Soil Moisture Sensor-Based Irrigation Scheduling to Optimize Water Use Efficiency in Vegetables

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Abstract

Advancement in the precision of soil moisture sensors has led to the adoption of these devices in the design, monitoring and control of irrigation systems in commercial agriculture, urban landscapes, and research. The World's soil sensor market has been estimated to grow at a rate of 16.2% between 2015 and 2020 reaching sales of 206.2 million U.S. dollars. While this rapid growth of the sensor market caters to the need of precision farming and effective irrigation, there still exists a need for researchers to determine effective depths for scheduling irrigation based on crop growth stage, soil texture, and infiltration rate. The overall goal of our ongoing study is to optimize water use efficiency (WUE) and irrigation scheduling in vegetable cropping systems. In this presentation, we focus on the technology and operating principles of the applications based on measurements of crop evapotranspiration (ET) or soil water content. For the ET-based approach, an irrigation-scheduling program was developed to: 1) poll daily ET data from a local state weather station using the California Irrigation Management Information System (CIMIS) web Application Programming Interface (API) over radio and internet links, and 2) calculate daily irrigation applications. For the sensor-based approach, six capacitance-soil moisture devices installed at three locations and two depths (6'' and 12'') were used with a datalogger and a 24VAC solenoid valve. Irrigation scheduling was programmed using upper (field capacity) and lower thresholds (30% maximum allowable depletion) of soil available water. Irrigation applications were triggered when the average soil moisture values reached the lower threshold and ended after field capacity was attained. In addition, some fields were irrigated based on visual crop and soil observations and manually operating irrigation valves. Results indicate that both ET- and soil sensor-based technology can improve water use efficiency and help growers optimize their irrigation scheduling.

Keywords: soil moisture sensor, water use efficiency, optimizing, irrigation scheduling, vegetable crops

Background

Efficient management of water resources is of utmost importance for the sustainability of irrigated agriculture, particularly in areas of diminished water supplies like California. One approach to improve irrigation efficiency is to implement scheduling practices that include the use of sensor technology and/or accurate measurements of crop water requirements based on replenishing evapotranspiration (ET). In

California, water conservation has become a top priority for vegetable producers as they thrive to adopt management practices that optimize irrigation and water use efficiency. One approach to improve irrigation efficiency is to implement irrigation scheduling practices to accurately estimate crop water requirements, and subsequently determine how much water to apply and when to irrigate. Implementation and the accuracy of these schedules could be improved with the use of soil sensor technology.

Soil moisture sensors (SMS) are good source for monitoring spatial variation of soil moisture and hence can be an effective tool for precisely managing water application to various crops. These sensors allow site specific crop management which is the most crucial part of precision agriculture (Badewa et al., 2018). Advancement in sensor technology have made them more accurate and precise in estimating soil water content. Development of technologies like internet of things (IoT) and data loggers have made these sensors to remotely monitor in-situ field dryness or wetness. SMS can be integrated with pump and valve controllers to automatically trigger irrigation based on crop water demand estimated indirectly from soil water content.

Every SMS can be categorized in to two basic types: volumetric water content (VWC) type and soil water potential type. VWC type measures percent volume of water in unit volume of soil while soil water potential type measures soil water potential. These sensors attached with controllers can be set with upper and lower threshold values for triggering and shutting off irrigation events. The upper threshold value is generally set at field capacity (FC) and lower threshold value at management allowable depletion (MAD) of soil. Field capacity is defined as the water content when free drainage ceases, and is equivalent the soil water content at a soil water potential is 0.33 bars and 0.1 bars for clay-textured and sandy soils, respectively (Enciso et al., 2007). MAD is defined as the soil water content below which the plants should not be allowed to stress, and is generally calculated as a percentage of the available water (AW). This value depends on crop types, growth stage and soil type (Enciso et al., 2007).

Besides using SMS, growers also use evapotranspiration (ET_o) data from weather stations and convert those values into equivalent crop evapotranspiration (ET_c) using crop coefficient (K_c) values with growing stage. Many growers still prefer to irrigate manually by visually observing dryness or wetness of soil and the crops.

