Comparing Smart Irrigation Technologies

Abstract

This paper describes two smart irrigation technologies: evapotranspiration-based watering and soil moisture sensor-based watering. The theories behind these technologies are briefly explained. The paper includes the results of evaluations done on these irrigation technologies including evaluations that compared the amount of water saved when using an ET-based controller with the amount saved when using a soil moisture sensor-based controller. The paper also describes the evolution of smart irrigation controllers and explains how Baseline's advanced soil moisture sensors support smart watering.

Introduction

With the ever increasing need to conserve water, many irrigators have embraced the use of "smart controllers." Unlike traditional irrigation controllers that operate on programmed schedule, a smart controller actively adjusts its watering schedule based on input from sensors. Smart controllers save water by applying the least amount of water possible to keep the soil moisture content in the root zone at the appropriate levels.

Evapotranspiration-based Watering

One smart irrigation technology uses evapotranspiration-based watering. Evapotranspiration (ET) refers to the loss of moisture from the soil by evaporation and by the transpiration of plants. Factors such as air temperature, relative humidity, solar radiation, rainfall, and wind speed affect the rate at which ET occurs.

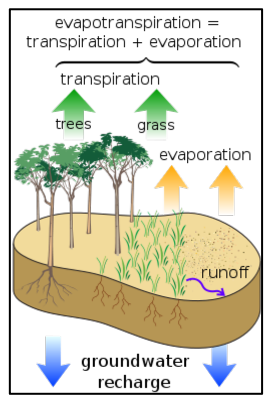

Figure 1: Surface Water Cycle, Wikimedia Commons

ET-based irrigation controllers attempt to calculate the loss of moisture from the root zone and adjust the watering schedule accordingly. The controller's ability to accurately adjust run times depends on the quality of the ET data and how many of the following site properties are considered along with the ET data:

- A specific plant type's water needs (known as the "crop coefficient")
- Root zone depth
- The plant's microclimate (ranging from full sun to total shade)
- The application rate of the irrigation method used (spray, rotor, drip, or bubbler)
- Type of soil at the site (clay, sand, or loam)
- Slope of landscape (ranging from slight to extreme)
- The latitude of the site

The ET-based irrigation controllers that are available today use a variety of methods to gather data and perform the calculations necessary to adjust the watering schedules:

ET Data Method	Description	Pros	Cons
Historical ET	The controller stores historical ET data and uses this data to calculate runtimes	Controller does not depend on a connection to another device	Does not account for periods of unusual weather
Sensor-based	The controller uses data from attached sensors (such as temperature and/or solar radiation) to estimate ET	Real-time sensor readings provide updated data to the controller	Data is limited to the type of sensors supplied with the controller and the accuracy of the calculated ET may be poor The sensors may not be properly located for ET parameter data collection
ET	Real-time ET data is transmitted to the controller from an outside source	Highly accurate data can be transmitted hourly from a precision weather station	The location of the weather station might have different conditions than the irrigation site Communication problems might interrupt the data transmission
On-site Weather Station	Precision weather station equipped with sensors that measure air temperature, relative humidity, solar radiation, rainfall, and wind speed is directly connected to the controller or to an associated computer	Highly accurate data can be transmitted regularly from a precision weather station that is in the same location as the irrigation site	A complete precision weather station can be quite costly

Evaluation of ET-based Controller Performance

Since 2008, the Irrigation Technology Center at Texas A&M University has been evaluating ET controller performance. Generally, these tests conclude that ET controllers with on-site weather stations perform fairly well across a range of conditions, but controllers that use off-site weather data, historical ET data, or limited data from on-site sensors aren't always able to adjust watering needs accurately. The results have shown that many of the ET controllers don't actually save water in real-world situations.

An excerpt from the summary of their 2012 evaluations is shown in Figure 2.

Programing smart controllers for specific site conditions continues to be a problem. Only two (2) of the nine (9) controllers tested could be programmed directly with all the parameters needed to define each zone.

Total Irrigation Amounts

- When looking at seasonal irrigation amounts for the entire landscape, one (1) controller was within +/- 20% of the TexasET Network for all six (6) station during the Summer Evaluation Period.
- Two (2) controllers applied more than ETo for one (1) or both seasonal periods
- Four (4) controllers did not have any station apply +/-20% of TexasET Network Recommendations for one (1) or both seasonal periods.

