometer and Watermark® blocks and compare them to some of the high tech sensors in publications more accessible to growers (Hanson, et al., 2000).

At issue is technology transfer and proving the value of potentially expensive equipment. And there's the rub, combine the variability of soils, crop type, different irrigation systems and grower management from one farm to the next and it is nearly impossible to guarantee the benefit of any one particular monitoring system. As a University of California irrigation extension advisor there is only one consistent answer I can give growers when I'm asked, "What's the best way to monitor my irrigation and crop ET?" – I reply, "Depends!"

This is not a satisfactory answer for most growers, who want a simple answer with a guaranteed benefit. Fortunately, most growers realize that optimal profit for their operation "depends" on a lot of variables and most of their decisions have some element of risk. But if an input, such as soil moisture monitoring, is not perceived as absolutely essential (such as monitoring insect pests) then growers will only "risk" the use of that input if: 1) the cost is minimal, say $10/ac, and will not eat up a big part of the crop profit margin, 2) they understand the how, when and why of using that input and the final benefit to crop performance.

***Sensitivity of alfalfa to water stress:*** Since the vegetative portion of the alfalfa plant is the yield component we're after there is basically a linear relationship between crop ET and hay tonnage. The amount of crop transpiration (water leaving the plant stomates) is directly related to the uptake of $CO_2$ out of the atmosphere absorbed by the plant through the stomates. Simply put, the more ET the more yield. Of course this is limited by the climate of the growing region. The potential evapotranspiration, $ET_o$, is the transpiration from a well-watered perennial cool season grass. This totals up about the same as a healthy non-dormant alfalfa stand on a normal cutting schedule. For the southern San Joaquin Valley (SJV) this is about 48 to 55 inches for an average year; for the high desert around Lancaster 60 to 65 inches and for the Imperial Valley about 70 inches. Figure 1 illustrates this yield-ET production function for a variety of regions.

One of the problems with this relationship is that the plant also respires and, especially in some desert areas with very high night time temperatures, this can reduce potential yield. This problem is illustrated in this particular set of ET-Yield production functions by the fact that the Imperial Valley comes out with the lowest tonnage "potential" per inch of water.

This 6 to 12 ton/acre is the usual range seen in most research studies. “But hold on a minute,” says the hay grower from the SJV, “I put on 50 inches of water and only get 8 to 9 ton/acre!” Insect and disease pressure? Is the stand and cutting schedule perfect? Is nutrition optimal? These other factors can impose significant losses to tonnage even though the irrigation may have been very efficient in fully supplying crop water demand.

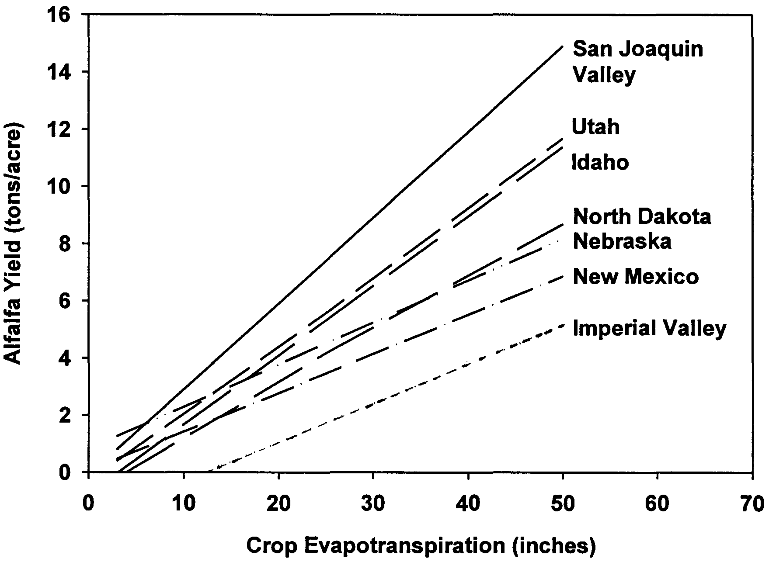


Fig. 1. Alfalfa production functions for various regions in the western US. (After Grimes, et. al, 1992 and Sammis, 1981.)

There are some studies that have revealed a very high production potential when all conditions have been optimal. Figure 2 shows the yield of two different non-dormant varieties as a function of applied water from a study in Yuma, AZ in the early 1980’s (Ludwig, 2000). A great deal of additional fertilizer was added to the treatments in this study and the top yield of 24 ton/acre was achieved with 150 inches of applied water. This yield is three times the average 8 ton/ac yield for the San Joaquin Valley at about three times the average 50 inch application. Even though the soil was a course loamy sand, the application of 161 inches actually depressed yield by an average 5 tons.

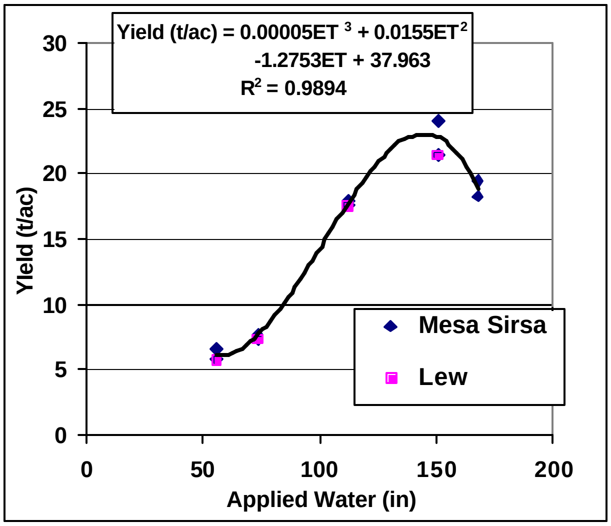


Fig. 2. Record alfalfa yield for two varieties as a function of applied water in Yuma, AZ (After Ludwick, 2000.)