The overall goal of our ongoing project is to evaluate the effectiveness of all these methods in terms of water use efficiency (WUE) for vegetables and other cropping systems typical of the San Joaquin Valley (SJV), California, USA. The specific objective of this presentation is to review the technology and operating principles of the applications based on measurements of ET_c and oil water content for estimating WUE of various surface drip-irrigated crops.

Materials and Methods

To evaluate these three irrigation scheduling options mentioned above, we conducted field studies on various crops (lettuce, tomato, sorghum, corn) irrigated with the following scheduling approaches (**Figures 1 to 10**): 1) soil moisture sensor (SMS), 2) ET_c, and 3) time-based with visual soil/plant inspection (control).The test site was located at the University Farm at California State University, Fresno. Soil texture at the test site was classified as a Sandy Loam.

For the sensor-based approach, **referred to as SMS**, six capacitance (Decagon 10HS) soil moisture sensors installed at three locations and at two depths (6’’ and 12’’) were used with a datalogger and a 24VAC solenoid valve. Irrigation scheduling was programmed using upper (field capacity) and lower thresholds (30% maximum allowable depletion) of soil available water. Irrigation applications were triggered when the average soil moisture values reached the lower threshold and ended after field capacity was attained. A Campbell Scientific CR1000 datalogger was used along with NL115 ethernet interface, RF401 radio modem, 900 MHz radio antenna and internet connectivity with 24 VAC solenoid valves in each irrigation treatment lines. Another CR1000 with RF401 radio modem and NL115 ethernet interface was used to give remote access to field data using internet. A PC with LoggerNet software and internet connectivity was used to monitor, control and download field data remotely.

For the climate based approach, **referred to as ET**, an irrigation-scheduling program was developed to: 1) poll daily ET data from a local state weather station using the California Irrigation Management Information System (CIMIS) web Application Programming Interface (API) over radio and internet links, and 2) calculate daily irrigation applications. Data from CIMIS station # 188 (Madera II) was used to poll daily ETo data by one of the CR1000 loggers connected to internet and then transfer this to field logger with irrigation control system. A CRBasic program was developed to calculate daily run time for ET based irrigation treatments.

For the “Control”, **referred to as “Manual**”, plots were irrigated based on visual crop and soil observations and manually operating irrigation valves. Typically, the operator would turn on the water in the morning and irrigate until the crop appeared turgid and/or when water began ponding on the soil surface. This was considered to be the practice adopted by grower based on the availability of water and the scheduling approach that took into consideration other crops plant on the farm.

Figure -1 Block Diagram of Overall System Design for ET and Soil Sensor Based Irrigation (*Left*), and photos of Lettuce plot (*Middle)* and Tomato plot (*Right*).

Fig. 2. Flowmeters with Valves (Tomato & Lettuce)

Fig. 3. Controller with Telemetry (Tomato & Lettuce)

Fig. 4. Soil Moisture Monitoring Station (Corn/Sorghum)

Fig. 5. Flowmeter Monitoring Station (Corn/Sorghum)

Fig. 6. Irrigation Controller (Corn/Sorghum)

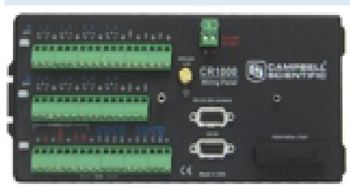

Fig. 7 CR1000 Datalogger

- Can be used to record analog and digital sensors.
- Can be programmed using CRBasic programming language for automation and control.
- Supports different communication protocols like SDI-12, RS232, PakBus, Modbus, DNP3, TCP/IP, FTP.

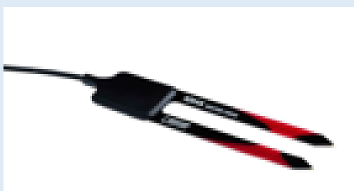

Fig. 8. Meter 10 HS Sensor

- Measures soil volumetric water content.
- Type: Capacitance (frequency domain).
- Range: 0-50% VWC.
- Measurement Time:10 ms.
- Output Type: 300-1250 mV.

Fig. 9. Seametrics MJR-200-1G Flowmeter

- Measures flow of liquid at higher rates.
- Sensor: Reed Switch.
- Output :Square Pulse.
- Flow Range: 0.44-52 GPH.
- No Power Required.
- Max Psi : 150 psi.
- K Factor: 1 Pulse/Gallon.