Adequacy Analysis

- Seven (7) Controllers were able to (across all 6 stations) to adequately meet the plant water requirements for any season.
- One (1) controller consistently applied excessive amounts of irrigation for all six (6) stations for both seasonal periods.

Factors that could have caused over irrigation of landscape are improper ETo calculation and insufficient accounting for rainfall. The 2012 study received only 16.41 inches of rainfall compared to historical averages of 24.20 inches for the same time period. ET values recorded off the controllers were inconsistent throughout the study, often calculating ET values greater than 150% of weather station (TexasET Network) ET.

Figure 2: Year 2012 Summary of Smart Irrigation Controllers, Irrigation Technology Center, Texas A&M University

Soil Moisture Sensor-based Watering

Another smart irrigation technology uses soil moisture sensors to water based on the moisture levels in the soil.

Rather than trying to estimate soil moisture depletion based on the weather the way that ET-based controllers do, soil moisture sensors actually measure the moisture level in the soil, and the controller uses this information to manage the frequency of irrigation. Irrigation is allowed after the soil dries to a pre-determined moisture threshold. A regular irrigation schedule is programmed into the controller, and when the soil moisture measurement read by the sensor drops below the moisture threshold, the controller runs the irrigation program.

Evaluation of Soil Moisture Sensor-based Controller Performance

For a number of years, the University of Florida has been testing the use of soil moisture sensors with irrigation systems. In one study, they compared the water savings on irrigation systems equipped with soil moisture sensors with irrigation systems equipped with rain sensors.

These tests showed that irrigation systems with soil moisture sensors saved a significant amount of water when compared to systems equipped with rain sensors. (See Figure 4.)

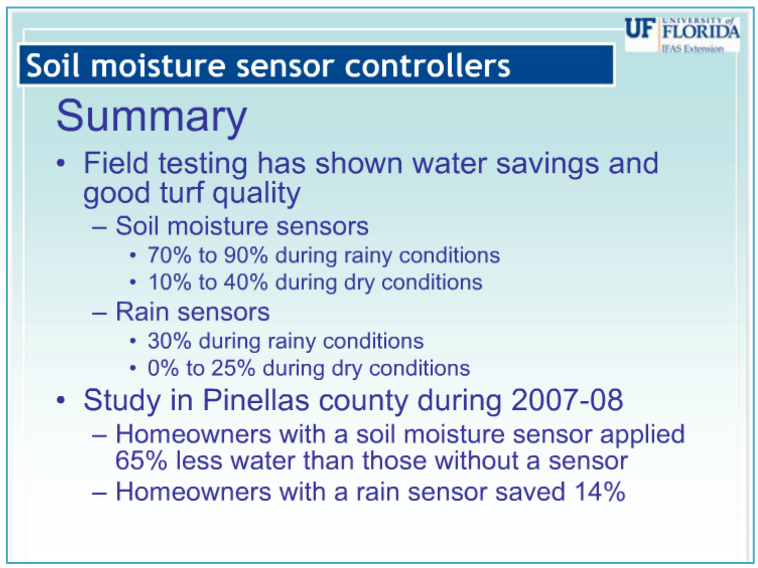

Figure 3: Soil Moisture Sensor Controllers in Florida. University of Florida, IFAS Extension

The University of Florida conducted another year-long study comparing the water savings of soil moisture sensor irrigation controllers with ET-based irrigation controllers. In this study, the participants were high-water users in locations with sandy soil and locations with the flatwoods* soil type that occurs in the southeastern United States. Half of the study participants received ET-based controllers and the other half received Baseline soil moisture sensor irrigation controllers. In each of these groups, some systems were simply installed and left to run, while other systems were installed with an accompanying tutorial on how to use the controller.

*****The southeastern flatwoods soil type is characterized as "poorly to somewhat poorly drained."

The results showed that the participants who received the tutorials saved the most water over the course of the study. In the sandy soil locations, the ET-based controllers and Baseline soil moisture sensor controllers achieved equal water savings, while in the flatwoods soil locations, the Baseline soil moisture sensor controllers showed a significant savings over the ET-based controllers. (See Figure 5.)

