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# Automatic Irrigation Based on Soil Moisture for Vegetable Crops[1]

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Improving irrigation efficiency can contribute greatly to reducing production costs of vegetables, making the industry more competitive and sustainable. Through proper irrigation, average vegetable yields can be maintained (or increased) while minimizing environmental impacts caused by excess applied water and subsequent agrichemical leaching. This publication is intended to help growers to conserve water through the use of soil moisture sensors.

## Water Conservation and New Irrigation Technology

Recent technological advances have made soil (water) moisture sensors available for efficient and automatic operation of irrigation systems. Automatic soil moisture sensor-based irrigation seeks to maintain a desired soil water range in the root zone that is optimal for plant growth. The target soil water status is usually set in terms of soil tension or matric potential (expressed in kPa or cbar, 1 kPa=1 cbar), or volumetric moisture (expressed in percent of water volume in a volume of undisturbed soil). Another benefit of automatic irrigation techniques is convenience. In a previous experience working with a soil-moisture-based automatic irrigation system, Dukes et al. (2003) found that once such a system was set up and verified, only weekly observation was required. This type of system adapts the amount of water applied according to plant needs and actual weather conditions throughout the season. This translates not only into convenience for the manager but into substantial water savings compared to irrigation management based on average historical weather conditions.

## Soil Moisture Sensors for Manual Irrigation Control

Although soil water status can be determined by *direct* (soil sampling) and *indirect* (soil moisture sensing) methods, direct methods of monitoring soil moisture are not commonly used for irrigation scheduling because they are intrusive and labor intensive and cannot provide immediate feedback. Soil moisture sensor probes can be permanently installed at representative points in an agricultural field to provide repeated moisture readings over time that can be used for irrigation management. Special care is needed when using soil moisture sensors in coarse soils because most devices require close contact with the soil matrix, which is sometimes difficult to achieve in these soils. In addition, the fast soil moisture changes typical of these

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soils are sometimes not properly captured by some types of sensors (Irmak and Haman 2001; Muñoz-Carpena et al. 2002; Muñoz-Carpena et al. 2005).

Many indirect methods are available for monitoring soil water content. An in-depth review of available techniques is given in Ask IFAS publication BUL343 focusing on working principles, advantages, and drawbacks (Tables 1 and 2) (Muñoz-Carpena 2004). These methods estimate soil moisture by a calibrated relationship with some other measurable variable. The suitability of each method depends on several issues such as cost, accuracy, response time, installation, management, and durability. Depending on the quantity measured (i.e., volumetric water content or soil tension), indirect techniques are first classified into *volumetric* and *tensiometric*. Both quantities are related through the soil water characteristic curve that is specific to a given soil. Therefore, it is important to remember that they cannot be related to each other the same way for all soil types. In addition, this relationship might not be unique and may differ along drying and wetting cycles, especially in finer soils. To calculate irrigation requirements (the amount of water that needs to be applied with each irrigation based on crop needs), suction values from tensiometric methods need to be converted to soil moisture through the soil characteristic curve. Among the available tensiometric techniques, tensiometers and granular matrix sensors (GMS) are the most used for automatic irrigation.

Most of the currently available volumetric sensors suitable for irrigation are dielectric. This group of sensors estimates soil water content by measuring the soil bulk permittivity (or dielectric constant) that determines the velocity of an electromagnetic wave or pulse through the soil. In a composite material like the soil (i.e., made up of different components like minerals, air, and water), the value of the permittivity is made up by the relative contribution of each of the components. Since the dielectric constant of liquid water is much larger than that of the other soil constituents, the total permittivity of the soil or bulk permittivity is mainly governed by the presence of liquid water. The dielectric methods use empirical (calibrated) relationships between volumetric water content and the sensor output signal (time, frequency, impedance, wave phase). These techniques are becoming widely adopted because they have good response time (almost instantaneous measurements), do not require maintenance, and can provide continuous readings through automation. Although these sensors are based on the dielectric principle, the various types available (frequency domain reflectometry — FDR, capacitance, time domain transmission — TDT, amplitude domain reflectometry — ADR, time domain reflectometry — TDR, and phase transmission) present important differences in terms of calibration requirements, accuracy, installation and maintenance requirements, and cost. An evaluation of available commercial low-cost sensors for manual monitoring of soil water status in south Florida vegetables is presented in Ask IFAS publication ABE 333 (Muñoz-Carpena et al. 2002).

## Automatic Soil Water-Based Irrigation Control: Water Use, Yields, and Implications

A soil water-based irrigation control system uses feedback on the soil water status to bypass a time-based pre-programmed schedule or to maintain soil water content within a specified range. These two approaches are *bypass* and *on-demand*, respectively. Bypass configurations skip an entire scheduled irrigation event based on the soil water status at the beginning of that event or by checking the soil water status at intervals within a time-based scheduled event.

Tensiometers and GMS were the first types of sensors adapted to automatic irrigation control. Phene and Howell (1984) first used a custom-made soil matric potential sensor to control subsurface drip-irrigated processing tomatoes. Their results indicated that yields of the automated system were similar to those from tomatoes irrigated based on pan evaporation with the potential to use less irrigation water.

