Soil Sensors for Irrigation Scheduling: Volumetric Water Content sensors (II)

Irrigation has become an important aspect in crop production since in most cases yield and profitability will significantly increase with its adoption. However, profitable yield increases are possible if irrigation water is applied according to the plant needs. Excess application of water through irrigation not only could be very expensive but also might not always result on a yield gain. The key to achieve optimum yield is to increase Plant Water Use Efficiency (WUE) which is translated in performing irrigation scheduling according to the plant water demand over each growth stage. Soil moisture sensors can be particularly useful not only in monitoring soil moisture levels but as decision tools to trigger irrigation events. The purpose of this publication is to describe the use of volumetric water content sensors with irrigation scheduling purposes.

**Dielectric permittivity sensors**

Dielectric sensors measure the soil dielectric constant, an important electrical property that is highly dependent on soil moisture content. The soil dielectric constant can be considered as the soil’s ability to transmit electricity and it increases with the increase of soil water content. Therefore, the constant for a dry soil is between 3 and 5; about one for air, and is 80 for water. Calibration equations are then used to convert the dielectric constant values to soil moisture content. These equations are soil specific and drive the accuracy of the measurements. In most cases, sensor manufacturers provide a list with the main soil types and the specific equation for each one, therefore; the user can select the one closer to the soil type where the sensors are installed.

There are two main types of dielectric permittivity sensors: Capacitance and Time Domain Reflectometry (TDR). These sensors provide an estimation of the soil moisture volumetric content which is the volume of water (cm³) that is contained in a certain volume (cm³) of soil and is expressed as a percentage (%) of water in the soil. The accuracy on the sensor’s readings depend on the good contact the electrode or tube has with the soil. Air gaps and empty spaces between the soil surface and the sensor result in false or inaccurate readings.

1. **Capacitance sensors**

Capacitance sensors are dielectric sensors that determine the soil moisture by measuring dielectric permittivity of the soil. They usually consist of two cylindrical shaped electrodes. When the sensor is installed, the soil plays the role of the dielectric material between the electrodes. A certain frequency is applied to the electrodes, forming an electromagnetic field (Figure 1), and as it passes through the soil it changes depending on the water content. Lower remaining frequency corresponds to higher soil moisture content.

![Figure 1. Capacitance sensors on probe](source: www.sentek.com)
2. Time Domain Reflectometry (TDR) sensors

TDR sensors consist of three main components; a voltage pulse generator, signal analyzer and waveguides (sensor rods) (Figure 2). A pulse is generated and travels across the length of the waveguides until the end and back. The travel time depends on the soil dielectric constant; longer pulse travel time means higher dielectric constant corresponding to higher water content.

Sensor installation

It is important to perform sensor installation correctly. The main consideration is the air gaps that might occur during installation between the sensor and the soil. TDR sensors and Decagon sensors are easier to install since they are just inserted in the soil without disturbing it. When installing sensor probes, caution must be taken. First, an access hole must be created to the desired depth and radius to fit the probe. This procedure disturbs the soil and creates empty space between the sensor probe and the soil. In this case, a slurry installation technique can be performed. The slurry helps create a tight fit between the tube, or sensor, and soil eliminating air gaps. The slurry is made by mixing water and fine soil (sieved to remove large particles and rocks), similar to the soil where the sensor is to be installed.

Sensor calibration

Calibration is essential when using these sensors. The accuracy of the volumetric water content estimation depends greatly on the calibration that is being performed for the specific soil where the sensors are installed. Field Capacity (FC) and Permanent Wilting Point (WP) are the two basic soil attributes that must be known in order to perform calibration. Without calibration, the soil water content measurements can be erroneous leading to over or underestimation of irrigation requirements (Figure 3). Usually the manufacturers provide a number of calibration equations corresponding to the most common soil types. These equations can be used directly to transform the sensor readings into soil moisture, if the soil type where the sensors are installed is known. In any case, it is recommended to follow the manufacturers’ instructions to perform proper calibration according to the sensor type and specifications.
Field capacity (FC) is the amount of water content which remains in the soil after the drainage of excessive water 2–3 days after a rain or irrigation event (Figure 4). Wilting point (WP) is when the water content is so low that plants are unable to extract it from the soil (plant water stress conditions). Plant available water (PAW) is the amount of water that can be used by the plant. It is calculated as the field capacity minus the wilting point. The goal is to maintain soil moisture under very low water stress levels for the plants (over WP and until FC). Irrigation timing and water application amount using capacitance sensors depend greatly on the soil type, crop demands, and the irrigation management tactics (e.g. irrigate up to field capacity or deficit irrigation).