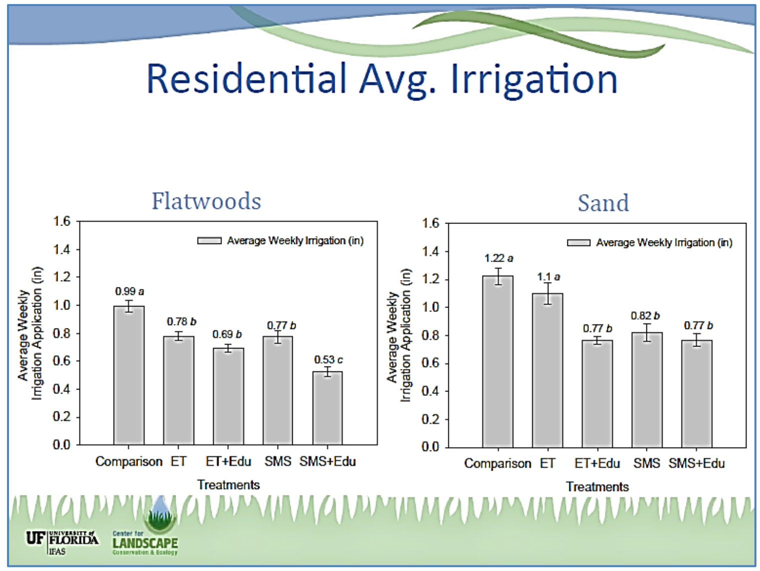

Figure 4: Year 1 of Implementing Smart Irrigation Controllers in Orange County, University of Florida

The Portland Water Bureau implemented a three-year Soil Moisture Sensor Pilot Study to investigate the ability of soil moisture sensor-based irrigation controllers to decrease the amount of water used for irrigation at landscape sites in Portland, Oregon. The study was also designed to determine whether soil moisture sensor-based irrigation works as well as weather-based controllers that require third-party communication.

The Bureau selected Baseline's soil moisture sensors (biSensors) and BaseStation 3200 irrigation controllers to enable soil moisture sensor-based irrigation. At one small study site a Baseline WaterTec S100 was installed to connect a biSensor to an existing irrigation controller. Baseline equipment was selected for use in this study due to its ability to work with the existing field wiring irrigation, its accuracy, reliability, and advanced features like remote communication and flow monitoring.

In their Project Summary of the Soil Moisture Pilot Program, the Portland Water Bureau states, "This study concluded that this particular soil moisture sensor-based irrigation product is more efficient than traditional automated methods. The less expensive WaterTec S100 system still provided substantial water savings, and it would be cost effective for many small to medium commercial landscape sites."

Additionally, they say that "soil moisture sensor-based irrigation will definitely be a way to irrigate landscapes efficiently, saving the customer time and money, as well improving the health of the landscape by keeping the soil moisture in the optimal range for plant health."

After comparing soil moisture sensor-based irrigation with weather-based controllers, the Bureau favors soil moisture sensors because this technology takes moisture readings directly from the soil at the site rather than requiring communication with off-site weather stations, and then estimating moisture depletion based on an equation. In addition to the direct moisture readings, soil moisture sensor technology saves money because users do not have to subscribe to the data feed from the weather station.

The Evolution of Smart Irrigation Controllers

If soil moisture sensor-based watering tends to come out on top in smart watering evaluations, why is ET the more commonly implemented technology in today's irrigation controllers?

To answer that question, we need to start with a brief history of the two technologies...

When early settlers started growing irrigated crops in the western US around 1850, over-irrigation was a common problem. In an effort to determine how much water plants need, scientists began developing methods for estimating evapotranspiration and consumptive use (CU) during the stages of crop growth.

Throughout the first half of the 20th century, engineers, soil scientists, and agronomists worked to standardize the methods for calculating ET. These efforts defined weather data requirements and developed equations that are used to calculate reference ET (ET_o).

When the manufacturers of automated irrigation controllers began looking for ways to automate water conservation, the method of using reference ET had been widely used for nearly a half century. Historical ET data was available and equations could be programmed into the irrigation controller firmware. By the late 1990s, these controllers were starting to become available in the market.

While work on ET methodologies was in progress, other researchers were developing various types of soil moisture sensors. When these sensors were put into use in agricultural and research applications, none proved very accurate, and each type seemed to have its own particular weakness. For example, capacitance sensors were highly affected by soil conditions right next to the sensor, and they gave widely variable readings. Tensiometers had maintenance issues – in climates where the ground freezes, these sensors had to be removed and stored for the winter months and reinstalled the following year. Granular matrix sensors were very sensitive to temperature and soil salinity. Resistive or conductive sensors corrode and rust over time because the bare metal of the sensor is exposed to the soil.

