

# Understanding Soil Moisture Sensors: A Fact Sheet for Irrigation Professionals in Virginia

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Note: This publication updates and replaces “Using Soil Moisture Sensors for Making Irrigation Management Decisions in Virginia,” Virginia Cooperative Extension publication 442-024 (out of publication).

Please refer to definitions in the glossary at the end of this publication. Terms defined in the glossary are in boldface on first use in the text.

In the Commonwealth of Virginia, water resources are increasingly being scrutinized due to changing surface water or **groundwater** availability. Access to good quality water is a continuing concern, and in many communities, managing **water use** — particularly **consumptive use** — is a priority to conserve public water supplies to meet the needs of a growing population.

According to the U.S. Geological Survey, in 2010, approximately 29 percent of surface water and 65 percent of fresh groundwater withdrawals in the United States were used for agricultural crops and other irrigation needs (Maupin et al. 2014). Public water supply systems in Virginia used approximately 476 million gallons per day (mgd) in 2010. A smaller but steadily growing quantity of water is used for irrigation, the majority from surface water (45.4 mgd). Approximately 16 mgd of groundwater was used for irrigation in 2010; these values represent increases of 37 percent for surface water and 9 percent for groundwater since the last survey conducted by the USGS in 2005 (Kenny et al. 2009). This expansion is mainly due to an 89 percent increase in irrigated land in Virginia between 2005 and 2010. According to the

USGS, 87 percent of the acreage irrigated in Virginia in 2010 was sprinkler-applied, and 13 percent was **microirrigated**. The latter method is the more efficient method to apply water to individual plants.

A significant, but unknown portion of irrigation water demand in Virginia is used for landscape irrigation. Landscape irrigation represents a growing proportion of total water use as the state population and suburban communities grow. Therefore, the potential economic and resource (e.g., applied water and nutrients) savings of improving irrigation **water use efficiency** is significant. Maximizing irrigation water use efficiency depends on applying irrigation water at the right time, in the right place, and in the right amount. Highly variable soils and climate, described in part by differing eco-regions — including the Coastal Plain, Piedmont, mountains, and ridges and valleys throughout Virginia — require customized irrigation strategies.

In order to minimize risk to plants, irrigation water is often applied to the entire landscape in excess at the first indication of potential plant water stress. **Automated irrigation systems** can help irrigation professionals minimize water use by using weather data, **soil moisture content**, and plant-specific information to make informed irrigation application amount and timing decisions. Ideally, automated irrigation enhances a sound irrigation strategy that applies water as efficiently as possible while minimizing **evaporation, runoff, and leaching**. The aim of efficient irrigation is to provide the least amount of water directly to the plant roots to replenish **root zone** moisture before water stress adversely

impacts the plant. Efficient irrigation conserves water and reduces potential leaching of **agricultural chemicals**.

One method for improving irrigation scheduling is measuring soil water content in real time, which can be conventionally measured on a **gravimetric** (g/kg) or **volumetric** basis ( $m^3/m^3$ ); soil water content can also be referred to as a depth (mm) over a given area ( $m^2$ ). Soil water content can be estimated by using **lysimeters** or **soil moisture sensors**. Both methods require careful **calibration** to provide accurate measure of soil water, or soil moisture content; however, both devices can be used to provide a relative measure (wet versus dry) using manufacturer-provided general calibration curves or by observing plants or soil conditions and relating it back to sensor measurements. **Weighing lysimeters** make direct weight measurements of the soil and water and require information that is often not practical to collect in most irrigation settings. On the other hand, soil moisture sensors measure water content at the location and depth where placed. If placed and used properly, these sensors can provide insight into soil water content and plant water status.

Many types of soil moisture sensors are available for a variety of applications. This publication provides an introduction to soil moisture sensors, describes how different types of commercially available sensors function, helps to guide the appropriate selection of sensors, and explains at which depths to install them for a variety of crops and turf. In addition, we discuss how to integrate real-time moisture data into a programmable **irrigation controller**. This knowledge can be used by irrigation professionals to improve irrigation water use efficiency to conserve water supplies and improve crop health.

