Soil Moisture Sensors and Grower "Sense"Abilities:
3 Years of Irrigation Scheduling Demonstrations in Kern County

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ABSTRACT

Starting Winter 2001 an irrigation scheduling demonstration program was initiated in Kern County by UC Cooperative Extension and the area Resource Conservation District Irrigation Mobile lab to instrument grower's fields with neutron probe access tubes, tensiometers, electrical resistance blocks (Watermarks®) and a continuously recording data logger with a visual display that does not require downloading to a computer. Growers were faxed one page weekly irrigation scheduling recommendations also containing a seasonal summary of CIMIS ET estimates, soil moisture and applied water history. Additional fields on the Westside of Kern County were added to this program in 2002 as part of a CalFed Ag Water Use Efficiency project. More grower fields were set up in 2003.

A total of 101 fields covering 8,687 acres belonging to 21 different growers were instrumented over this time period covering 12 different crops, 11 soil textures and 9 different irrigation system types. The frequency of grower reference to field loggers and faxed irrigation schedules ranged from almost nil to very high; with a serious look at these soil moisture data averaging once every 7 to 14 days. Overall grower response was positive, with most stating that the program had made their irrigation more efficient and/or improved crop yield and quality. Often the degree of scheduling responsiveness was limited by ranch logistics and available labor. Many of these fields, primarily low volume systems using expensive water on the Westside, were near were optimal or deficit irrigated before entering the program, and, in some cases, soil moisture deficits recorded with this demonstration effort called for **increasing** applied water. The estimated water use efficiency (WUE) using crop ET calculated from local CIMIS weather station potential evapotranspiration (ETo) and appropriate crop coefficient values (Kc) divided by the applied water was very high, averaging 96% for 2002 (the most complete year). This estimate was almost identical to the 97% WUE determined by field measurement of soil water depletion with the neutron probe.

However, every grower has said that the most helpful part of the program has been the "human element" – direct interaction with the consultant through field/lunch meetings and phone calls. Despite the simplicity of the logger used in this study, most growers needed repeated visits to interpret soil moisture trends recorded by field data loggers and to explain the calculations used in faxed irrigation schedules.

INTRODUCTION

For more than a half century, a great deal of work has gone into the development of soil moisture monitoring technologies. Benchtop testing and field calibration in small plots and lysimeters are important activities and lend themselves well to generating scientific papers. 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) with some of the common generalities used for this old standard (i.e. probable error ~ 0.1 inch per reading or 6 inches 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 type 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 uplinked 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 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.

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.

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 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.

These two factors, minimal cost per acre and simplicity of concept/use, were the two constraints that underlay the last three years of soil moisture monitoring/irrigation scheduling demonstrations in Kern County.

PROCEDURES

A total of four programs with different funding sources have been used to carry out field instrumentation and grower demonstrations. (Programs (1) and (3) had additional objectives beyond those covered below.)

1) Sugarbeet Nitrogen Fertilization & Irrigation Scheduling Demonstrations for 2001 & 2002 (California Beet Grower's Association)
2) Kern County Irrigation Scheduling Demonstrations (Pond-Shafter-Wasco Resource Conservation District Mobile Irrigation Lab and CA Dept. of Water Resources)
3) Quantification of Benefits Attributable to Irrigation Scheduling as an On-Farm Water Management Tool (CALFED Water Use Efficiency Program, CA Dept. of Water Resources)
4) Kern County Grower Cost Share Program for Soil Moisture Monitoring (Individual Kern growers and the PSWRCD Mobile Irrigation Lab)

Core objectives of soil moisture monitoring/scheduling demonstrations:

1) Demonstrate efficient irrigation scheduling using a combination of:
   a Historical ET
   b "Real time" CIMIS ETo updates and crop Kc
   c Soil moisture monitoring
2) Evaluate the uniformity and water use efficiency for a variety of crops, irrigation systems and soil types.
3) Evaluate and compare different methods of soil moisture monitoring using weekly readings of:
   a. Neutron probe – total water content
   b. Tensiometers – soil moisture "tension"
   c. Watermark – electrical resistance estimate of soil moisture "tension"
4) Compare continuous monitoring with an inexpensive logger using Watermark resistance blocks to weekly monitoring. Evaluate grower "friendliness" and usefulness of method.
5) Interest growers in purchasing soil moisture sensors/logger system to improve water crop performance and dedication to more than "seat-of-the-pants" scheduling.