***“Normal year” alfalfa water use for various regions in California:*** Table 2 lists approximate crop coefficient (Kc) values by month for established alfalfa in different regions of California. Using these Kc values and multiplying by the monthly “normal year” reference crop ET ($ET_0$), as given by the area CIMIS station listed in the table, the ET for alfalfa for an average year is then calculated in Table 3.

The major differences in water use are basically related to dormancy and the natural heat of the climate. Roughly speaking the mountain areas need around 3 to 3.5 feet of water, the Valley 4 to 5 feet and the deserts at 5 to 6 feet. ***Special Note:*** There is still significant debate about some of the “normal year” $ET_0$ values and appropriate crop coefficients for different regions. A different Department of Water Resources publication (DWR, 1993) puts average alfalfa ET at 48.5 inches. This number has been used as optimal ET for the following analyses in the SJV.

Table 2. Approximate crop coefficient (Kc) values by month for established alfalfa in different regions of California. Listed from southern to northern California by the area CIMIS weather station.

| CIMIS Location | Meloland (Imperial) | Victorville (S. High Desert) | Shafter FS (Kern) | Belridge (W. Kern) | Five Points (W. Fresno) | Bishop (Central High Desert) | Orland (Glenn) | Tulelake FS (Siskiyou) |
|---|---|---|---|---|---|---|---|---|
| **No.** | **87** | **117** | **5** | **146** | **190** | **35** | **61** | **91** |
| **Jan** | 1.10 | 0.40 | 1.00 | 1.00 | 1.00 | 0.20 | 0.40 | 0.00 |
| **Feb** | 0.95 | 0.50 | 1.10 | 1.10 | 1.10 | 0.20 | 0.50 | 0.00 |
| **Mar** | 0.95 | 0.90 | 1.10 | 1.10 | 1.10 | 0.30 | 0.70 | 0.20 |
| **Apr** | 0.95 | 1.15 | 0.95 | 0.95 | 0.95 | 0.40 | 0.95 | 0.40 |
| **May** | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.80 | 0.95 | 0.80 |
| **Jun** | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| **Jul** | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| **Aug** | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| **Sep** | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| **Oct** | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.70 | 0.95 | 0.70 |
| **Nov** | 0.95 | 0.80 | 0.95 | 0.95 | 0.95 | 0.50 | 0.95 | 0.50 |
| **Dec** | 0.95 | 0.60 | 0.90 | 0.90 | 0.90 | 0.20 | 0.90 | 0.00 |

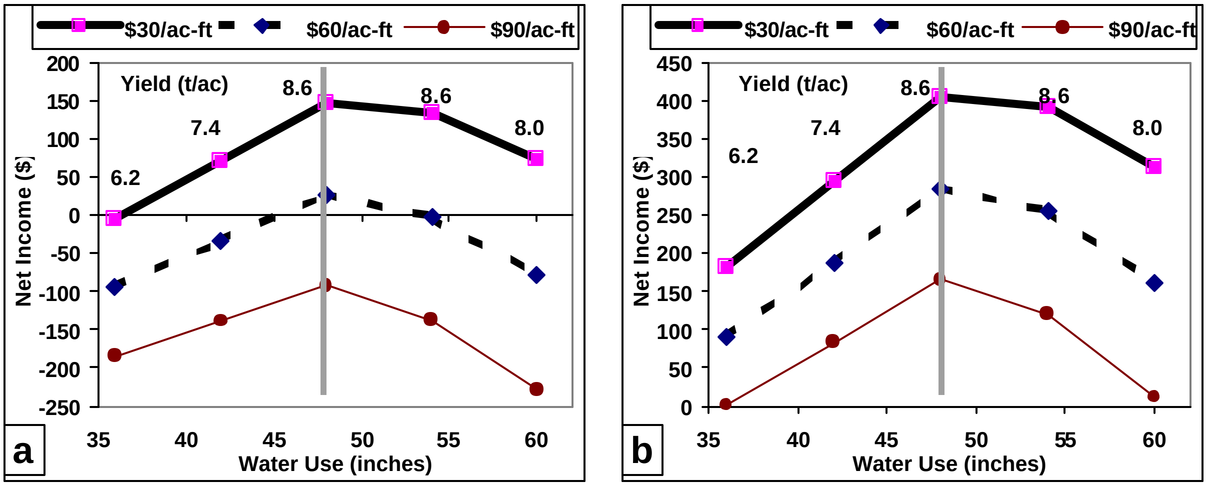
Table 3. Monthly alfalfa ET calculated from "normal year" weather data recorded by area CIMIS stations multiplied by Kc values in Table 2.

