CASE STUDY: Improved Agricultural Irrigation Scheduling Using a Soil Water Content Sensor

Jordan L. Varble[1] and José L. Chávez
Department of Civil and Environmental Engineering, Colorado State University

Abstract. The key to scheduling irrigation timing and amounts is determining moisture depletion in the soil. Two common methods include tracking crop evapotranspiration (ET_c) and tracking the water content with a sensor buried in the soil. In Colorado, a popular online tool that estimates the ET_c for a variety of well-irrigated crops is the Colorado Agricultural Meteorological Network (CoAgMet). However, the use of CoAgMet to estimate the ET_c of a water-stressed crop is limited. Therefore, this study analyzed the capability of a digitized Time Domain Transmissometry (TDT) soil water content sensor (Acclima, Inc., Meridian, ID) to schedule irrigation timing and amounts of a fully-irrigated and a water-stressed maize crop in eastern Colorado. According to the results, it was concluded that the TDT sensor can reliably be used to monitor soil water use and thus help reduce pumping costs, while ensuring that the soil moisture remains within the Management Allowed Deficit (MAD).

1. Introduction

Improvements in agricultural irrigation efficiencies are currently available through a variety of existing solutions. Cooley et al. (2010) performed an inventory of currently available options for “improving the efficiency of water use in California agriculture”, and pointed out that all solutions fall under one of three categories: efficient irrigation technologies, improved irrigation scheduling, or regulated deficit irrigation. Furthermore, the category with the largest potential for water savings is improving irrigation scheduling.

Other researchers have verified through widespread surveys that (on average) irrigators who adopt currently-available technologies consistently improve irrigation efficiency (Cooley et al., 2010). For example, the use of nearby weather stations to estimate evapotranspiration (ET) reduced by water use by 13% in California (DWR, 1997) and 15% in Oregon (Dokter, 1996). Similarly, the use of irrigation scheduling in general reduced water use by 11% in Nebraska (Kranz et al., 1992) and 20% in Kansas (Buchleiter et al. 1996).

2. Materials and Methods

During the summer of 2010, a digitized Time Domain Transmissometry (TDT; Acclima, Inc., Meridian, ID) soil water content sensor was installed in an agricultural research plot near Greeley, CO. The soil in this field was a sandy clay loam, with a bulk density of 1.52 g cm^{-3}. The sensor was placed horizontally at a depth of 10 cm, and was calibrated (RMSE = 0.029 m^3 m^{-3}) using gravimetric samples collected nearby. Maize was grown on this plot, which was irrigated using the furrows. However, the first irrigation event did not take place until July 13th; thus, the crop experienced considerable yield-

[1] Graduate Student, Civil Engineering
Colorado State University (CSU)
Fort Collins, CO 80523-1372
Tel: (970)-214-6466
e-mail: Jordan.Varble@colostate.edu

reducing water stress during the three weeks prior. Through the rest of July and August the plot was irrigated at regular intervals (see Figure 1), with irrigation durations of 12 hours.

A datalogger was used to collect data from the TDT at 11:00 pm every evening, from July 15th to October 4th. The soil water deficit (mm) was computed from this data, using equation 1.

$$\text{Deficit} = (FC - \theta_v)*R_z*10 \qquad (1)$$

where FC is the volumetric water content at field capacity (%), θ_v is the actual volumetric water content (%) measured by the TDT, and R_z is the depth of the root zone (m). A field capacity of 26% was assumed from Fangmeier et al. (2006). The root zone depth was estimated to increase linearly from 0.55 m on July 15th to 1.00 m on October 4th (Bauder and Schneekloth, 2007).

