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Smart irrigation control using inexpensive capacitance probes

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The mass marketing of inexpensive capacitance probes has opened the door for development of smart irrigation controllers based on soil moisture content. The advantage over climate based irrigation is that these systems are easier to use and can compensate for rainfall and variations in the irrigation system application rate. In this work, a smart irrigation controller was developed using EC-5 Echo sensors connected to Siemens LOGO microcontrollers to start the irrigation process. The system was validated in a lettuce crop grown in a greenhouse in southern Portugal. The sensors were buried 10 cm in the center of mini-lysimeters with four different trigger points: 25, 22, 20 and 17% volumetric soil moisture, and the irrigation depth set to replenish the soil to field capacity. The results indicate that the main challenge to soil irrigation control is the precise location of the sensor in relation to the drippers. In this work no significant differences in crop yield were observed between the three treatments, although there was a water economy of some 5% when using the lower trigger point, possibly due to smaller losses from soil evaporation.

Keywords: Smart Irrigation control

1. Introduction

Advancements in electronics and shortage of water have led to the development of “smart” or adaptive irrigation controllers that adjust the water application depth to plant needs, and thus increase water savings. The two most common types are soil moisture based and evapotranspiration based systems. In the first type, one or more sensors monitor the evolution of the soil water content, and trigger irrigation when a pre-defined soil moisture deficit is achieved, or a certain water tension is reached in the soil. The climate based systems usually measure one or more weather parameters and based on these establish the water application depth for the period.

Water deficient and the consequently lowered substrate water potential is considered as one of the most important underlying stressors in crops, even at relatively small water deficits (Rodriguez, 2009). Measuring the energy status and water content are therefore of greater value for providing a rigorous indication of water availability to plants, with values that can allow for comparison between any growing substrate (Jones, 2007).

The management allowable depletion (MAD) technique uses the percent of available water depleted (or remaining) in the soil profile, as the factor to minimize crop stress. Once the irrigation is triggered, the application depth is determined based on the crop rooting depth, to refill the soil to field capacity.

Deep rooted crops will use a greater volume of the soil profile for withdrawing water than a shallow rooted crop, such as peppers [*Capsicum annuum* L.], and thus have access to more water in between irrigations (Thompson *et al.*, 2007; Hanson and Orloff, 2007). During the critical plant growth stages, such as fruiting, the management allowable depletion levels are smaller to meet the crop's higher water use. For instance, in the cell division and pre-harvest stage for peaches, the recommended MAD is 40% whereas at other stages it can be up to 65% (Hanson *et al*., 2004)

Critical factors for determining the right irrigation triggers based on soil moisture levels are the type of irrigation system (i.e. drip, trickle, sprinkler, etc.) used; the crop being grown; the growth stage of the crop; and the soil characteristics. For drip irrigation, different studies have recommended different levels of soil moisture depletion (MAD) varying from 10% (Lebouef *et al*., 2007), 15% (Nyvall, 2005), 25% (Nyvall, 2002) and a range of 10-30% (Bierman, 2005). The corresponding range in studies with sprinkler systems was from 30-50%. Nyvall (2002) suggested MAD levels of 50% for strawberries, while Hanson (2004) suggested 15% and Ley (1994) suggested a range of 50-65%.

Most of the soil moisture based controllers function such that a preset irrigation quantity is applied when the measured soil moisture level drops to a threshold point set by the user. Ideally, the irrigation quantity applied replenishes the soil moisture to field capacity with minimal surface runoff and seepage below the root zone (over-watering). Others begin and end irrigation based on two preset thresholds; the first is set at a moisture level well above the wilting point and the second is set at near field capacity.

The objective of this work was to develop soil moisture based smart irrigation controller that could be set by the farmer at the desired MAD level. The controller was then validated in a lettuce crop in greenhouses in southern Iberia.

2. Material and Methods

The experiment was carried out at the greenhouse complex of Mitra Experimental Station, near Évora, Portugal. Plastic weighing mini-lysimeters were used to grow Boston type lettuce from 2 week old seedlings. The mini-lysimeters were 30 cm in diameter and 25 cm in height with a total volume of 15 L. Each treatment was replicated in five mini-lysimeters. The trial was replicated outside of the greenhouse with an identical setup.