Key technology assumptions for grower response and program success:

- "One-shot" soil moisture estimates (tensiometers, soil moisture feel, etc.) are often poorly recorded and give growers an incomplete picture of the dynamic water content changes in the crop rootzone.

- Grower use of soil moisture monitoring will increase significantly if the monitoring system costs are about $10/acre. This includes monitoring multiple depths and locations.
- Equipment is easy to install, requires little/no maintenance and will perform for several years.
- Real-time soil moisture trends over the last 4 to 6 weeks are logged so that **they may be viewed at the field** any time without time-consuming downloads and data processing.
- Graphic displays of soil moisture changes, as opposed to one or a series of numbers, will be most easily understood be growers.

EQUIPMENT & FIELD LAYOUT

At present, the only sensor/logger combination that fulfills the above requirements utilizes six Watermark® blocks (manufactured by the Irrometer Co,) and the AM400 logger (M.K. Hanson). The resistance across the stainless steel electrodes embedded in these sensors has been calibrated to give an approximation of the soil matric potential (soil moisture "tension") equivalent to a tensiometer reading. The AM400 logger performs this calibration and stores one reading (from 0 to 199 centibars) for each of up to 6 sensors every 8 hours. A thermistor comes with the logger to provide for soil temperature correction of the readings.

The unique feature of this logger compared to other inexpensive loggers now on the market is the graphic LCD screen about 1.5" tall by 3" wide that, with the push of one button, displays a chart of the last 5 weeks of data (105 records) for a particular sensor without having to do a data download to a laptop or hand-held PC. A numeric display at the top of the LCD gives the sensor, soil temperature and current soil moisture. The button is pressed up to 6 times to view each of the sensors. Though an entire season of data can be stored on this logger, the face plate must be removed for access to the serial port for downloading. A simple graphing software is provided by the manufacturer, but all logger programming is fixed at the factory. The benefit of this approach allows a grower to install such a system without ever having to hook up to a computer. Inexpensive Category 3, 24 gauge communication wire can be used to hook up to sensors as far away as 1000 feet. Retail cost for 6 sensors, 1 logger, 1000 feet of 4 pair-Cat3 wire and a 4x4 post is about $650. Figure 1 illustrates a typical layout for a furrow field.

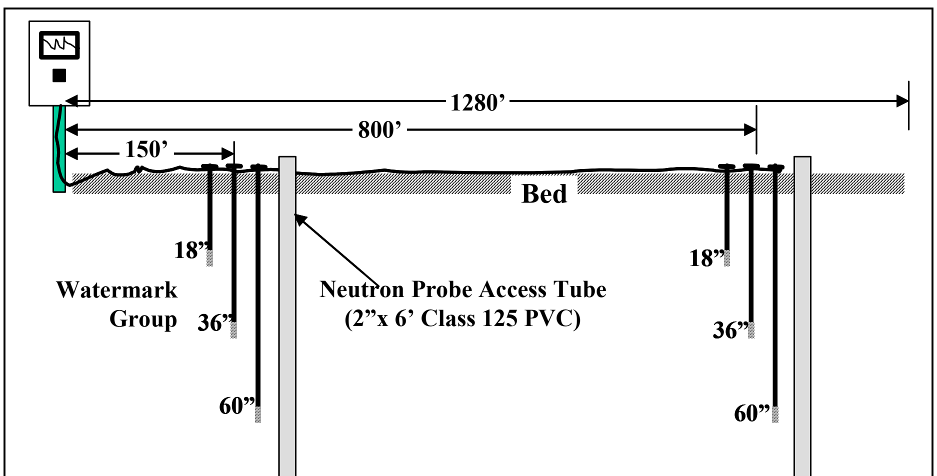

Fig. 1. Typical field layout of monitoring sites with surface irrigation. Spacing of Watermark sensor groups varied according to irrigation system, but usually set @ 18, 36 and 60 inch depths. (Not to scale.)