Switching tensiometers are devices that operate in bypass mode, typically with a timer, such that irrigation will be allowed within a timed irrigation window if the soil matric potential exceeds a threshold setting. Smajstrla and Locascio (1996) reported that using switching tensiometers, placed at depths of 15 cm and set at 10 and 15 kPa tensions in a fine sandy soil in Florida, reduced irrigation requirements of tomatoes by 40%–50% without reducing yields.

Meron et al. (2001) discussed the use of tensiometers to automatically irrigate apple trees. They noted that spatial variability was problematic when the tensiometers were installed 30 cm from the drip irrigation emitters. Smajstrla and Koo (1986) discussed the problems associated with using tensiometers to initiate irrigation events in Florida. Problems included entrapped air in the tensiometers, organic growth on the ceramic cups, and the need for recalibration.

Muñoz-Carpena et al. (2005) found that both tensiometer- and GMS-controlled drip irrigation systems on tomato saved water when compared to typical farmer practices.

The irrigation savings of switching tensiometers set at 15 kPa on a coarse soil compared to farmer practices were 70%. The GMS-controlled system failed to bypass most irrigation events due to slow response time. Tomato yields were similar across all soil water-based control systems and the farmer field. Shock et al. (2002) described a system to irrigate onion with frequent bypass control using GMS. The overall water used was slightly lower than calculated crop evapotranspiration with acceptable yields.

Although dielectric sensors have only found limited use in vegetable production, research to date shows promising results in terms of water savings. Nogueira et al. (2003) described an automatic subsurface drip irrigation control system used in a sweet corn/peanut crop rotation. This system used TDR sensors to control a subsurface drip irrigation system on-demand. During subsequent testing of this system, 11% irrigation savings with the on-demand subsurface drip irrigation system (23 cm deep) compared to sprinkler irrigation were reported with similar yields between the systems (Dukes and Scholberg 2005). Dukes et al. (2003) used a commercially available dielectric sensor for lawns and gardens to control irrigation on green bell pepper (*Capsicum annuum* L.). They found 50% reduction in water use with soil water-based automatically irrigated bell pepper when compared to once-per-day, manually irrigated treatments that had similar yields; however, maximum yields and water use were on the farmer treatment that was irrigated 1–2 times each day.

An irrigation controller has been developed that uses a voltage signal from a dielectric probe that is related to soil water (Figure 1) (Muñoz-Carpena et al. 2004). This system performed similarly to switching tensiometers (both in bypass mode) by reducing irrigation water by 70% on drip-irrigated tomato in south Florida (Figure 2).

## Conclusions and Future Direction

As water supplies become scarce and polluted, there is a need to irrigate more efficiently in order to minimize water use and chemical leaching. Advances in soil moisture sensors make the commercial use of this technology possible to automate irrigation management for vegetable production. However, research indicates that different sensor types may not perform alike under all conditions. Compared to farmer practices, reductions in water use range as high as 70%, with no negative impact on crop yields. Due to the soil's natural variability, location and number of soil moisture sensors may be crucial; future work should include optimization of sensor placement. Additional research should also include techniques to overcome the limitation of requiring a soil-specific calibration if needed for a particular technology.

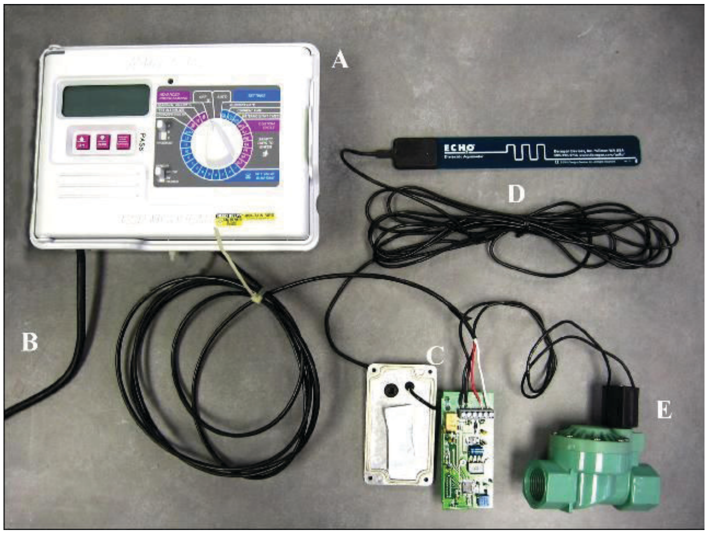

Figure 1. Details of the irrigation soil moisture interface (QIC) prototype developed at the UF/IFAS Department of Agricultural and Biological Engineering. The prototype is shown retrofitted with a standard irrigation timer and solenoid valve. A) Time-based controller. B) Power supply. C) QIC circuitry. D) Capacitance soil water probe (ECH20, Decagon Devices, Inc., Pullman, WA). E) Solenoid valve.
Credits: Rafael Muñoz-Carpena, UF/IFAS

Figure 2. Application of the QIC prototype to automatic soil moisture-based irrigation of tomatoes at the UF/IFAS Tropical Research and Education Center in Homestead, FL.
Credits: Rafael Muñoz-Carpena, UF/IFAS

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