Each mini lysimeter was filled with 1700 g of air dry peat moss and lettuce was planted on 28 February 2013. Three plants were planted in each mini-lysimeter. The lysimeters were weighed with a digital scale with a precision of 0.5 g, which, given the area of the container, represent a precision of 0.02 mm of water.

The Echo probe is manufactured by Decagon Devices and operate on the principle of capacitance by measuring the dielectric constant of soil. It is made up of copper electrodes further sealed in epoxy-impregnated fiberglass (Fares and Polyakov, 2006).

The EC-5 soil moisture sensor uses capacitance to measure the apparent dielectric constant of the surrounding medium (Sakaki et al. 2008) . The Echo probe measures soil ε in volts, by measuring the charge time of a capacitor placed in the soil (Czarnomski *et al.* 2005). Although the Echo probe displays readings in volts, it is easiest to interpret these readings as a trend line for the purposes of scheduling irrigation (Sakaki et al. 2008). The probes can easily be connected to a data logger or any other system which has an analog input.

The EC-5 sensor reads mV and the data logger converts the mV reading into an analog-to-digital converter number, or raw data. Calibration consists of relating the raw data directly to volumetric water content values (θ) (Czarnomski et al., 2005, Kizito et al, 2008). The standard procedure for calibrating capacitance sensors is outlined by Starr and Paltineanu (2002) in which the voltage reading is taken under various soil tension values, θ. The results are usually linear for mineral soils, and in organic soils can be best fitted with a quadratic equation (Decagon Devices, 2006). Kizito et al. (2008) observed that the Decagon sensors with a measurement frequency of 70MHz, such as is the case of the EC-5, did not need any soil-specific or sensor-specific calibration. Sakaki et al. (2008) measured the sampling volume of the EC-5 sensor and observed that the bulk sampling volume of the EC-5 sensor was approximately 2 cm (parallel to prongs) x 1 cm (perpendicular to prongs) x 9 cm (longitudinal including the sensor head), totaling 18 cm^3.

Voltage is then converted to soil moisture content through an equation such as equation 1, provided by the manufacturer:

$$Vwc = 0.00119mV - 0.400 \qquad \text{(Eq. 1)}$$

where Vwc is the volumetric water content of the soil in $m^3\ m^{-3}$, and mV is the milivolt reading produced by the sensor when an excitation voltage of 2 to 3.6 V is applied. Some authors have concluded that these probes require unique polynominal calibration equations to obtain moisture content from probe output (Yoshikawa et al. 2004).

The controller was build around LOGO PLCs from Siemens. Analog input ports were used to receive the ON signal, and irrigations were scheduled to start at three occasions during the day: 8:00, 16:00 and 24:00 hours. In each irrigation the soil moisture content was replenished to the upper limit of field capacity (pF 1.7). The sensors were connected to a data logger (Campbell CR1000) to make readings every 10 min. Whenever the soil moisture was bellow a pre-determined value, the data logger would send an ON signal to the LOGOs, thus triggering an irrigation at the next scheduled opportunity.

Once an irrigation event was triggered, a pre-defined depth of water necessary to restore the soil to field capacity was applied. The use of a pre-defined application depth has the advantage of avoiding irregularities arising from the irrigation being cut off too early or too late due to the infiltration of water at the specific location of the sensor.

Three drippers were placed in each lysimeter, in order to balance irregularities that rise from the unavoidable differences in the dripper flow rate. For the purpose of this study EC-5 Echo probes were buried vertically to a depth of 10 cm, at the centre of the mini-lysimeter and exactly between the three drippers. At this place the sensor is located between the three wet bulbs, and detects the average soil moisture content.

The irrigation was set to start at four different soil moisture contents, corresponding to a depletion of 17, 20, 22 and 25% of soil moisture content at 10 cm depth. The length of each irrigation necessary to replenish the soil moisture to field capacity in each treatment was calculated based on lysimeter volume, trigger point and soil moisture content at field capacity.