Watermark sensors were glued to the ends of ½" Schedule 315 PVC pipe cut to the desired installation length. A "tee" was glued to the top to facilitate installation and removal in annual crops. A PVC access tube was installed within 1 foot of all sensor groups at all sites to allow for neutron probe water content measurements to a depth of 6 feet with the exception of 8 systems installed this year. Growers purchased these systems, we assisted in the installation and they have been monitoring them on their own this season. (Some CalFed project fields are monitored only with the neutron probe.) In permanent crops with micro systems, sensor groups were placed near the end of the hose and by the "tee" in a 'typical' row. Small household-scale flowmeters were also installed in the hose serving the monitoring site to get an exact record of applied water. In some almond orchards, sensors were placed by a Nonpareil tree and wire buried under the drive row to a sensor group installed on the adjacent pollinator variety. In some vineyards and one subsurface drip irrigated almond orchard more information about the degree of subbing from the drip hose was desired and sensors were buried at a 2 foot depth at a 2 to 6 foot distance from the hose.

IRRIGATION SCHEDULING REPORT -- BLK20 SW (R4T5,10)

Adjustment factor (% of Mature Water Use): 110%

CURRENT DATE: 9/4/2002 LAST READING DATE: 9/3/2002

SOIL TYPE: course sandy loam
FIELD CAPACITY (in/ft): 1.7
REFILL POINT (in/ft): 0.8
ROOTING DEPTH (ft): 6
ROW SPACING: 21' x 24'
IRRIGATION SYSTEM: A-55 Fanjet
NORMAL RUN TIME (hrs): 24
WETTED VOLUME (%): 60%

Total Avail @ 100% (in): 5.4
AREA/TREE (sq ft): 504
DESIGN FLOW (gph): 18
WET AREA APPLIC (in): 2.29
NUMBER of SETS: 2
TOTAL AREA APPLIC (in): 1.38

CURRENT DEPLETION 5.31 (in)

PROJECTED IRRIGATIONS 9/5 9/7 9/9

CIMIS ET Estimates			
Week	Avg ET	2002 ET	Meas Use & Drainage
1/6	0.00	0.00	
1/13	0.00	0.00	
1/20	0.00	0.00	
1/27	0.00	0.00	
2/3	0.00	0.00	
2/10	0.00	0.00	
2/17	0.00	0.00	
2/24	0.11	0.19	*0.19*
3/3	0.23	0.33	*0.33*
3/10	0.37	0.58	*0.58*
3/17	0.44	0.53	*0.53*
3/24	0.52	0.73	*0.73*
3/31	0.61	0.82	0.72
4/7	0.68	0.79	0.86
4/14	0.77	0.93	1.65
4/21	0.89	1.07	1.48
4/28	0.99	0.90	1.15
5/5	1.10	1.09	0.55
5/12	1.24	1.48	1.86
5/19	1.36	1.64	0.91
5/26	1.47	1.59	1.86
6/2	1.56	1.37	1.73
6/9	1.65	1.83	1.41
6/16	1.76	1.88	2.25
6/23	1.85	1.95	1.65
6/30	1.89	1.97	1.06
7/7	1.91	1.98	2.15
7/14	1.89	1.83	2.20
7/21	1.86	1.94	1.50
7/28	1.82	1.85	2.32
8/4	1.74	1.79	1.36
8/11	1.67	1.51	1.43
8/18	1.58	1.58	0.73
8/25	1.51	1.51	2.10
9/1	1.43	1.43	1.30
9/8	1.33	1.33	0.78
9/15	1.21		
9/22	1.09		
9/29	0.95		
10/6	0.84		
10/13	0.69		
10/20	0.61		
10/27	0.51		
11/3	0.41		
11/10	0.31		
11/17	0.24		
11/24	0.18		
12/1	0.00		
12/8	0.00		
12/15	0.00		
12/22	0.00		
12/29	0.00		
Total	43.3	38.4	37.4