| CIMIS Location | Meloland (Imperial) | Victorville (S. High Desert) | Shafter FS (Kern) | Belridge (W. Kern) | Five Points (W. Fresno) | Bishop (Central High Desert) | Orland (Glenn) | Tulelake FS (Siskiyou) |
|---|---|---|---|---|---|---|---|---|
| **No.** | **87** | **117** | **5** | **146** | **190** | **35** | **61** | **91** |
| **Jan** | 2.7 | 0.8 | 1.3 | 1.6 | 1.3 | 0.4 | 0.4 | 0.0 |
| **Feb** | 3.1 | 1.3 | 2.3 | 2.4 | 2.2 | 0.5 | 0.9 | 0.0 |
| **Mar** | 5.2 | 4.1 | 4.2 | 4.0 | 4.3 | 1.4 | 2.3 | 0.5 |
| **Apr** | 7.1 | 7.1 | 5.4 | 4.8 | 5.8 | 2.4 | 4.7 | 1.6 |
| **May** | 8.5 | 6.9 | 7.1 | 6.5 | 7.4 | 5.6 | 6.1 | 4.3 |
| **Jun** | 8.7 | 8.4 | 7.6 | 7.4 | 8.0 | 7.2 | 7.1 | 6.0 |
| **Jul** | 8.6 | 9.3 | 7.8 | 8.2 | 8.3 | 7.7 | 7.5 | 6.7 |
| **Aug** | 8.0 | 8.5 | 7.0 | 7.4 | 7.6 | 7.0 | 6.4 | 6.1 |
| **Sep** | 6.4 | 6.2 | 5.5 | 5.4 | 5.9 | 5.2 | 5.0 | 4.4 |
| **Oct** | 5.0 | 4.4 | 3.9 | 3.8 | 4.3 | 2.8 | 3.7 | 2.0 |
| **Nov** | 2.9 | 2.1 | 1.9 | 2.0 | 2.2 | 1.2 | 1.7 | 0.5 |
| **Dec** | 2.1 | 1.2 | 1.1 | 1.4 | 1.1 | 0.4 | 1.2 | 0.0 |
| **TOTAL** | **68.4** | **60.5** | **55.1** | **55.1** | **58.3** | **41.7** | **47.2** | **32.2** |

## ECONOMIC ANALYSIS

Before we can make a final practical assessment of the profitability of soil moisture monitoring we first need to use the above production functions and estimate a theoretical net profit for different levels of applied water. The following figures all assume a base capital and variable cost of $300 per acre without any associated water cost. The field yield is calculated based on the applied water. Net income is then calculated by subtracting the standard base cost and the varying water/harvest costs from the gross value of the hay. Except for ***Case 2 – Tulelake*** (where we assume 10 inches of effective rain will be available for ET) all water use is assumed to be supplied by irrigation. Harvest costs and hay prices are listed under each figure.

## *Case 1 – Net income for "average" production potential in the San Joaquin Valley*



**Assumptions:**

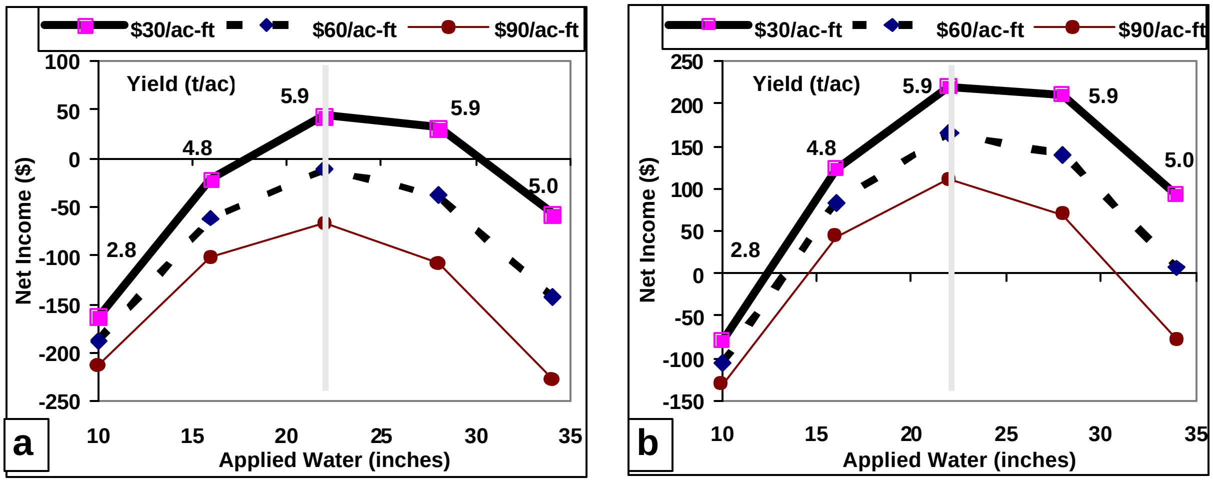
| | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 7 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$90.00** |

**Assumptions:**

| | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 7 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$120.00** |

Fig. 3. San Joaquin Valley: Net income as a function of applied water for associated variation in alfalfa yield @ (a) $90/ton and (b) $120/ton. Assumes all ET from irrigation.