3. Results and discussion

The irrigation system was installed and commissioned after some minor electronic and electric issues that had to be sorted out. Daily ETo and ETc observed at the greenhouse are presented in Figure 1.

A great variability in the daily values of ETc can be observed, which is common in the spring season under Mediterranean climate and justify the need for smart irrigation control. It can also be observed that the Lettuce (T1) had lower water loss than grass at the latter part of the experiment, which was probably due to the fact the lettuce had matured by that time.

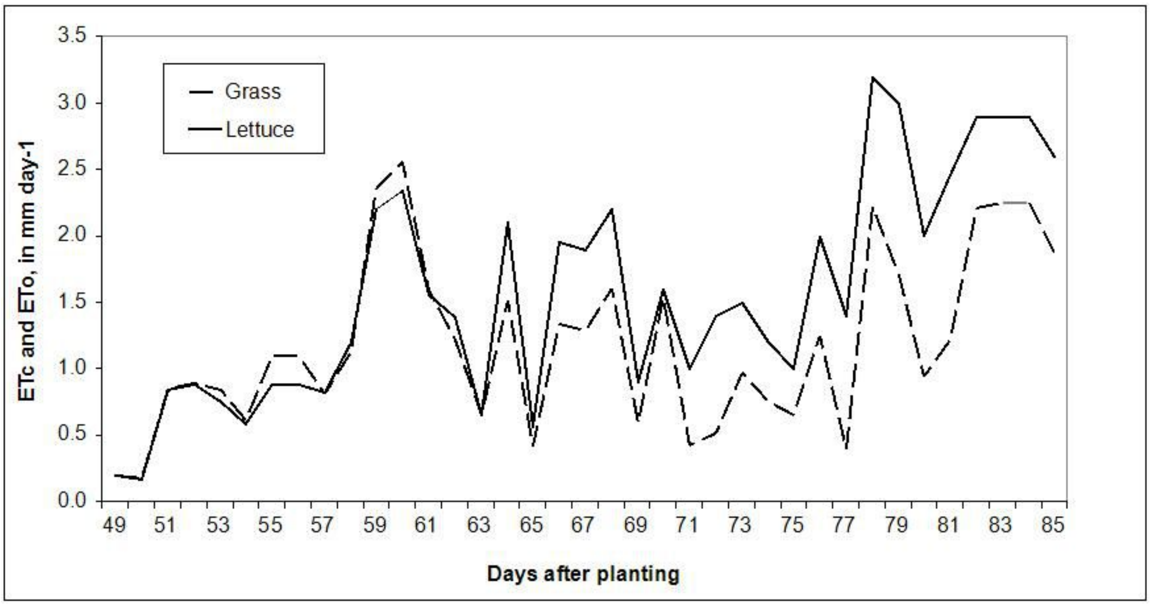

Figure 1. Daily average values of ETc, ETo and E inside the greenhouse between days 49 and 85 after plantation.

A one day hourly pattern of ETc of the four treatments is presented in Figure 2. The data show that ETc picked up after sunrise (7:50) and that quickly reached a plateau of around 0.75 mm h^{-1}. This rate was more or less maintained during the day until around 15:30, when it started to decrease gradually. The peaks in the ETc can be traced to changes in solar radiation due to clouds. As would have been expected, the treatments with the highest stress had lower ETc values. An interesting result is that while T1 maintained a relatively stable ETc rate, in T3 and T4 (20% and 17% volume water, respectively) the values of ETc were very unstable, decreasing rapidly with a decrease in solar radiation.