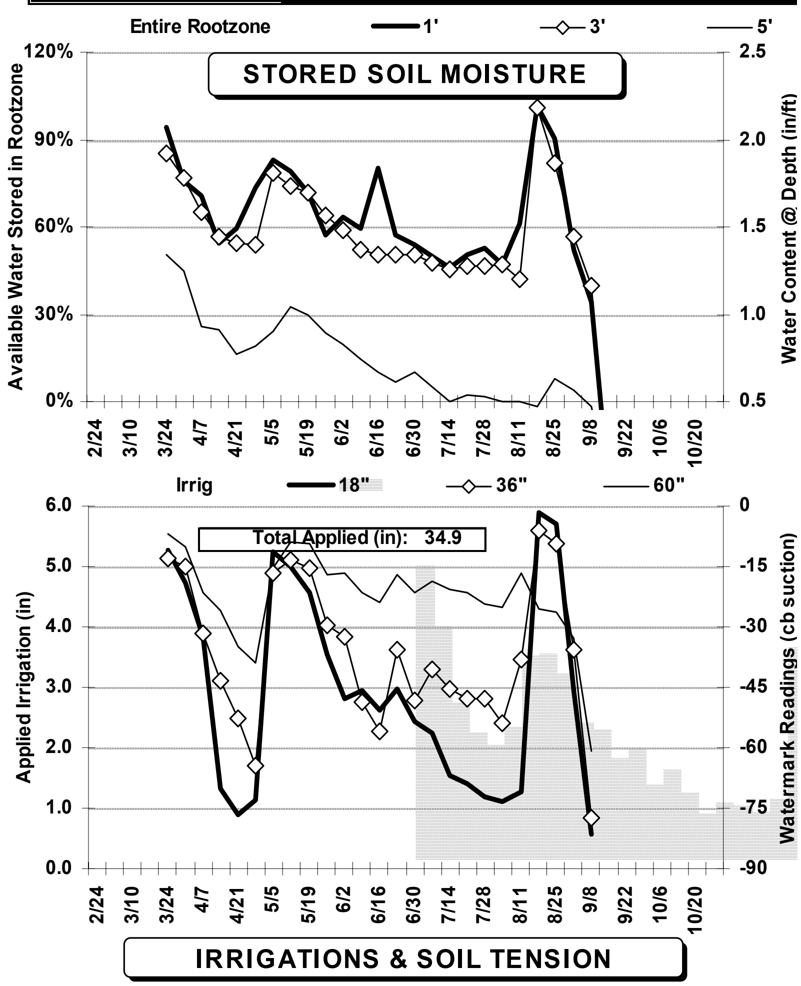

Fig. 2. Typical irrigation schedule for permanent crop low volume system. "CIMIS ET Estimates" are historical and real time values from the nearest weather station multiplied by appropriate crop coefficients. "Measured Use & Drainage" is calculated from neutron probe depletion.

Project tensiometers were used in a total of 9 fields over the years for comparison to Watermark readings, but only for the 18 and 36 inch depths. In these settings the Watermark and tensiometer were installed within 4 inches of each other. All monitored project sites were visited weekly during the season for 1 to 2 years depending on entry into the demonstration program. Data was recorded, averages of the weekly readings compiled for the two sites in a given field and the results faxed to the grower in a weekly report showing accumulated water content changes and recommended irrigation dates.

RESULTS

Figure 2 at the left shows a typical weekly schedule for a microsprinkler almond orchard. Neutron probe (NP) readings (indicated under "Stored Soil Moisture") show a more dramatic decline in soil moisture at the 5 foot depth than does the Watermark (WM) reading, but in general the WM readings are a good indication of changing water status. Both methods indicate slow drying in the lower rootzone; indicating slight deficit irrigation with almost no water lost to deep percolation. This farming company uses an in-house irrigation manager scheduler.