## Soil Water

Soil moisture sensors measure **plant-available water** as a function of soil volumetric water content as it relates to **matric potential**, the behavior of which is illustrated in Figure 1. A completely dry soil sample contains void spaces between the soil particles, a soil property known as **porosity**. As water infiltrates into soil, these voids are filled. Some water drains through the voids due to the effects of gravity, but a portion remains held in the voids by forces exerted by the soil particles. Examples of soil at the extremes, sand and clay, are shown in Figure 1. Sandy soils have a

low matric potential and relatively high **hydraulic conductivity**. That is, water enters them relatively freely and travels quickly along a **gradient**. Clay soils have high matric potential and low hydraulic conductivity. Water does not enter these soils easily, and it travels slowly through the soil profile. The finer particles in the clay soils tend to hold the water more tightly than in sandy soils. The strength of this bond is expressed as matric potential. It is useful to define soil moisture with respect to an operational range.

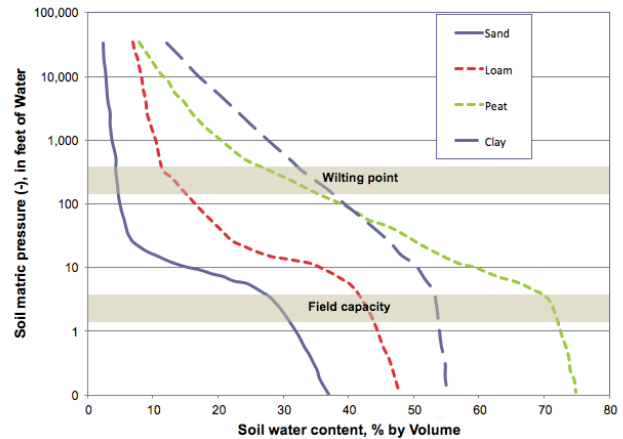


Figure 1. Soil matric potential in relation to volumetric water content by four soil textures.

The high end of this range — the **field capacity** of soil — is typically defined as the moisture content two to three days after a rainfall or irrigation event has ended, where excess water has drained away. At the low end, the **permanent wilting point** of a soil is the value at the lower moisture threshold beyond which a plant can no longer withdraw moisture from the soil. By convention, the wilting point is defined as the soil water content measured at approximately 15 bars (502 feet of water) of matric potential. Sandy soils have both a lower wilting point and higher field capacity but dry out quicker. Thus, sandy soils hold less water than clay soils. However, the water within the **pores** of a sandy soil is more available to the plants than water in a clay soil. Therefore, “relative” boundaries can be set using these observed parameters by setting the upper threshold of soil moisture measurements at field capacity (e.g., two days after a rain event) and the lower threshold at the value when wilting is observed. This can be further investigated by pulling a soil plug and feeling the moisture content of the soil to determine if it is relatively dry, taking into consideration the **soil type** (USDA 1998). For

more information on soil water properties, consult Rawls, Brakensiek, and Miller (1983) and the Web Soil Survey (USDA 2016) data available at <http://websoilsurvey.nrcs.usda.gov/>.