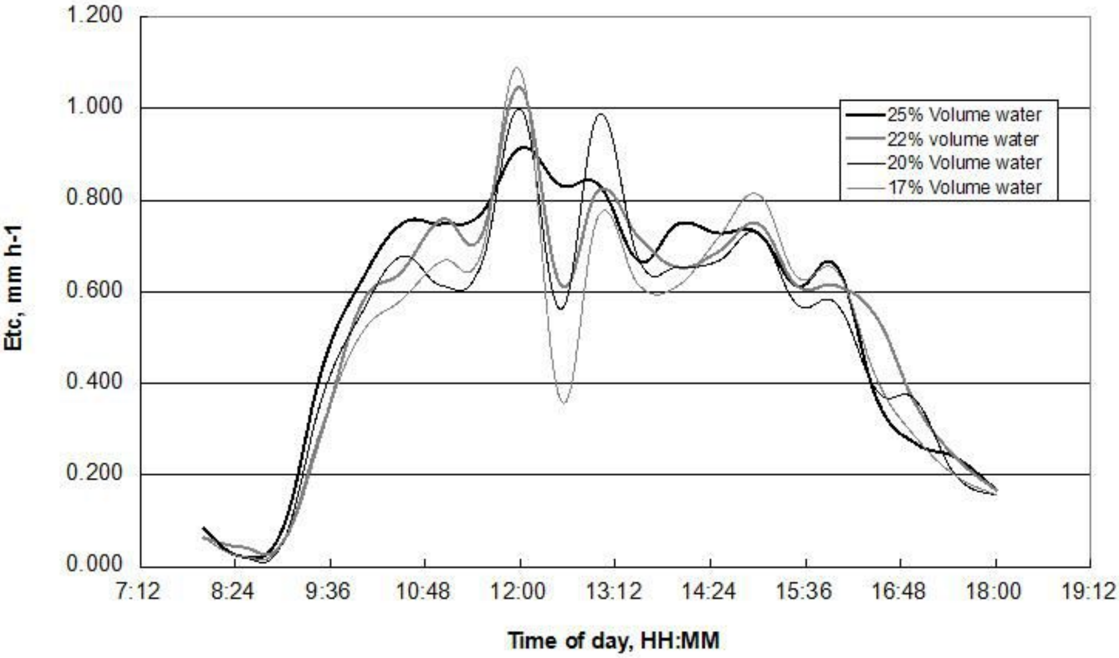

Figure 2. Evolution of hourly ETc for the four treatments

The smart irrigation controller based on soil moisture sensors performed as expected, maintaining the soil moisture content within the pre-defined bands. The soil moisture for a 10 day period for the four treatments is shown in Figure 3. It can be observed that in T1 (25% volume water), the crop was irrigated daily, while T2, T3 and T4 were progressively watered less and less frequently.

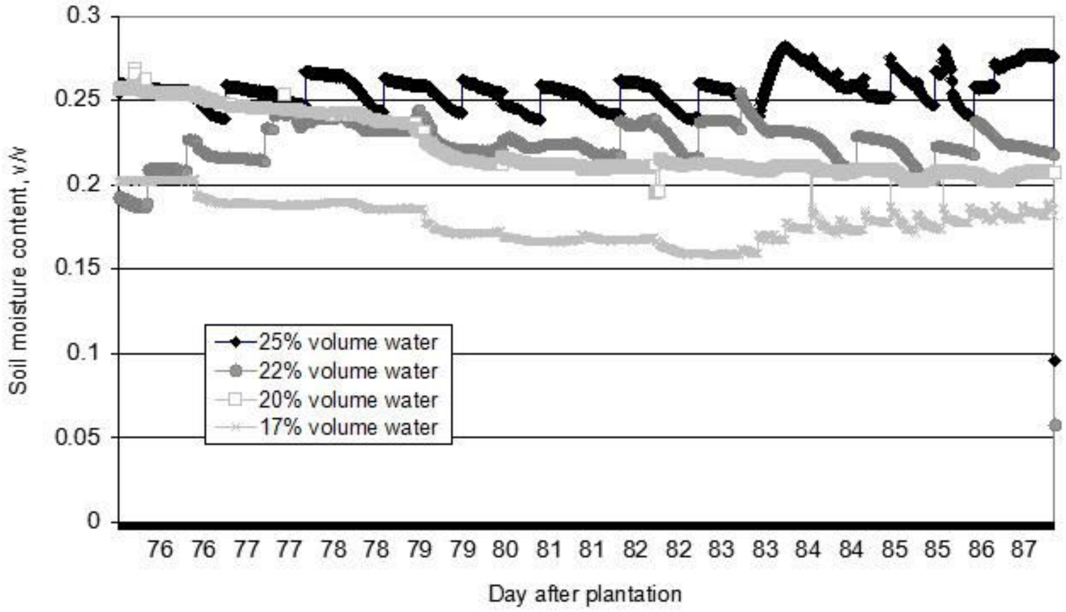

Figure 3. Evolution of soil moisture content, during a 10 day period.