The Management Allowed Deficit (MAD; mm) was then computed using equation 2.

$$MAD = AW*R_z*MAD_{\%} \qquad (2)$$

where AW is the available water that the soil is able to hold and $MAD_{\%}$ is the MAD expressed as a percent. Available water was estimated to be 100 mm per meter (Fangmeier et al., 2006). $MAD_{\%}$ changes during the growing season, depending on the growth stage of the crop, and daily values were assumed using Bauder and Schneekloth (2007). To protect crop yield, irrigation ideally take place such that the actual soil moisture deficit does not exceed MAD. During this study, the TDT sensor confirmed that the actual soil moisture deficit did not exceed MAD.

The Colorado Agricultural Meteorological Network (CoAgMet) "is a network of automatic weather stations that provides Internet access to weather and crop water use data" (Andales et al., 2009). This data is used to estimate the potential amount of ET from an unstressed crop, which can be used in irrigation scheduling. The recommended method for using this information is to sum the daily ET measurements, subtract from that the sum of the daily precipitation, and divide that difference by an irrigation efficiency. The result is the recommended depth of water to apply to the field. Two necessary assumptions with this method are an initially full water content profile (which is often the case due to frequent spring rains and/or an early-season irrigation to leach the salts) and an irrigation efficiency (60% in this case). This irrigation scheduling tool was compared with the actual irrigation application depths to investigate the potential savings that TDT sensor-controlled irrigations offer over CoAgMet-based irrigations.

3. Results and Discussion

In this study, a reduced volume of water was applied to an agricultural research plot. During the period July 15th to October 4th, CoAgMet recommended that 360 mm of water needed to be replenished to the soil (423 mm ET - 63 mm precipitation). Assuming furrow irrigation efficiency of 60%, this results in a required application depth of 599 mm.

However, the measured depth of irrigated water applied to this plot was 342 mm, which is a savings of 43%.

Furthermore, the TDT sensor confirmed that the moisture deficit was never greater than the threshold value established by MAD (Figure 1). Despite the fact that the irrigation scheduling of this field was not controlled by the TDT sensor in this situation, this data confirmed that significant water (and pumping) savings are possible without exceeding MAD. Furthermore, a close inspection of Figure 1 indicates that the soil moisture deficit was minimal prior to the irrigation on August 5th. Therefore, additional water savings were possible, had the irrigations been controlled by the TDT sensor.

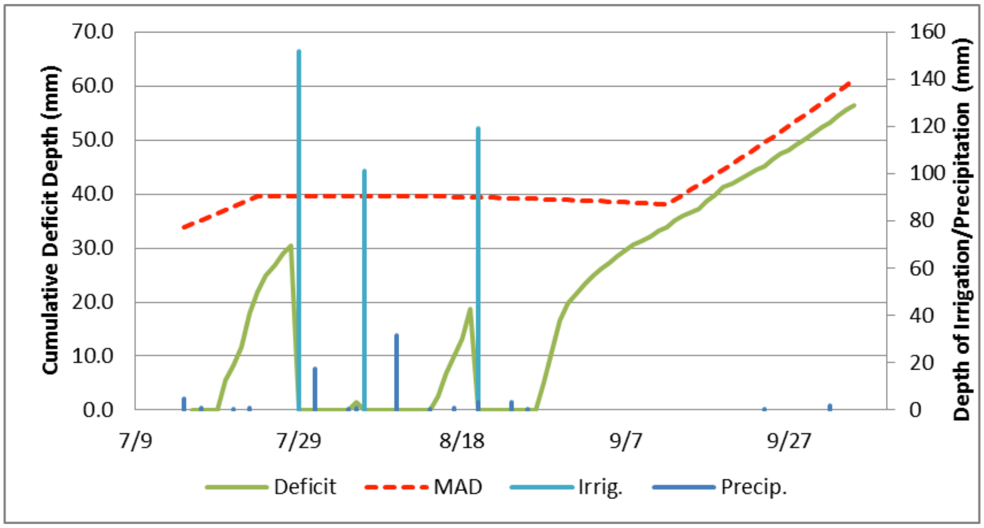

Figure 1. Actual Soil Moisture Deficit Compared to the Management Allowed Deficit (MAD)