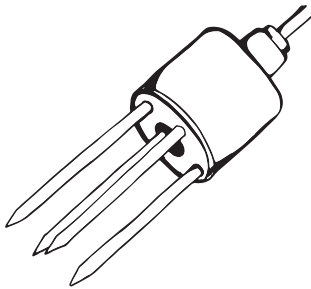
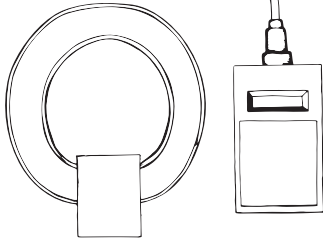
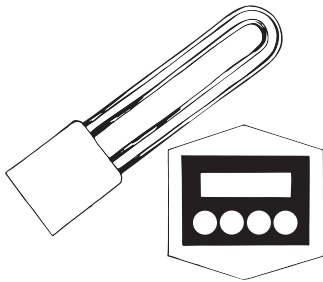
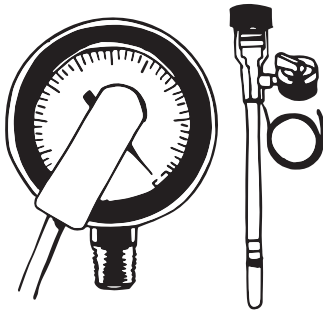
be noted that sensor readings or output are relative to a successful installation in which there is a good soil/sensor contact. This becomes increasingly difficult with coarse-textured soils (i.e., sandy or gravelly soils) in which air surrounds the sensor or the sensor loses contact with the soil and associated water.

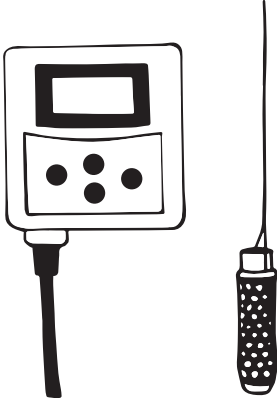
## Sensors Currently Used for Irrigation Management

Table 1 summarizes of the relative strengths and weaknesses and other attributes of each sensor; the information is adapted from Munoz-Carpena (2012) and Smajstrla and Harrison (2011). Note that sensor technologies vary widely, and sensor choice should be based on knowledge of local conditions, the purpose of the sensor, and the intended use of the soil moisture data. Table 2 provides an overview of all sensors with respect to multiple attributes. It should

**Table 1. Summary of Moisture Sensors**

Sensor	Description	Photo or diagram	Advantages	Disadvantages
Time domain reflector (TDR)	Time domain reflectometers consist of two to three parallel rods that are inserted into the soil. An electromagnetic wave is passed through the soil via the rods from a transmission line. The speed and strength of the wave after it travels from one rod to the other is directly related to the dielectric properties of the soil, and hence, its soil moisture content.		<ul style="list-style-type: none"> <li>• Highly accurate (<math>\pm 1\%</math>).</li> <li>• Can be used without calibration to specific soils, however it reduces accuracy.</li> <li>• Not easily influenced by moderately saline soil conditions.</li> <li>• Minimal soil disturbance.</li> </ul>	<ul style="list-style-type: none"> <li>• Need for good contact between sensor and soil.</li> <li>• Small sensing area (2.4-inch diameter).</li> <li>• Might have limited applicability in highly saline or heavy clay soils.</li> <li>• Might have to be recalibrated for soils with tightly held water.</li> </ul>
Frequency domain reflector (FDR)	This sensor uses the soil as a capacitor, which stores part of an electric charge that is run through two or more electrodes inserted into soil. Changes in frequency of the wave as it passes through the soil are related to this capacitance and its dielectric properties of the soil (i.e., the greater the frequency, the more soil moisture).		<ul style="list-style-type: none"> <li>• Accurate once calibrated to a specific soil (<math>\pm 1\%</math>).</li> <li>• Can be used in saline soils beyond the range of the TDR.</li> <li>• High resolution signal (less noise than TDR).</li> <li>• FDRs tend to be less expensive than TDRs.</li> </ul>	<ul style="list-style-type: none"> <li>• Must be calibrated to a specific soil.</li> <li>• More sensitive to temperature and bulk density than TDR.</li> <li>• Small sensing area (3.2-inch diameter).</li> <li>• Need for good contact between sensor and soil.</li> <li>• Sensitive to air gaps.</li> </ul>