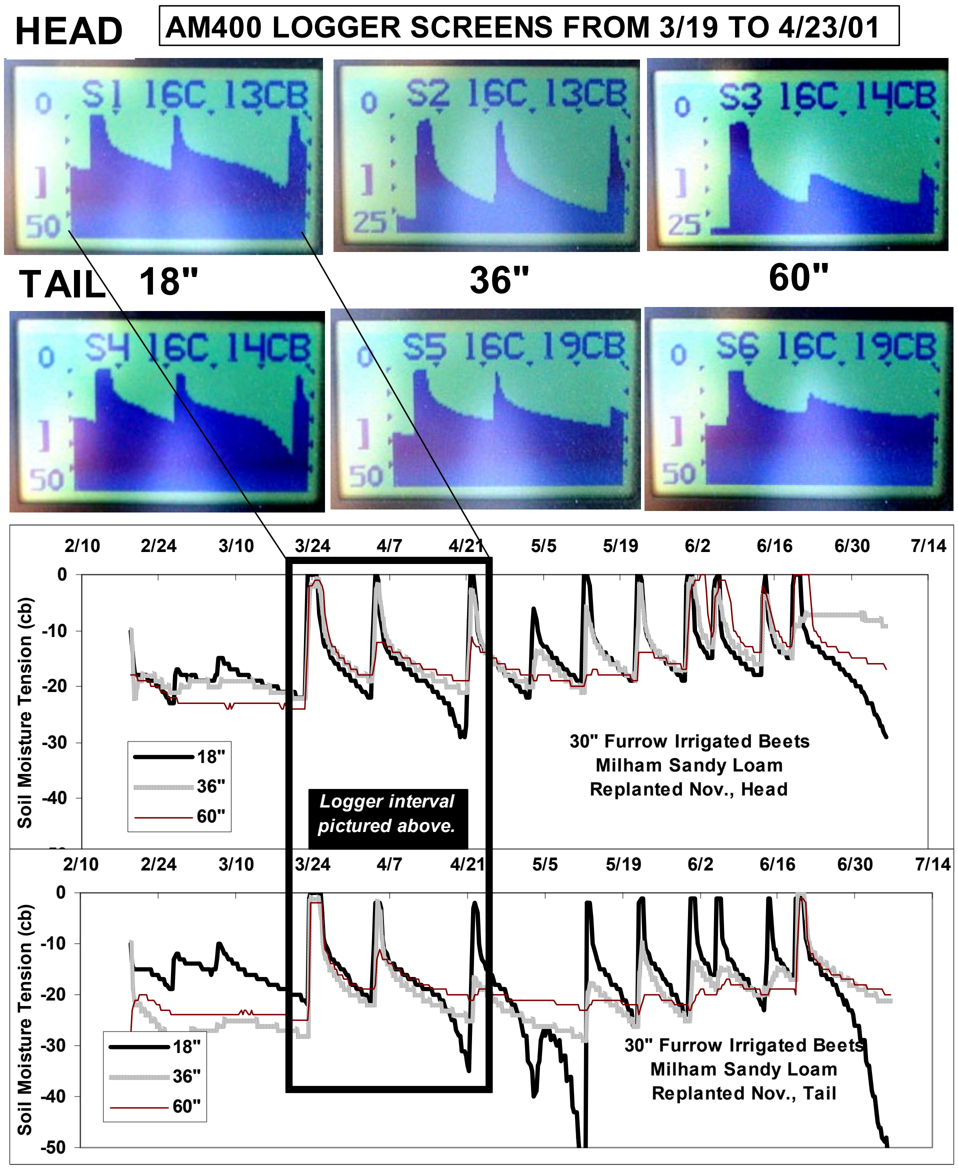

Fig. 3. Logger screen displays (top) for all Watermark sensors for 3/19-4/21/01. This monitoring period is bracketed in the season-long charts shown below. Total applied water was 38" with actual ET estimated @ 31". Alternate furrow irrigation using siphons on a 1280 foot run.

Contrast Figure 2 with Figure 3, furrow irrigated sugarbeets on a Milham sandy loam. The top part of the figure shows the screens as they appear on the logger just as a grower would view them while looking at the field. The charts below are created from a download of the logger at the end of the season. The value of real-time continuous monitoring is perfectly illustrated by this figure. The sharp peaks up to 0 cb indicate transitory saturation during irrigation at the 18, 36 and occasionally 60" depths. These are followed by a quick falloff down to about -10 cb with a slower, more even decline starting about 2 days after irrigation that represents actual crop water use. These figures clearly indicate that the irrigation schedule is too frequent – causing a significant amount of deep percolation (the sharp peaks). Weekly, 'one-shot' observations of soil moisture can not provide as clear a picture of this dynamic (and wasteful) water movement. This grower wanted to "keep the beets wet and leach the nitrate out of the rootzone to get better sugar" … and had to add water-run N fertilizer in April. Even with personal consultations he saw little need to change what he was doing in 2001 or 2002.