4. Conclusions

The results of this work indicate that it is possible to build economic smart irrigation controllers using standard soil moisture probes and commercial PLCs. This irrigation controller has the advantage of allowing the farmer to set the irrigation trigger points as well as the depth of water to be applied in each irrigation, according to his specific needs. The systems performed in a satisfactory manner, keeping the soil moisture in the desired range.

The results also indicate that the average values of crop ETc were slightly affected by the soil moisture content, which could have been also a result of moisture loss from the soil surface in the more frequently irrigated treatments.

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6. References

Bierman, P. (2005). Managing Irrigation for High-Value Crops. *University of Alaska Fairbanks Cooperative Extension Service*. FGV - 00649

Bonachela, S., González, A.M., Fernández, M.D. (2006) Irrigation scheduling of plastic greenhouse vegetable crops based on historical weather data. *Irrigation Science* 25(1):53–62

Czarnomski, N. M., Moore, G. W., Pypker, T. G., Licata, J., & Bond, B. J. (2005). Precision and accuracy of three alternative instruments for measuring soil water content in two forest soils of the Pacific Northwest. *Canadian journal of forest research*, *35*(8), 1867-1876.

Decagon Devices, Inc (2006), ECH$_2$O soil moisture sensor. *Operator's manual for models EC-20, EC-10 and EC-5,* version 5, 23 pp., Pullman, Wash.

Fares, A., & Polyakov, V. (2006). Advances in crop water management using capacitive water sensors. *Advances in agronomy*, *90*, 43-77.

Hanson, B., Schwankl, L. & Fulton, A. (2004). Scheduling Irrigations: When and how much water to apply. Water Management Series publication number 3396. Davis, California, Department of Land, Air and Water Resources, University of California.

Hanson, B., Orloff, S., & Peters, D. (2000). Monitoring soil moisture helps refine irrigation management. *California Agriculture*, *54*(3), 38-42.

Kizito, F., C. S. Campbell, G. S. Campbell, D. R. Cobos, B. L. Teare, B. Carter, and J. W. Hopmans (2008), Frequency, electrical conductivity and temperature analysis of a low-cost capacitance soil moisture sensor, *J. Hydrol.,* 352, 367–378, doi:10.1016/j/jhydrol.2008.01.021.

Rodriguez, F.R.A. 2009. Calibrating capacitance sensors to estimate water content, matric potential, and electrical conductivity in soilless substrates. Thesis submitted to the Faculty of the Graduate School of the University of Maryland, CollegePark, in partial fulfillment of the requirements for the degree of Masters in Science

Sakaki, T., Limsuwat, A., Smits, K. M., & Illangasekare, T. H. (2008). Empirical two point α mixing model for calibrating the ECH2O EC 5 soil moisture sensor in sands. *Water resources research*, *44*(4).

Starr, J. L., and I. C. Paltineanu (2002), Methods for measurement of soil water content: capacitance devices, in Methods of Soil Analysis: Part 4, Physical Methods, Soil Sci. Soc. Am. Book Ser., vol. 5, edited by J. H. Dane, and G. C. Topp, pp. 463–474, Soil Sci. Soc. of Am., Madison, Wis.

Thompson, R.B., M. Gallardo, L.C. Valdez, and M.D. Fernandez. (2007). Determination of lower limits for irrigation management using in situ assessments of apparent crop water uptake made with volumetric soil water content sensors. *Agricultural Water Management* 92:13-28.

Yoshikawa K, Oveerduin P.P., Harden JW. 2004 Moisture content measurements of Moss (Sphagnum spp.) using commercial sensors.