If the Permanent Wilting Point and Field Capacity are known, the Available Water can be calculated. Irrigation is applied before Available Water is depleted and the appropriate amount of irrigation water is the point where Field Capacity is reached. Application of additional water will lead to surface runoff.

Usually, the first few years of using sensor-based irrigation scheduling are exploratory. Maybe it is a good practice to use soil moisture sensors just to monitor for the first year and get familiar with the system. After some time the farmer will be able to specify the soil moisture content levels that will indicate when to start and terminate the irrigation for the specific site and application.

Table 1. Advantages and disadvantages of dielectric soil moisture sensors

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<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>• Highly accurate after calibration</td>
<td>• Require soil-specific calibration. The measurements are greatly affected by soil properties (mainly texture and porosity)</td>
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<td>• The response to changes in soil moisture is instant</td>
<td>• Small sensing distance from the sensor (0.5 to 0.8 inches)</td>
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<td>• Wide measurement range (from wet to very dry)</td>
<td>• Expensive compared to tensiometric sensors</td>
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<td>• Can be used in saline soils</td>
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<td>• Many choices on the market</td>
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Commercially available sensors

**Decagon**
They are high accurate dielectric sensors. Several sensor type options are provided. The selection of the appropriate one depends on the soil properties (if there are salinity issues or not), the desired measurement specifications (if there is need to monitor just soil water content or also soil temperature), and the cost. In order to monitor soil moisture at various depths, a sensor per depth is required. The installation process of these sensors is easy and rapid. First a hole is opened to the desired depth and the sensors are inserted directly into undisturbed soil at the bottom or the side of the hole (Figure 5).

**Sentek**
It is suitable for use in all soil types covering a wide range of soil water content levels, from saturated to oven dry. Normally site specific calibration is needed but for commercial reasons, a default calibration equation based on data obtained from scientific studies is used to provide an output in volumetric water content (mm of water per 100 mm of soil measured). The probe includes multiple sensors, as to monitor soil moisture at various depths covering the active soil profile.

**Aqua Spy**
Capacitance volumetric water content sensors on probe. It comes with sensors every 4 in and is available in three different lengths, 20 in (5 sensors), 40 in (10 sensors) and 60 in (15 sensors) for soil profile moisture monitoring. It is accurate, with 0.008% resolution and ideal for heavy or saline soils.

**Aquacheck**
Capacitance volumetric water content sensors on probe. They offer up to six depths or sensors per probe. Different sensor options are available depending on the measurement depth needs; the probe length varies between 16 in and 47 in. There is also available a wireless probe with on board memory which can also work as data logger.
**Adcon**
They use the principle of capacitance measurement. They can be used in all kinds of soils and in a wide range of depths, from 12 in to 59 in. All the sensor models come with one sensor every 4 inches.

**Dynamax**
They provide a variety of soil moisture sensors, both TDR and capacitance sensor technology, providing a range of options such as multi-depth soil moisture probes, portable probes, soil moisture sensors coupled with soil temperature sensors or single sensors.

**Sensor data acquisition**
There are several choices for data collection procedures.

**Manually**
Handheld reading devices can be used to collect data manually. This option is the cheapest for soil moisture data collection but also the most time consuming. The reading device is connected to the sensor cable and a single measurement is displayed on the monitor. The main disadvantage is that this method does not allow continuous data collection or automated data collection at any time. It is necessary to manually read and record data from every single sensor installed in the field.

**Data collectors**
There are several automated data collecting options. A data logger is usually installed close to the field and used to record and store measurements several times per day. It is significantly more expensive compared to the manual method but it provides the flexibility of continuous data monitoring.

**Wireless**
Most of the data loggers present the option of wireless connection for remote communication with the sensors for data storage. These loggers may be using different options of wireless connection such as Bluetooth, radio link, cell modem or satellite uplink.

**Sensor specifications and installation details can be found in:**
http://www.irrometer.com/sensors.html
http://www.decagon.com/products/sensors
http://www.aquaspy.com
http://www.aquachecktech.com
http://www.dynamax.com/IrrigationControl.htm
http://www.adcon.at
https://fieldconnect.deere.com
http://www.irrigationmatters.com/im
http://www.smartfield.com/smartfield-products/equipment

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