Calibration to actual water content and consistent performance of soil moisture sensors are the two biggest concerns always raised with these devices. Hanson, et al. (2000) in looking at 5 different soils found correlation coefficients of determination (r^2 values) of 0.67 to 0.83 for calibration curves developed for the NP by volumetric soil sampling. This degree of variation is often due more to volumetric sampling errors and natural soil variability than the instrument itself. The average correlation coefficient relating the NP water content to WM readings of soil 'tension' (an instrument to instrument comparison) was 0.87 with a standard deviation of 0.13. Even though the WM calibration is supposed to align with tensiometer readings, Hanson reported 66% of tensiometer readings were higher than WM readings.

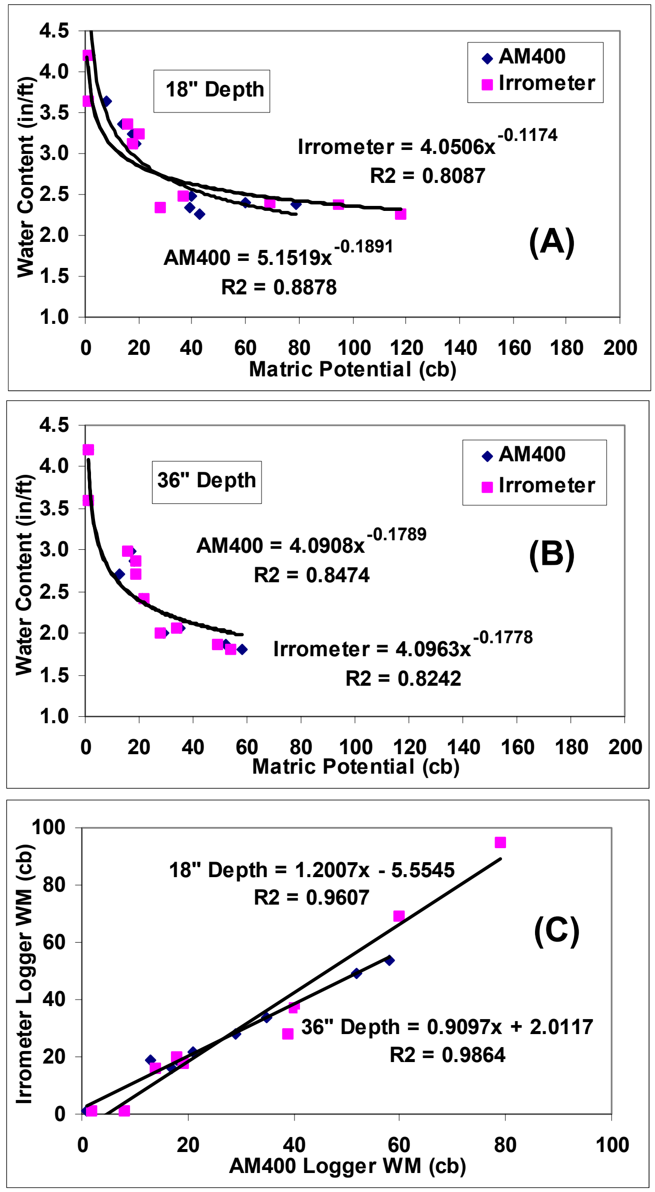

Fig. 4. Soil moisture release for a Lerdo complex clay loam in winter wheat (spring 2003) with water content decline as a function of matric potential as estimated by Watermark blocks attached to two different loggers (a), (b). Relationship of paired WM readings at the 18 and 36" depths (c).

These figures are similar to what we've seen in one area of the Kern Demonstration Project. In a comparison of the AM400 logger to a beta version of the Irrometer logger in wheat in 2003 we found an average r^2 value of 0.86 with a standard deviation of 0.036 for six WMs in a Lerdo clay loam (Figure 4). However, a very strong difference in soil moisture release can be seen between the 18 and the 36" depths due to a slightly higher sand content @ 36".

Problems with Absolute Numeric Thresholds and Accurate Sensor Calibration

Figure 4c. shows excellent correlation of WM sensors at the same depth for the two different loggers (>0.96), but close examination reveals the difference in predictive slopes is about 30%. Is this a difference in loggers or WM quality control? Probably not! In this case, the paired WMs that are correlated against each other are installed to the same depth (one set @ 18" and another set @ 36") and are only 4" apart. Even over this small distance it is possible to have enough soil textural/root density changes to significantly change what should be a 1:1 relationship. This difference clearly shows the limitations of exact calibration and using absolute numeric thresholds of soil tension and/or water content for deciding when to irrigate.