All of these factors gave soil moisture sensors a bad reputation among irrigation managers. This negative opinion became so deep-rooted that users continued to have doubts about the effectiveness of soil moisture sensors even when new technology significantly advanced their dependability and reliability.

Baseline's biSensor – Innovative and Accurate

The design and technology of Baseline's soil moisture sensors make them the most advanced sensors in today's market. Baseline's patented soil moisture sensors use TDT (time domain transmission) technology to send a high frequency pulse of electricity down an embedded wire path. The high frequency of the pulse causes the sphere of influence of the pulse to move outside the sensor blade and into the soil around it. When the pulse travels through moisture, it slows down. The sensor measures the speed, and then converts this measurement to a moisture content reading.

Figure 5: Baseline's biSensor

Baseline's biSensors have the following specifications:

- **Sensitivity** is the sensor's ability to monitor small changes in soil moisture content. Many sensors on the market are ± 2-3 percent; however, Baseline sensors can reliably track less than 1/10th of a percent of change *volumetrically*. Sensitivity is very important in light soil such as sand or engineered soils.

- **Repeatability** refers to how well the sensor can report the same value when measuring the same moisture content. You cannot have repeatability without sensitivity. Often this number is reported as the same value as sensitivity. Baseline's repeatability and sensitivity is outstanding at less than $1/10^{th}$ of a percent.
- **Accuracy** is sometimes used to describe sensitivity and repeatability; however, it can also describe the sensor's ability to report true volumetric moisture content (VMC). Not all sensors report in VMC: some use a scale of 1-100, while others simply display a graph. Baseline has chosen to standardize on the VMC method of reporting, and consequently, accuracy is a measurement of our ability to accurately report VMC. Baseline's soil moisture sensors are ± 3 percent in accuracy within most soil types.
- **Durability** or reliability is arguably the most important factor in a commercially used soil moisture sensor. Baseline has been building soil moisture sensors for over 13 years. Our sensors are used all over the globe — from Death Valley where soil temperatures can be in excess of 100° to northern environments with freezing conditions. Baseline sensors have no metal in contact with the soil and are expected to last 25 years.

Converting to Baseline's Smart Watering Solution

If you're managing a site with an ET-based system that is coming to the end of its lifecycle, you might consider converting to soil moisture sensor-based watering.

Baseline's soil moisture sensor has complete two-way communication with Baseline irrigation controllers, which means that our sensor is much more than a simple reporting device. It sends the soil moisture readings to the Baseline controller, which then reads the soil moisture data and uses that information to automate when/how often to turn on the sprinklers and how long to run/when to shut off the sprinklers.

> **The University of Florida's testing has shown that watering with Baseline's soil moisture sensors can result in water savings of 70% to 90% in rainy conditions and 10% to 40% in dry conditions.**
>
> **The average water savings in the Portland Water Bureau's Soil Moisture Sensor Pilot Study was 42%.**

A Baseline irrigation controller can use two basic watering strategies when watering with soil moisture sensors: lower threshold and upper threshold (also known as lower limit and upper limit).

- **Lower threshold** tells the system to turn on based on soil moisture, and then turn off based on time. To conserve water and optimize the plants' water-use efficiency (WUE), lower threshold is the recommended strategy. With lower threshold, you could set your controller to one or more start times each day, but the sensor will only allow irrigation when the soil has dried out to a level at or below the threshold.
- **Upper threshold** tells the system to turn on based on time, and then turn off based on soil moisture. For areas that have a restricted schedule such as specific watering days or specific use schedules like sports fields, upper threshold is a more popular option. With upper threshold, you can choose which day and what time of day to start watering and the sensor will shut off watering when soil moisture reaches the upper threshold.

Benefits for Sports Fields and High Use Areas

In addition to the water conservation benefits of soil moisture sensor-based watering, this smart watering methodology is useful for sports fields and other high use areas such as parks and school grounds where irrigation must be managed according to a stringent schedule.

If you install multiple sensors, the controller can manage different irrigation schedules for the various areas of your site. You can use the upper threshold strategy to increase turf durability on the playing fields, and you can use the lower threshold strategy in other areas to maximize water conservation.

Easy to Install

Finally, converting to soil moisture sensor-based watering is easy. Just bury your sensors and wire them to the nearest valve box or the two-wire path. Then install and connect your controllers, and you're ready to start fine tuning your irrigation schedules.

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