## *Case 2 – Net income for "average" production potential in the Tulelake area*



**Assumptions:**

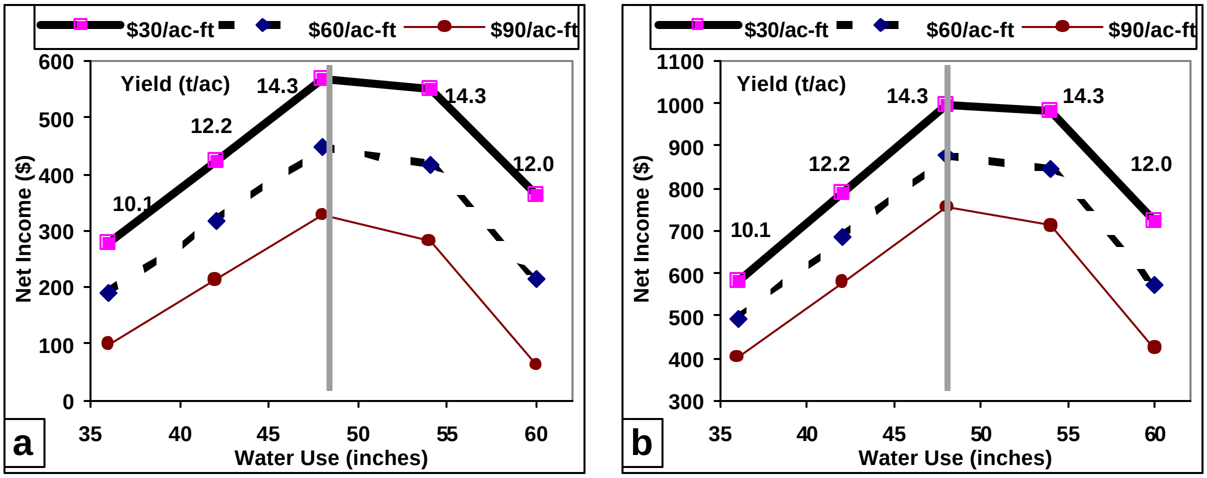
| | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 4 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$90.00** |

**Assumptions:**

| | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 4 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$120.00** |

Fig. 4. Tulelake: Net income as a function of applied water for associated variation in alfalfa yield @ (a) $90/ton and (b) $120/ton. Assumes 10 inches of ET from precipitation.

### *Case 3 – Net income for San Joaquin Valley 14 ton potential yield production function*

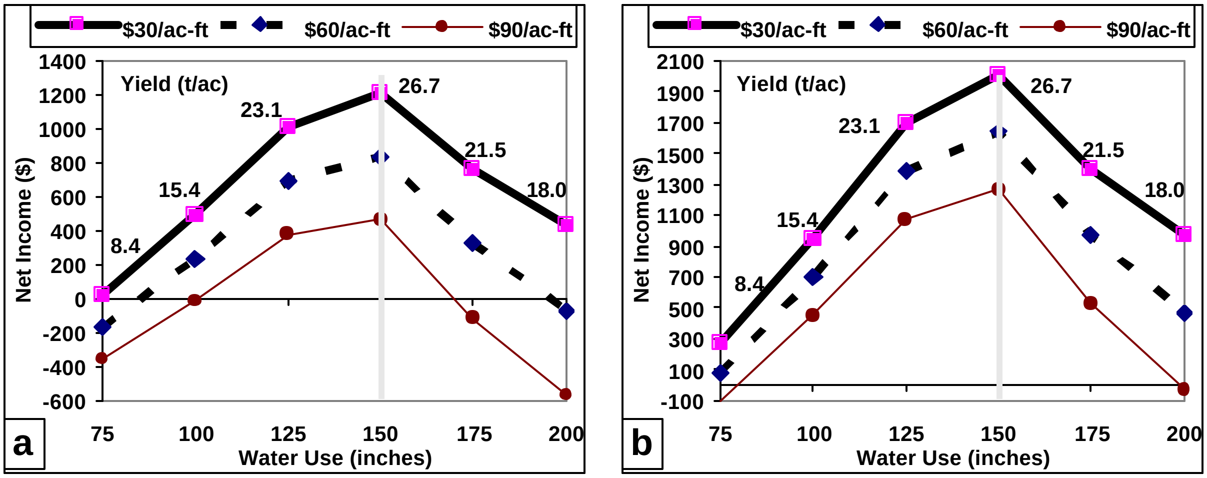


| **Assumptions:** | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 8 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$90.00** |

| **Assumptions:** | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 8 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$120.00** |

Fig. 5. SJV "high production": Net income as a function of applied water for associated variation in high potential alfalfa yields @ (a) $90/ton and (b) $120/ton.

### *Case 4 – Net income for Yuma, AZ record test plot yields*



| **Assumptions:** | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 11 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$90.00** |

| **Assumptions:** | |
|---|---|
| All base costs without water ($/ac): | $300.00 |
| No. of cuttings: | 11 |
| Cost of cut and rake ($/ac/cutting): | $12.00 |
| Custom bale ($/ton): | $10.25 |
| Harrow bed ($/ton): | $4.00 |
| **Hay price ($/ton):** | **$120.00** |

Fig. 6. Yuma record yield: Net income as a function of applied water for associated variation in test plot yields @ (a) $90/ton and (b) $120/ton.