Fig. 10. RF 401 Radio

- Used for transmission and reception of data signals via radio frequency.
- Frequency range: 910-918 MHz.
- Designed to be used in PakBus network.
- Distance Range: up to 10 miles.

Results and Discussion

In Figure-1, FM1, FM2, FM3 and FM4 represent the flowmeters used in each irrigation line for tomato project. In the lettuce project, there were only three flowmeters as there were only three irrigation treatments. Flowmeters used for lettuce were analog type and hence no data from them could be recorder by datalogger. Therefore, all the readings were taken manually. However, for the tomatoes, Seametrics MJR-100-1P flowmeters were used that could send output pulses equivalent to amount of water flowing through irrigation lines.

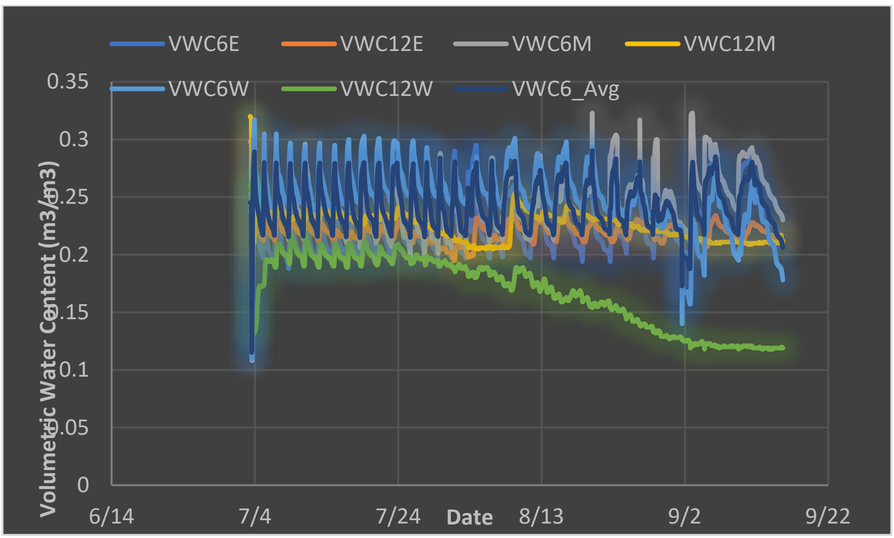

Figure-11 Soil Moisture Profile for SMS-Based Irrigation in Tomato.

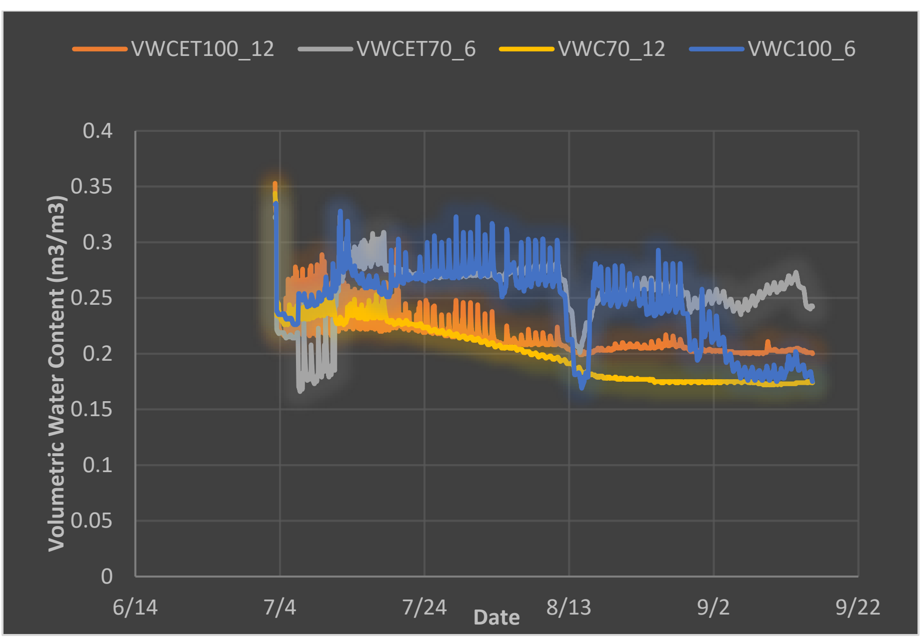

Figure-12 Soil Moisture Profile for ET-Based Irrigation in Tomato.