Sensor	Description	Photo or diagram	Advantages	Disadvantages
Amplitude domain reflectometer	This sensor consists of two metal rods arranged in a circle around a central rod that acts as the transmission line. The sensor measures impedance of a signal from the transmission probe to the receiving probes. Impedance contains two parts: the dielectric constant and the soil electrical conductivity. The latter is minimized by signal selection, thus leaving the dielectric constant, which is proportional to soil moisture.		<ul style="list-style-type: none"> <li>• Accurate once calibrated to a specific soil (<math>\pm 1\%</math> with calibration, <math>\pm 5\%</math> without).</li> <li>• Can be used in highly saline soils.</li> <li>• Minimal soil disturbance.</li> <li>• Inexpensive.</li> <li>• Temperature does not interfere with signal.</li> <li>• Can simultaneously measure bulk density.</li> </ul>	<ul style="list-style-type: none"> <li>• Calibration to a specific soil is recommended.</li> <li>• Volume of measurement is relatively small (<math>\approx 0.3 \text{ in}^3</math>).</li> <li>• Sensitive to air gaps, stones, or water traveling through channels separate from soil matrix.</li> </ul>
Phase transmission	Consists of two metal rings, one inside the other, through which an electromagnetic wave is passed. As the wave passes through soil, its frequency is shifted; the extent of this shift is directly related to the soil moisture content.		<ul style="list-style-type: none"> <li>• Accurate once calibrated to a specific soil (<math>\pm 1\%</math>).</li> <li>• Large sensing volume (<math>\approx 100 \text{ in}^3</math>).</li> <li>• Inexpensive.</li> </ul>	<ul style="list-style-type: none"> <li>• Calibration to a specific soil is required.</li> <li>• Very sensitive to soil salinity.</li> <li>• Large disturbance.</li> <li>• Sensor tends to be permanent.</li> <li>• Signal is noisy, low-resolution.</li> <li>• Availability is limited.</li> </ul>
Time domain transmission (TDT)	This sensor operates similarly to a TDR, however the rod is connected to the electrical source at both the beginning and end of the rod. The TDT measures the travel time of the wave propagation between the rods.		<ul style="list-style-type: none"> <li>• Accurate (<math>\pm 2\%</math>).</li> <li>• Large sensing volume (<math>\approx 30 \text{ in}^3</math>).</li> <li>• Inexpensive.</li> </ul>	<ul style="list-style-type: none"> <li>• Signal is noisy, low-resolution.</li> <li>• Larger disturbance than TDR.</li> <li>• Sensor tends to be permanent.</li> </ul>
Tensiometer	Consists of a glass tube filled with water that is connected to a vacuum gauge. A porous ceramic cup is placed at the end of the tube. As water is used by plants or as the soil moisture decreases, soil matric potential increases. This is measured by changes in pressure on the vacuum gauge. Conversely, as soil moisture increases, the vacuum decreases.		<ul style="list-style-type: none"> <li>• Capable of high frequency sampling.</li> <li>• Salinity buffering.</li> <li>• Inexpensive.</li> <li>• Large sensing area (8-inch diameter).</li> </ul>	<ul style="list-style-type: none"> <li>• Limited range.</li> <li>• Maintenance to replace water in tube could be necessary.</li> <li>• Might have to be reset frequently in coarse or swelling soils.</li> <li>• Less intuitive due to negative relationship between volumetric water content and tensiometer reading.</li> </ul>

Sensor	Description	Photo or diagram	Advantages	Disadvantages
Granular matrix sensors	Sensor consists of electrodes contained in a granular matrix (usually quartz) that is enclosed within a gypsum solution, a membrane, and a metal case. Gypsum buffers salinity affects. A small charge is placed on the electrodes and electrical resistance through the sensor is measured. As water is used by plants or as the soil moisture decreases, water is drawn from the sensor and resistance increases. Conversely, as soil moisture increases, resistance decreases.		<ul style="list-style-type: none"> <li>• Can measure a large area (8-inch diameter).</li> <li>• Can be used in moderately saline soils.</li> <li>• Can be used to sense wet or dry soil moisture readings for irrigation.</li> <li>• Inexpensive.</li> <li>• If soil does not dry out, little maintenance is required.</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively inaccurate.</li> <li>• Performs poorly in sandy soils due to slow reaction time (water moves fast in sandy soils).</li> <li>• Performs poorly in soils that shrink/swell.</li> <li>• Susceptible to drying; must be dug out and solution reset when this occurs.</li> </ul>