***Discussion:*** Given constant hay prices, two things are obvious from the previous figures: 1) Under irrigation has the most significant impact on the loss of net income due to decreased yields and 2) Over irrigation by 5 to 15% usually has no deleterious impact on yield. The loss of income in this case is the same as the cost of the extra water. Using **Case 1 @ $120/ton** as a practical representative example, a 6 inch ET deficit results in a loss of 1.2 ton/ac. Adjusting for the decreased water and harvest cost this translates to a net income loss of about $81/acre at the $90/ac-ft water cost to $111/acre @ $30/ac-ft water cost. Since nearly all the water in the SJV now costs much more than $30/ac-ft, **Case 1 @ $90/ton** proves out the common saying, "I can't make any money on hay if the price is less than $100/ton!" **Thus, on a theoretical basis, avoiding a 6 inch ET deficit (12.5% of average season demand) in SJV hay would be worth $80 to $110 depending on hay and water prices. If you over irrigate by 6 inches, lost income is the cost of the water, which can be $15 to $45/acre in this example.** Additional over irrigation is often an invitation to stand loss due to scalding, phytophthora and invasion by grasses.

***Impact of irrigation uniformity:*** Theoretical production functions may be a nice starting point but the reality is that the highest yields shown in ***Cases 3 & 4*** above were done on small plots at ag research stations where irrigations were very short and nearly 100% uniform. Production field **distribution uniformity (DU)** may range from a low of 65% for a coarse sandy border flood system to 95% for sub-surface drip or new pivots and linear move sprinklers in low wind conditions. In Kern County from 1988 to 1999, the average DU for border systems was 80% (Brian Hockett, unpublished data). The average DU of hand move and big gun sprinkler systems is actually less than this number, but ranges from 65 to 91%. The DU is determined by taking the average depth of water applied to the driest ¼ of the field (the tail end for flood and ends of the sprinkler laterals) and dividing by the average depth of water applied to the whole field. Table 4 shows the impact on yield for different DU's and different amounts of applied water.

Table 4. Estimated effective depths of applied water over different quarters of an alfalfa field with a 70, 80 and 90 % distribution uniformity (DU) and the resulting hay yields using the "average" SJV production function.

| | | [1]Qtr Irrig by Avg Depth (in) | | | | [2]Qtr Yield by Avg Depth (t/ac) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Field Qtr** | **42** | **48** | **54** | **60** | **42** | **48** | **54** | **60** |
| **70% DU** | Wettest | 55 | 62 | 70 | 78 | 8.5 | 7.6 | 6.0 | 5.0 |
| | Wet | 46 | 53 | 59 | 66 | 8.2 | 8.6 | 8.1 | 6.7 |
| | Drier | 38 | 43 | 49 | 54 | 6.6 | 7.8 | 8.5 | 8.5 |
| | Dry | 29 | 34 | 38 | 42 | 3.6 | 5.3 | 6.6 | 7.6 |
| | **Field Average Yield (t/ac):** | | | | | **6.7** | **7.3** | **7.3** | **7.0** |
| | | 42 | 48 | 54 | 60 | 42 | 48 | 54 | 60 |
| **80% DU** | Wettest | 50 | 58 | 65 | 72 | 8.5 | 8.3 | 7.0 | 5.9 |
| | Wet | 45 | 51 | 58 | 64 | 8.1 | 8.6 | 8.3 | 7.2 |
| | Drier | 39 | 45 | 50 | 56 | 7.0 | 8.1 | 8.5 | 8.4 |
| | Dry | 34 | 38 | 43 | 48 | 5.3 | 6.8 | 7.8 | 8.4 |
| | **Field Average Yield (t/ac):** | | | | | **7.2** | **7.9** | **7.9** | **7.5** |
| | | 42 | 48 | 54 | 60 | 42 | 48 | 54 | 60 |
| **90% DU** | Wettest | 46 | 53 | 59 | 66 | 8.2 | 8.6 | 8.1 | 6.7 |
| | Wet | 43 | 50 | 56 | 62 | 7.8 | 8.5 | 8.4 | 7.6 |
| | Drier | 41 | 46 | 52 | 58 | 7.3 | 8.3 | 8.6 | 8.2 |
| | Dry | 38 | 43 | 49 | 54 | 6.6 | 7.8 | 8.5 | 8.5 |
| | **Field Average Yield (t/ac):** | | | | | **7.5** | **8.3** | **8.4** | **7.8** |

[1] The effective depth of irrigation for the respective "wettest to driest quarters" of the field given the average depth of applied water given in the top row.

[2] The yield from the "average" SJV production function corresponding to the applied depth of water for that "quarter" of the field given in the left hand section of the table.

Table 4 may be overly conservative because it basically says that you have to hit seasonal ET about +/- 3 inches with a 90% irrigation uniformity to get better than an average 8 ton yield for your field, otherwise you're going to drop into the 7 ton range. This is definitely too low for the best hay growers I know in the SJV, but it's very close to the average yields reported by County Ag Commissioners.

***Case 1 (revised) – Net income for "average" production potential in the San Joaquin Valley adjusted for yield impacts due to irrigation non-uniformity:*** Figure 6 below shows the revised net income after taking irrigation non-uniformity into account at the 70 and 80% DU levels and a hay price of $120/ton. All other costs are the same as given in Figure 3.