The problem is further underscored by the correlations with tensiometer and WM readings from our first year of the project. Using 7 fields with tensiometers installed at the 18 and 36" depths with 2 WM sensor groups and NP access tubes we ended up with 28 pairs of instruments to compare. Soil textures ranged from coarse loamy sand to sandy clay loam. A slurry of finer soil was added into the installation holes on the coarse textured soils. For determining tensiometer values as a function of WM readings the average of all regression slopes was 0.95 with a mean intercept of 10.5 and a mean r^2 of 0.645. Not bad in general, but the standard deviation of the slope and r^2 values was 0.61 and 0.23, respectively.

Table 1, following, lists the average season-long matric potential at the 5 foot depth, along with two estimates of irrigation efficiency and project rating characteristics by irrigation system, soil texture and crop for the 2001 and 2002 seasons.

Table 1. Various soil moisture, calibration, irrigation efficiency and project rating characteristics by irrigation system, soil texture and crop for the 2001 and 2002 seasons. 2003 data has not been collated.

Criteria	No. Fields	[1]Avg. 5' WM (cb)	[2]Mean Soil Moisture Release R^2 Best	Worst	[3]Irrigation Efficiency Estimate CIMIS	Meas.	[4]Sensor Performance	[4]Grower Use Ratings Logger	Faxed Sched.	Consultation	[4]General Efficiency Rating Original Grower	Demo Program
IRRIGATION SYSTEM												
Border	11	-39	0.62	0.15	100%	92%	2.0	2.0	1.7	1.8	2.3	2.4
Drip	21	-63	0.64	0.22	94%	97%	2.9	2.4	1.9	2.0	2.7	2.9
Drip SDI	1	NA	NA	NA	NA	NA	3.0	1.0	1.0	1.5	2.5	2.5
Drip Tape	3	NA	NA	NA	NA	NA	2.7	1.9	1.7	1.6	2.4	2.5
Fanjet	28	-59	0.70	0.18	98%	99%	2.7	2.2	1.6	1.9	2.8	2.9
Furrow	29	-20	0.79	0.21	90%	88%	2.8	1.3	1.4	1.8	1.3	2.1
Sprink/Furrow	1	-20	0.97	0.39	100%	100%	1.5	2.0	1.5	1.5	2.0	2.5
Sprnk-Big Gun	5	-30	0.47	0.05	99%	100%	2.2	1.0	1.0	1.5	2.3	2.3
Sprnk-Hnd Mv	7	-37	0.84	0.10	100%	92%	2.6	1.0	1.3	1.5	2.5	2.5
	Average	**-38**	**0.72**	**0.18**	**97%**	**95%**	**2.5**	**1.6**	**1.4**	**1.7**	**2.3**	**2.5**
SOIL TEXTURE												
C	2	-17	0.47	0.03	96%	92%	3.0	1.8	2.0	2.0	1.5	2.5
CL	14	-11	0.83	0.35	90%	89%	3.0	1.2	1.4	2.0	1.1	2.2
SiL	3	-30	NA	NA	91%	86%	2.3	2.0	2.3	2.0	2.7	2.5
SCL	16	-49	0.78	0.23	99%	97%	2.7	1.5	1.4	1.6	2.4	2.5
L	27	-48	0.71	0.12	98%	94%	2.5	1.7	1.4	1.8	2.6	2.6
csL	4	-13	0.75	0.07	87%	100%	3.0	1.4	1.3	1.1	2.3	2.4
fSL	5	-69	0.91	0.49	100%	97%	2.6	1.7	1.3	1.8	1.8	2.4
SL	25	-52	0.63	0.15	96%	96%	2.6	2.1	1.7	1.9	2.5	2.7
csSL	4	-29	0.50	0.23	83%	100%	2.6	2.5	1.5	2.3	2.4	2.6
LS	5	-44	0.71	0.30	90%	96%	2.7	2.3	1.7	1.9	2.3	2.5
csLS	1	-32	0.55	0.17	100%	100%	2.5	3.0	2.5	2.5	3.0	3.0
	Average	**-36**	**0.68**	**0.21**	**94%**	**95%**	**2.7**	**1.9**	**1.7**	**1.9**	**2.2**	**2.5**
CROP												
Alfalfa	6	-28	0.50	0.07	99%	100%	2.1	1.1	1.0	1.5	2.3	2.3
Almond	32	-59	0.69	0.18	98%	99%	2.6	2.1	1.7	1.9	2.8	2.9
Citrus	3	-13	0.75	0.07	87%	100%	2.8	2.5	1.5	2.3	2.2	2.7
Cotton	21	-27	0.83	0.19	95%	91%	2.9	1.1	1.4	1.9	1.6	2.4
Grape	14	-53	0.59	0.23	96%	92%	2.6	2.5	2.0	2.2	2.4	2.7
Melons	1	-39	0.52	0.01	100%	73%	1.0	2.0	1.0	1.5	2.5	2.5
Peppers	1	NA	NA	NA	NA	NA	3.0	1.5	NA	0.5	2.5	2.5
Pistachio	10	-62	0.66	0.14	96%	92%	2.8	2.0	1.6	1.7	2.9	2.8
Snap Beans	1	NA	NA	NA	NA	NA	3.0	1.5	NA	0.5	2.5	2.5
Sugar beet	7	-18	0.69	0.10	89%	89%	2.9	1.6	1.7	1.6	1.9	2.3
Tomatoes	3	-20	0.97	0.39	100%	100%	2.5	2.0	1.5	1.3	1.8	2.2
Wheat	8	-4	0.95	0.32	82%	79%	2.7	0.5	1.0	1.4	1.0	1.6
	Average	**-32**	**0.71**	**17%**	**94%**	**92%**	**2.6**	**1.7**	**1.4**	**1.5**	**2.2**	**2.4**
	***Project Means**	**-46**	**0.69**	**0.18**	**96%**	**95%**	**2.7**	**1.8**	**1.5**	**1.8**	**2.3**	**2.5**