**Table 2. Comparison of soil moisture sensors.**

Sensor		Type of sensor	Attributes of sensor											
Type	Acronym	Dielectric constant Matric potential	Accuracy across ranges of soils with limited calibration	Accuracy with specified soils once calibrated	Signal noise	Adaptable for use in saline soils	Soil disturbance	Temperature dependence	Bulk density dependence	Area of measurement sample	Sensitivity to air gaps and pores	Widespread availability	Ease of installation and maintenance	Cost
Time domain reflectometer	TDR	●	⊙	●	⊙	⊙	○	○	○	○	○	●	●	●
Frequency domain reflector	FDR	●	⊙	●	○	●	○	⊙	⊙	○	⊙	⊙	●	⊙
Amplitude domain reflectometer	ADR	●	○	●	⊙	●	○	○	○	●	●	⊙	⊙	⊙
Phase transmission	—	●	○	●	○	⊙	●	○	⊙	●	○	○	○	⊙
Time domain transmission	TDT	●	●	●	●	●	●	○	○	●	○	⊙	○	○
Tensiometer	—	●	○	⊙	○	●	○	○	○	○	○	●	⊙	○
Granular matrix sensors	—	●	○	⊙	⊙	⊙	○	○	○	○	○	●	○	○

○ = low   ⊙ = medium   ● = high

## Types of Soil Moisture Sensors

The majority of soil moisture sensors used with commercial irrigation controllers are based on measuring **dielectric permittivity**, which is often treated as a constant for a given soil. In practice, however it varies slightly by soil water and/or salt content (i.e., metals contained in the soil that are dissolved in soil solution), **soil texture**, and **bulk density**. Soil **permittivity** is a composite of permittivity values for each subcomponent material of a particular soil. To measure bulk permittivity of soils *in situ*, the velocity of an electromagnetic wave passed through the soil is measured. A material with a larger **dielectric constant**, or  $K_{ab}$ , such as water, will slow the wave sufficiently to detect a change. The  $K_{ab}$  of water is much larger than that of **soil minerals** or air; thus water is the principal material being detected.

The advantages to using these devices are that they are relatively inexpensive, they can be installed with minimal soil disturbance, and their measurements are not greatly influenced by the amount of salt in the soil. However, these devices must be permanently installed with good soil/sensor contact to ensure there are no air gaps. Additionally, this type of sensor must either be calibrated to a specific soil or it must use a manufacturer-supplied generic calibration curve. Another type of sensor assesses soil matric potential. Soil matric potential reflects the ability of the soil to uptake water and is influenced by gravitational pressure, **osmotic pressure** (salts in solution), air pressure, and soil texture. Soil matric sensors mimic the process plant roots use to absorb soil moisture (Smajstrla and Harrison 2011). These sensors consist of a porous material placed in contact with soil such that water can move through porous material as the **suction head** or matric potential changes as the soil wets and dries. Types of sensors that assess matric potential include **tensiometers** and **granular matrix sensors** (Table 1). Since water matric potential varies inversely with soil moisture, users must understand that high readings on the sensor indicate low soil moisture.

In addition to these devices, there are several other types of sensors, such as **neutron probes**, **capacitance sensors**, and **soil psychrometers**, that are described in the glossary. These devices are not commonly used in Virginia.