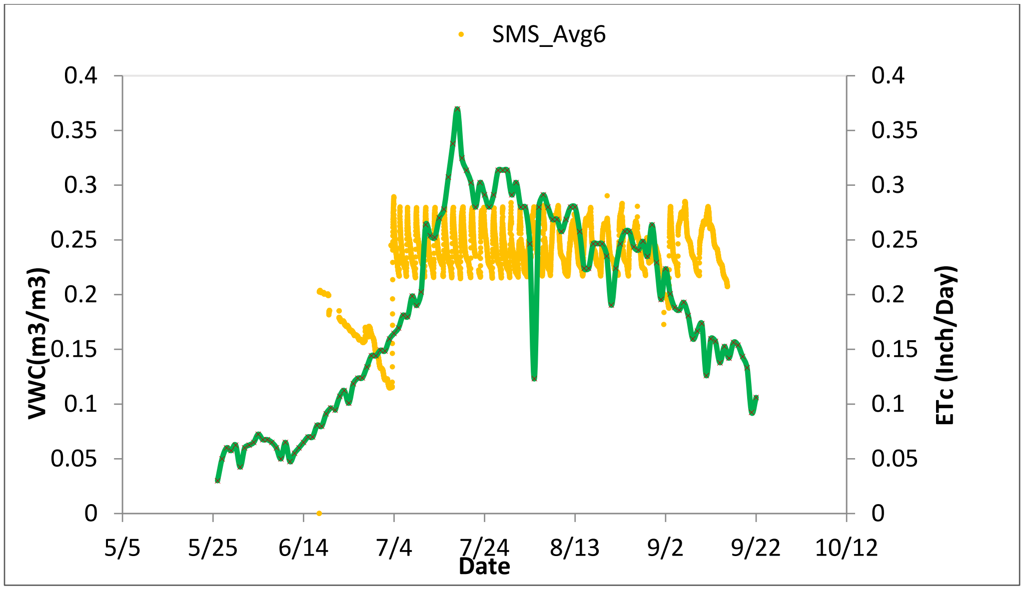

Figure-13: Soil Moisture vs. Daily ET$_c$ (SMS-Based)