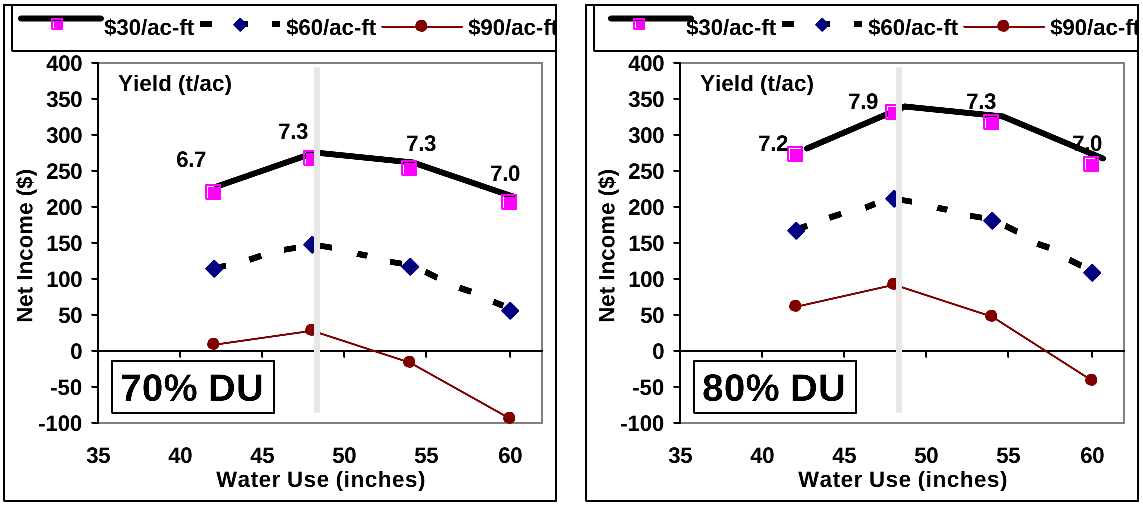


Fig.6. Differences in net income adjusted for non-uniformity of yield caused by a 70 and 80% irrigation distribution uniformity for different average depths of applied water.

example if you have a 70% DU. If the DU is 80% then a deficit of 6 inches will cost you $44 and 6 inches excess will again be a $30 loss. For ***Case1*** without adjusting for DU a 6 inch ET deficit was $96 in lost income. The greatest increase to net income in this example is increasing the DU from 70 to 80% -- a net gain of $63.

## MONITORING EXAMPLES

For most soils, alfalfa will not stress when soil moisture "tensions" are between -5 and -60 centibars. (Soil moisture "tension" is measured as a negative pressure. One centibar, cb, is 1/100th of a bar or one atmosphere of pressure – 14.7 psi.) The following figures illustrate soil moisture patterns for different irrigation systems and schedules. These figures also reveal the problems in getting accurate soil moisture readings and then being able to act upon the information to actually improve scheduling.

Figure 7 (following page) shows the greatest changes in soil moisture tension occurring at the 18 inch depth 400 feet from the tail end. While the 36 inch depth remains fairly dry for the whole season. There is virtually no response at the 60 inch depth (which stays about 20 cb for the whole season) – indicating virtually no, or minimal, deep percolation. The 60 inch sensor at the head end shows a similar pattern with a few small bumps that reveal some water penetration to this depth. The 18 and 36 inch sensors at the head end have almost identical patterns. This contrast with the tail end is consistent with flood irrigation where infiltration at the head end is greater than the tail. Late spring rains saved the grower an irrigation, but he made this decision for all his hay fields without reference to this data. Monitoring the field did not change his scheduling nor improve yield. This field yielded 7.5 ton in 6 cuttings and was terminated early in preparation for planting almonds.

Figure 8 illustrates soil moisture changes for a 155 acre alfalfa field on slightly rolling ground in western Kern County in the Belridge Water Storage District. This field is irrigated once per cutting with big gun sprinklers moved down laterals spaced at 135 by 150 feet, applying 7.4 inches of water per 24 hour irrigation.

The first thing the reader will notice is the big gap in July and August when the logger was knocked down and the wires cut by the harvester. In the lower chart are lots of horizontal lines that show intermittent bad connections between the sensor and the logger. This problem happened about 15% of the time until we started soldering connections between cables and sensors in the field.