## Soil Moisture Sensor Calibration

Measuring soil water content of a given soil requires a calibration process to ensure the selected soil moisture sensor readings are as accurate as possible. There are two types of calibration — absolute and relative. Absolute calibration involves correlating soil moisture sensor readings with soil water content measurements made using some independent measuring technique (e.g., a weighing lysimeter or some other measurement device) over some period of time, such as a growing season. The accuracy offered by an absolute calibration might not be required for typical soil moisture sensing applications (e.g., irrigation scheduling). A relative calibration of the soil moisture sensor could suffice. Relative calibration involves observing wet and dry soil conditions and the response of the crop being irrigated and assessing the relative performance of the sensor. Many manufacturers can supply “typical” calibration curves for selected soil textures that might suffice for many applications. Any errors in soil moisture measurement using a typical calibration curve is likely tied to how closely the user’s soil matches that of the typical reference curve.

Because of the variety of technologies used and the varying length of the monitoring period, calibration of any given sensor could vary depending on site-specific conditions. Calibration is very closely aligned with evaluating system performance. At present, there is no common performance standard for soil moisture sensors. To address this gap, The Irrigation Association — a national association of irrigation professionals and allied suppliers — is developing a series of independent testing protocols for controllers and climatological, soil moisture, and/or rainfall cutoff sensors. This protocol is known as Smart Water Application Technologies, or SWAT, which combines the concept of efficient water delivery with direct measurement of soil moisture. SWAT is currently administered through the Center for Irrigation Technology — an independent testing laboratory, applied research facility, and educational resource center based at California State University-Fresno. A recent U.S. Bureau of Reclamation (2012) document provides a summary of current performance data on various sensors and controller systems.

## Installation of Soil Moisture Sensors

Soil moisture sensors come with a variety of recommendations for choosing an appropriate location and depth. Sensors can be connected to a computer or irrigation controller via a direct connection (wire) or remotely (wireless), which typically depends on application (agricultural versus residential), user preference, and area and number of sensors used. Generally, one should choose the location(s) with like vegetation or plants with similar water needs, similar soil texture and depth, and similar ground cover (i.e., mulch versus no mulch). The online tool Web Soil Survey (USDA 2016; <http://websoilsurvey.nrcs.usda.gov/>) can provide soil maps that include soil chemical and/or physical properties. This tool is not useful for users in poorly defined or disturbed soils such as urban fill. In these areas, one should consult with a professional soil scientist and/or collect a representative soil sample and have it analyzed by a state or private laboratory. Users should be aware that soil analysis provided by the Virginia Tech Soil Testing Laboratory does not typically provide textural analysis; this can be conducted using a simple procedure outlined in VCE publication 452-129 (Hunnings, Donohue, and Heckendorn 2011).

Irrigated areas should be grouped by areas with similar characteristics (soil, plant type, mulch, sun exposure, etc.). Each area should be monitored and irrigated separately to maximize water use efficiency. Soil moisture sensors should also be placed in a location that receives sunlight to account for **evapotranspiration** effects of the soil and plant; the location should also be where runoff water cannot pool and provide an inaccurate reading. Areas that should be avoided include property lines, impervious areas, high traffic areas, and plant beds of differing **species**. Sensor(s) can be installed to provide a single point and depth reference or to provide a soil water profile using sensors that measure volumetric water content at incremental depths. Table 3 provides guidelines on effective rooting depths for various crops found throughout Virginia. In addition, sensors should be placed at the midpoint of the effective root zone of a plant or crop, between irrigation heads where the crop or landscape site receives relatively uniform irrigation.

Installation instructions vary depending on sensor type, but the general practice is to ensure good sensor

to soil contact, cover and protect any loose wiring, and install the sensor when soil conditions are damp or wet (for ease of installation). Electrical resistance or tensiometers could require soaking prior to installation to aid in equilibrating the device with the soil environment.