Cautionary Note

The reader must keep in mind that this crop was water-stressed prior to July 14th. Thus, the growth was stunted and the yield (133 Bushels/ac) was less than optimal (Trout, 2010). Therefore, the reported water savings (43%) should not be understood quantitatively because other methods exist (but were not used in this application) to apply a stress coefficient to the CoAgMet-based ET data to determine more-realistic ET estimates. Instead, the findings should be recognized qualitatively that water savings beyond CoAgMet recommendations are possible with the aid of an accurately-calibrated TDT sensor. The actual water savings are based on a number of variables, such as climate (geographic and seasonal), crop (type and condition), irrigation method, irrigation manager's level of expertise, and soil type. For example, Blonquist et al. (2006) found that irrigations based on the TDT sensor used under Kentucky bluegrass applied 16% less water than ET-based irrigation recommendations. Due to these wide ranges of accuracies reported and variables under consideration, exact savings cannot be predicted. However, it is consistent that accurate, real-time information on soil water content will reliably provide highly efficient irrigation scheduling.

4. Conclusions

Scheduling irrigations according to real-time ET estimates (using local weather data) is a proven method that results in increased irrigation efficiency if well utilized. This study investigated further savings made possible through the use of an accurate, buriable soil water content sensor. According to this study, the actual depth of water that was applied to a research plot of maize that had previously experienced significant water stress was 43% less than the depth recommended by the weather based method (CoAgMet) for a well-watered crop. Furthermore, the TDT sensor verified that, during the period evaluated, the actual soil moisture deficit never exceeded the Management Allowed Deficit.

References

Andales, A.A., T.A. Bauder, and N.J. Doesken. 2009. "The Colorado Agricultural Meteorological Network (CoAgMet) and Crop ET Reports". Colorado State University (CSU) Extension. Available online at: http://www.ext.colostate.edu/pubs/crops/04723.html (verified 13 Jan 2011).

Bauder, T. and J. Schneekloth. 2007. Irrigated Field Record Book. Colorado State University Cooperative Extension Publication XCM-228.

Blonquist, J.M., S.B. Jones, and D.A. Robinson. 2006. Precise irrigation scheduling for turfgrass using a subsurface electromagnetic soil moisture sensor, Agric. Water Manage. 84 (2006), pp. 153–165.

Buchleiter, G.W., D.F. Heermann, R.J. Wenstrom. (1996). Economic Analysis of On-Farm Irrigation Scheduling. In: Evapotranspiration and Irrigation Scheduling: Proceedings of the International Conference, November 3-6, 1996. San Antonio, Texas.

Cooley, H., J. Christian-Smith, and P.H. Gleick. 2009. Sustaining California Agriculture in an Uncertain Future. Pacific Institute, Oakland, CA. Available online at: http://www.pacinst.org/reports/california_agriculture/ (verified 7 Jan. 2011).

Department of Water Resources (DWR). (1997). Fifteen Years of Growth and a Promising Future: The California Irrigation Management Information System.

Dokter, D.T. (1996). AgriMet – The Pacific Northwest Cooperative Agricultural Weather Station Network. Evapotranspiration and Irrigation Scheduling: Proceedings of the International Conference. November 3-6, 1996. San Antonio, Texas.

Fangmeier, D.D., J.E. William, S.R. Workman, R.L. Huffman, and G.O. Schwab. 2006. Soil and Water Conservation Engineering, 5th Ed. Thomson Delmar Learning, Clifton Park, NY. p. 337.

Kranz, W.L., D.E. Eisenhauer, and M. T. Retka. (1992). Water and energy conservation using irrigation scheduling with center-pivot irrigation systems. *Agricultural Water Management,* 22: 325-334.

Trout, T.J. 2010 Personal Communication. US Department of Agriculture - Agriculture Research Service. Fort Collins, CO.