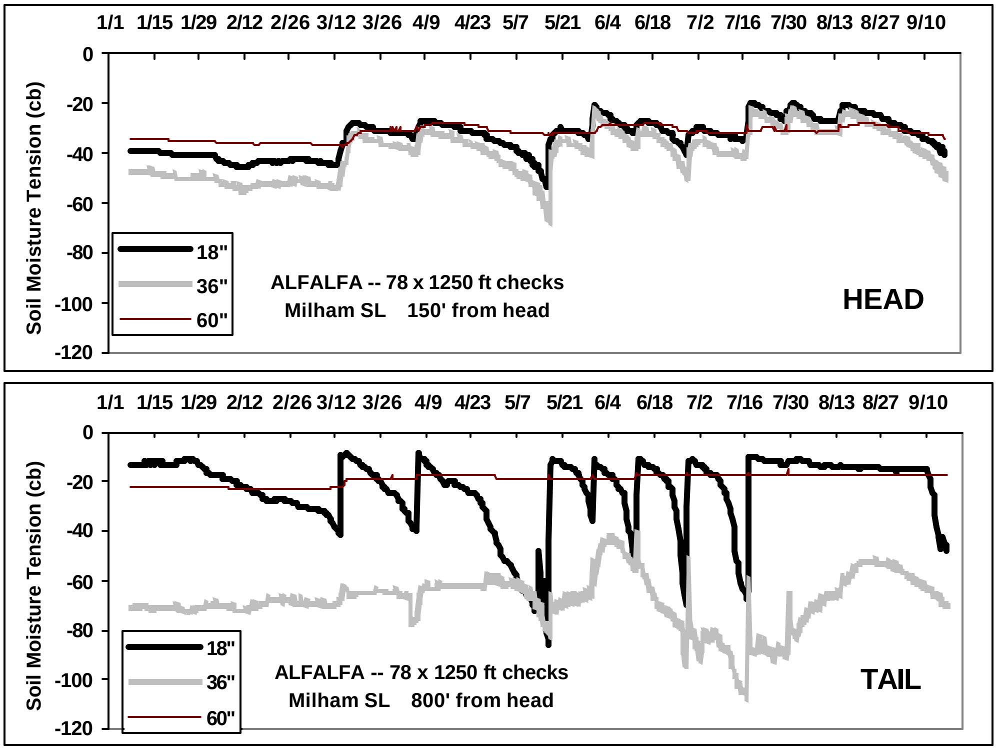


Fig. 7. Soil moisture tension changes for 2003 in a border strip irrigated alfalfa field in Kern County. Irrigated twice per cutting starting in May.

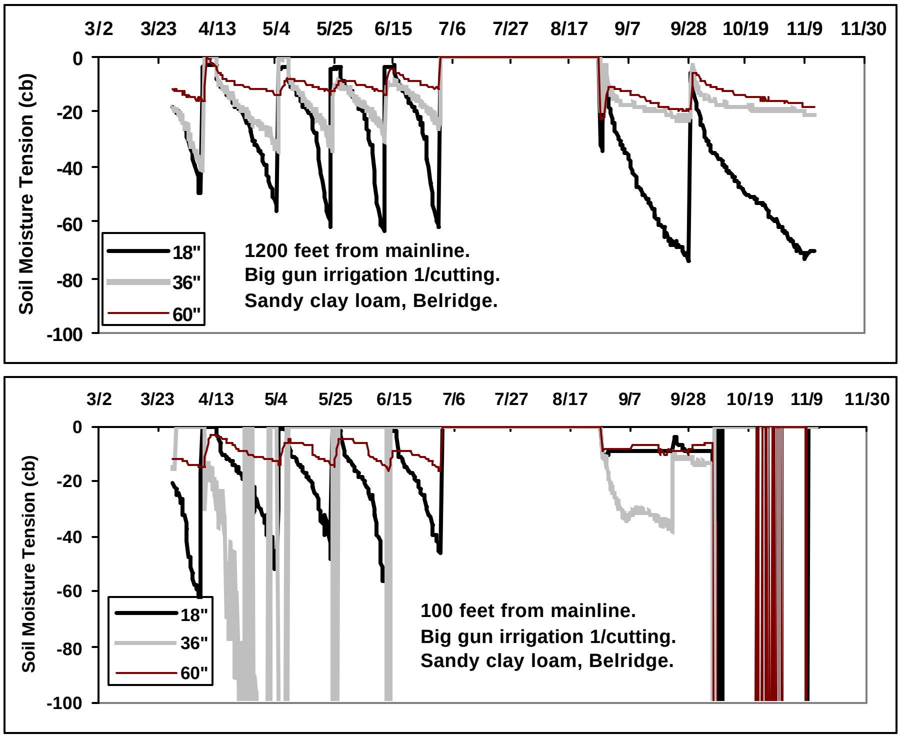


Fig. 8. Soil moisture tension changes for 2002 in an alfalfa field in western Kern County irrigated one time per cutting (7.3 inches over 24 hours) with big gun sprinklers

For both the end of the lateral (top chart) and near the mainline (bottom chart) the sensors show recharge down to 60 inches for every irrigation, with tensions usually going between 0 to -10 cb. This definitely resulted in some deep percolation for the spring irrigation period, but is about the perfect application rate for the summer. The grower applied 55 inches for the season and harvested 9 tons/acre of horse hay. Can he change his irrigation schedule given cutting requirements? No! Can he reduce some of the hours run time in the spring – maybe. Would it pay him to save 4 inches? Water in Belridge is $90 to $120/ac-ft depending on the year's allocation. You do the math.

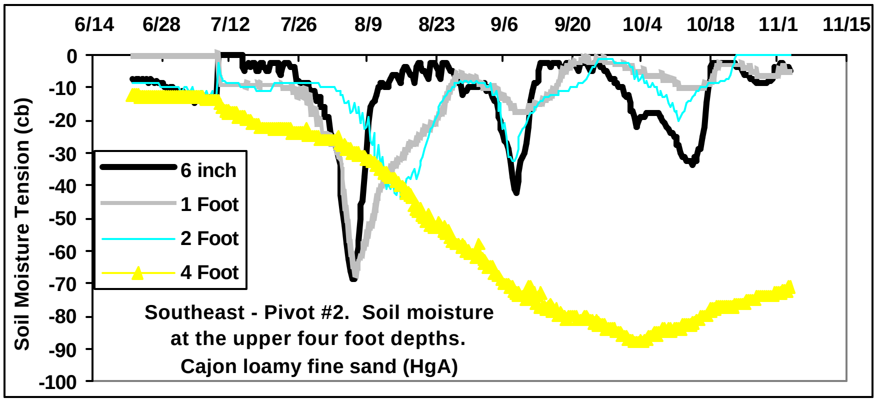


Fig. 9. Soil moisture tension changes for 2003 under a center pivot irrigating alfalfa (1inch/pass) in the high desert, northern Los Angeles County.