**Table 3. Effective rooting depths for soil moisture sensor installation guidelines.**

Crops	Root depth (inches)
<b>Field crops</b>	
Barley, corn, cotton, flax, oats, peanuts, rye, sorghum, soybeans, sunflower, wheat, tall fescue	24
Tobacco	18
<b>Forage crops</b>	
Alfalfa, bromegrass, orchardgrass, clovers, sudangrass, rye grass	24
Bluegrass, ladino clover, bermudagrass	18
<b>Fruit</b>	
Blueberries, cane fruits and grapes, peaches, pears, cherries, apples	18-48
Watermelon, cantaloupe	18-24
Strawberries	6
<b>Turf</b>	
Athletic field (not active), grass sod	6
Athletic field (active), golf greens and fairways, grass sod immediate sale	4
<b>Nursery plants</b>	
Ericaceous ornamentals, gladioli, peonies, irises, bulb and corn plants, lining out plants, finished landscape plants, perennial ornamentals, trees, shrubs	12-24
Annual flowers, bedded plants, groundcover plants	6
<b>Vegetables</b>	
Asparagus, corn, cucumber, kale, peas, peppers, potatoes, snap beans, squash, tomatoes	18-24
Broccoli, cabbage, carrots, cauliflower, celery, onions, lettuce, radish, spinach	12-24

## Automated Irrigation in Action

The ultimate goal of using soil moisture sensors is to quantify crop or plant water needs as related to soil moisture. This data is used for determining when to irrigate and how much water to apply to avoid water stress (i.e., irrigation scheduling). For automated systems, irrigation scheduling can be accomplished by coupling one or more of the aforementioned soil sensors to irrigation controllers that turn the irrigation system on and off as illustrated in Figure 2. Soil water gain (irrigation and precipitation) and loss (evapotranspiration) will vary with climatic conditions, altering the frequency or duration of irrigation events.

In normal operation, most automatic irrigation systems simply assess whether the irrigated soils are relatively wet or dry and depend on the operator to observe vegetative response, thus indirectly calibrating the desired range of soil moisture content. The lower threshold is set to ensure that there is no crop or plant damage; the upper threshold is set to reduce runoff and provide for more efficient use of water. If site-specific

soil information is known, the sensor can be calibrated to a specific soil, and the irrigation threshold can be set more accurately (Figure 2.) Regardless of whether a relative or actual soil moisture measurement is used, the landscape receives the scheduled irrigation if soil moisture is less than the threshold. If soil moisture is greater than the threshold, irrigation does not occur. More sophisticated controllers can determine the amount of water to be applied based on volumetric water content and irrigation system parameters (i.e., application rate, root zone depth, soil available water capacity) at the time of irrigation. Because a large part of the market for irrigation control applications is intended for use with urban lawns, the programming usually allows the user to restrict irrigation on days where lawn irrigation is restricted by city or county ordinance. Soil moisture sensor systems have been shown to reduce water consumption by up to 70 percent compared to the use of rain sensor systems, which reduce consumption by 34 percent (University of Florida Program for Resource Efficient Communities 2007).