[1]Season long average matric potential at a 5 foot depth as recorded by a WM sensor.

[2]Mean correlation coefficient R2 for paired WM and NP water content readings. Does not include 2003 data.

[3]Water use efficiency estimated by 1) dividing a CIMIS weather station season long crop ET by the applied water and 2) dividing the Project measured water content depletion by the applied water for the season.

[4]Sensor Performance, Grower Use Ratings and General Efficiency Ratings are anecdotal estimates by project staff and cooperators on the degree of use/benefit of various project aspects. "0" is no use/benefit, with "3" being high.

For most project fields, regressions of WM readings with NP data have yielded more than one usable soil moisture release curve. The mean "Best" R^2 value given in Table 1 is the mean value of the best curve fit from each field. The "Worst" value is the mean of the worst of the field curve fits. In general, results are fairly similar for all three categories. The notable exception being that of furrow irrigation and cotton. These reveal the greatest improvements in general efficiency going from a 1.3 to a 2.1 rating for furrow irrigation and attaining an 88% water use efficiency.

CONCLUSION

The point is that the perfect installation and highly calibrated instrument reading is seldom going to occur in large production field settings. Grower's "sense" abilities are quick to grasp this fact. We have made some progress in increasing these abilities during the last three years of field work. Some growers have simply changed the frequency on their calendar scheduling, but this is still and improvement. A few others have embraced the idea have "push button information" on soil moisture. The following points should be emphasized:

1. Growers need access to a consultant or farm advisor to help navigate the maze of monitoring technology.
2. Even with experienced help for installation, soil and crop rooting variability make exact calibration nearly impossible. Tracking the 'relative', dynamic changes in soil moisture is most easily done by continuous data logging and graphical presentation of real-time data.
3. Growers will only take advantage of this data if they can understand the presentation and access these charts quickly, reliably, and probably for less than $10 to $15/acre.
4. The most significant gains to be made by this type of monitoring are in annual, furrow irrigated row crops. These are also the tougher locations to install (and subsequently remove) monitoring equipment.
5. Out of nearly 500 Watermark installations only 3 sensors were unresponsive. Only one logger out of 80 was found to be defective and was quickly replaced by the manufacturer. The Watermark/AM400 logger systems can last for at least 3 years.
6. Average water use efficiency for Kern County Demonstration Fields has proven to be quite high. Benefits of soil moisture monitoring and scientific irrigation scheduling will likely come in the form of higher crop yields and NOT WATER SAVINGS.

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