Figure 9 shows soil moisture patterns under a center pivot in Palmdale that continued with a slow deficit of applied water from when sensors were installed in June, 2003. With the application of around 1 inch per pass every 2 to 3 days this high frequency irrigation kept adequate moisture available to the crop while avoiding any losses to deep percolation.

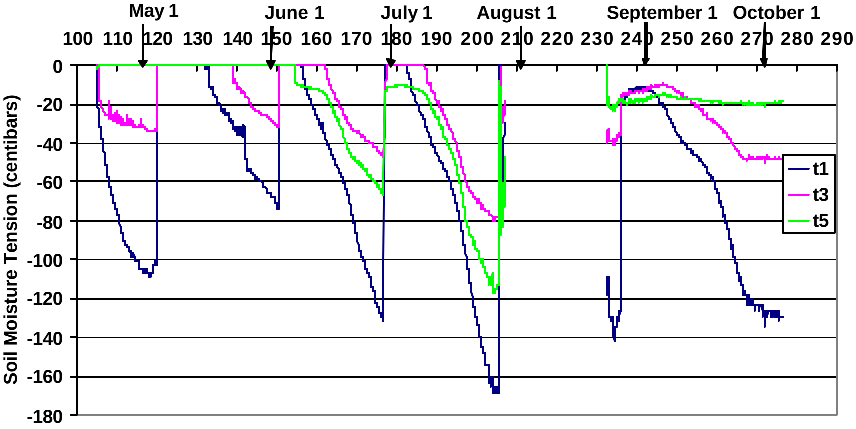


Fig. 10. Soil moisture tension changes for 2003 in a clay soil in the Delta border irrigated once per cutting. Sensors @ 1, 3 and 5 feet.

Figure 10 is an alfalfa field in the Sacramento delta area; heavy clay soil, border irrigated once/month. Extended periods of saturation for all depths are shown in the chart where readings go to 0 cb. Then in June and July the field dries to levels where stress starts to occur. This grower is losing yield due to water logging and stress, but his soil has a high infiltration rate and is too heavy to dry out enough for 2 irrigations per cutting.

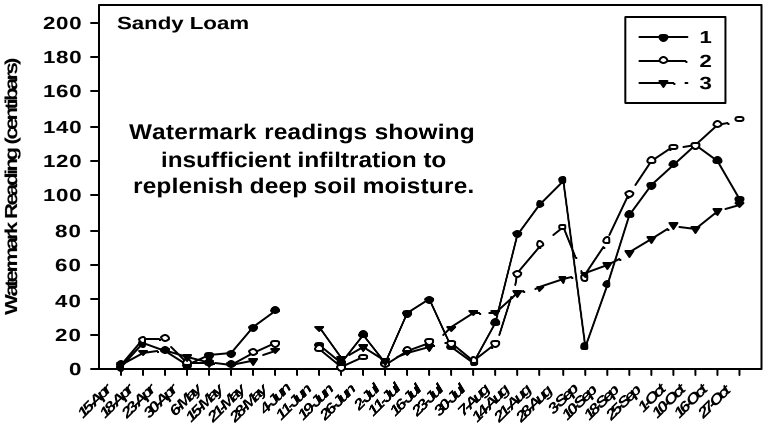


Fig. 10. Soil moisture tension changes for alfalfa irrigated by side-roll sprinklers in the intermountain area.

Figure 11 shows increasing soil water tensions for a field in the Tulelake area irrigated with side-roll sprinklers irrigated 4 times for the whole season – May, June and the end of July and

August. After June the 3 foot depth just continues to dry out. Tensions in the 1 and 2 foot depths in July and August indicate that crop ET may have been restricted and probably cost the grower some yield for his last 2 cuttings. An additional irrigation would have been possible, given the extended cutting schedule in this area, and probably increased the grower's net income.

## CONCLUSION

For average San Joaquin Valley yields (7 to 9 ton/ac), hitting alfalfa ET requirements within 10% of optimal can return a grower $15 to $50/acre, depending on water and hay prices. This increases significantly for potential yields >10 ton/ac. Increasing DU from 70 to 80% either through leveling, changing run lengths and/or flow rates and runtimes can return a SJV grower $60/ac @ hay prices of $120/ton.

**For soil moisture monitoring**; at a cost of about $10/acre (~$3/year over 3 years) for Watermark Blocks and a logger installed in an 80 acre field, there is good potential for a positive payback. But only if ranch logistics and flexibility of irrigation allow a grower to respond to the data being collected. Changing irrigation scheduling on flood blocks is very difficult for most operations; meaning that monitoring soil moisture will not provide a positive return on your investment. **Growers using hand lines, linears, pivots and siderolls are in a better position to profit from effecting real time scheduling changes with a potential payback of 3 to 5 times their investment in the monitoring equipment.**

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