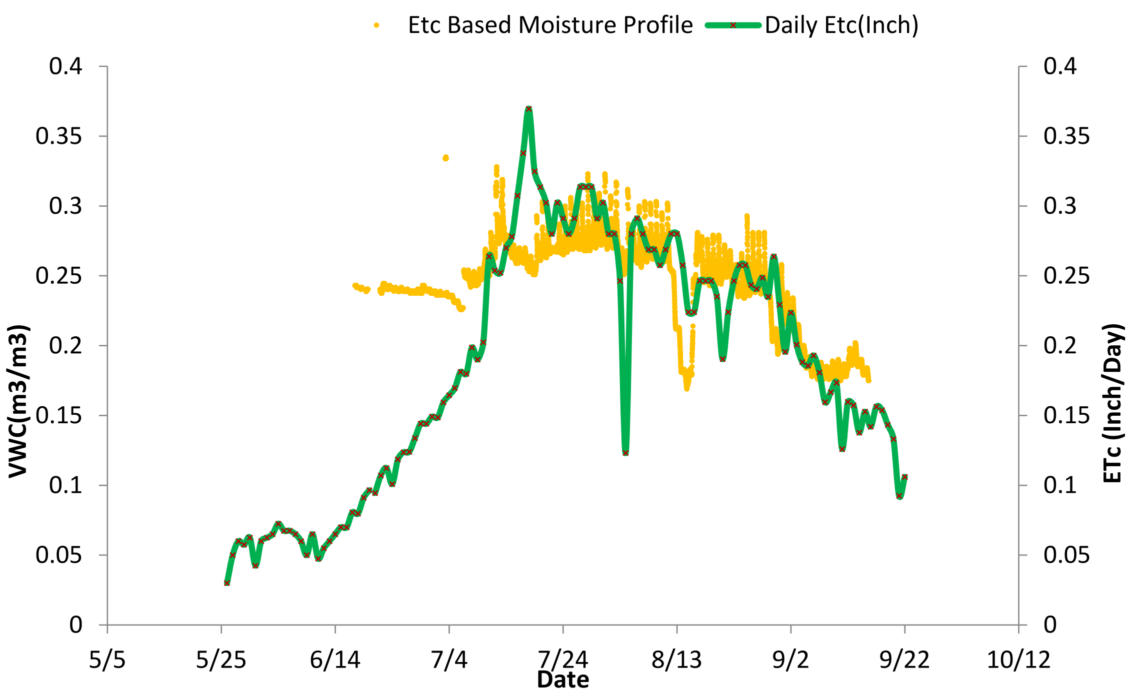

Figure-14: Soil Moisture vs. Daily ET$_c$ (ET-Based)

Figures 11 and 12 show soil moisture sensor profiles for SMS- based and ET based irrigations. Both show that irrigation was triggered whenever average moisture value for three six-inch depth sensors reached the set lower threshold value of 21% VWC (30% less than field capacity of 31% VWC) and was shut off whenever this value reached 31% VWC. These values were locally determined in lab by bringing soil samples and following manufacturer's recommended process. In Figure12, around date 8/13 there can be seen a bigger dip in soil moisture profile. This was because web server was down and hence, no ET data could be polled during a week time which resulted in no irrigation for the entire week time for ET based irrigation zone.

Figure-13 shows comparison of soil moisture profile for SMS based irrigation with that of daily ET. With increasing ET values, the frequency of irrigation also increases for soil moisture-based irrigation. Figure 14 shows comparison of soil moisture profile for ET based irrigation with daily ET. It ca be seen that both of them follow similar trend as expected.

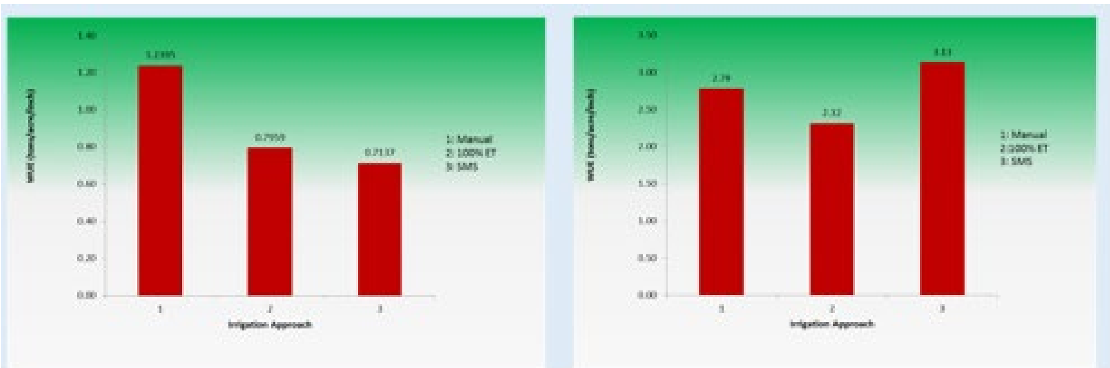

Fig. 15: WUE under various irrigation scheduling approaches for Tomato (left) and Lettuce (right)

The WUE, calculated as yield per unit of water applied was lowest under the SMS-based approach for tomato but found to be the highest for lettuce with values of 0.714 tons/acre/inch and 3.13 tons/acre/inch, respectively (Fig. 15). These differences were in part due to: 1) sensor depths which remain constant during the growing seasons, 2) number of sensors used to trigger irrigation events, and 3) timing of the growing seasons. In lettuce, the depth of water applied was significantly lower under the SMS approach (5.74 in) compared to the ET method (10.38 in), indicating that in-situ measurement of soil water content is critical to optimize irrigation efficiency. The lower WUE values obtained for the ET-based approach are most likely attributed to high water depth applied despite elevated yields.

Conclusion

The most significant conclusion from these preliminary findings is that both ET- and soil sensor-based technology can improve water use efficiency and help growers optimize their irrigation scheduling. However, it appears that for SMS based irrigation, moisture sensors responsible for triggering irrigation need to be buried at varying depth with growing season of crops for optimized water use and better yield. Additional studies are currently being conducted addressing the differences in WUE values observed in this phase of the study.

References

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