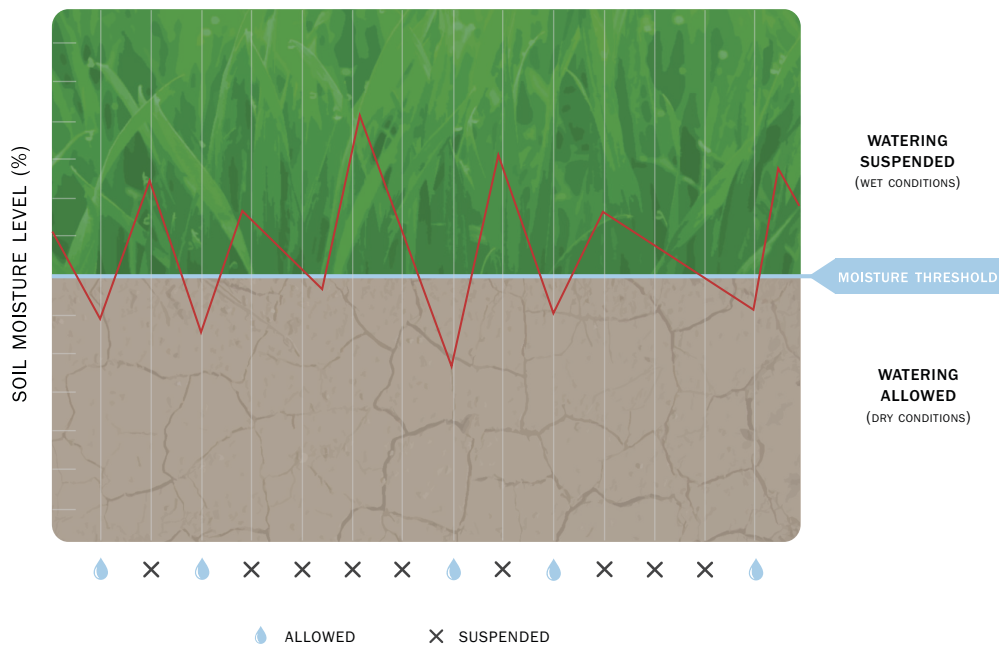


Figure 2. For a given soil and plant/crop combination, a soil moisture threshold (blue line) is established based on soil moisture level. If the soil moisture falls below the threshold, irrigation (watering) is allowed. If the soil moisture is above the threshold, watering is suspended. Clouds illustrate that rain events increased soil moisture (red line).

Adapted from Rain Bird Corporation, Turn Any Controller Into a Smart Controller: SMRT-Y Soil Moisture Sensor Kit (Tuscon, AZ: Rain Bird, 2009, 2).



In summary, installation of soil moisture sensors and the associated control of irrigation can assist irrigation operators maintain healthy vegetation and conserve water. They can also reduce runoff and reduce leaching of agrichemicals. Selection of the most appropriate sensor for installation will depend on the irrigation strategy, type of irrigation management system, crop type and value, and the availability and cost of water supplies.

## Additional Resources

### Online Resources

**Campbell Scientific** - [www.campbellsci.com/soil-water-content](http://www.campbellsci.com/soil-water-content)

**Decagon Inc.** - [www.decagon.com/en/soils/volumetric-water-content-sensors/](http://www.decagon.com/en/soils/volumetric-water-content-sensors/)

**Irrigation Association** - [www.irrigation.org](http://www.irrigation.org)

**Irrrometer Company** - [www.irrometer.com/sensors.html#wm](http://www.irrometer.com/sensors.html#wm); [www.irrometer.com/sensors.html](http://www.irrometer.com/sensors.html)

**Troxler Electronic Laboratories** - [www.troxlerlabs.com/products/4301.php](http://www.troxlerlabs.com/products/4301.php)

**University of Florida, IFAS Extension** - <http://edis.ifas.ufl.edu/ae266>

**USDA Natural Resources Conservation Service, Web Soil Survey** - <http://websoilsurvey.nrcs.usda.gov/>

**Wescor Inc.** - <http://water.wescor.com/pct55.html>

### Companion Virginia Cooperative Extension Publications

Benham, B., and B. Ross. 2009. Filtration, Treatment, and Maintenance Considerations for Micro-Irrigation Systems. VCE publication 442-757.

Goatley, M. 2014. Summer Lawn Management: Watering the Lawn. VCE publication 430-010.

Straw, R. A. 2015. Irrigating the Home Garden. VCE publication 426-322.

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## Glossary

**agrichemicals** – A term used for pesticides, herbicides, nutrients, and hormones.

**automated Irrigation system, irrigation system** – An automated system that controls irrigation duration and intensity, depending on the operator’s programming.

**bulk density** – A measurement of the total weight of a dried sample divided by the total volume. This gives a representation of the weight of the particles only, while including pore space in the volume.

**calibration** – The process of fine-tuning a device so the desired measurement is observed when measuring a standardized sample.

**capacitance sensors** – Sensors that measure capacitance — the ability to hold an electric charge — of the surrounding soil in order to obtain the dielectric permittivity of the soil.

**consumptive use** – Water that cannot be returned to the water shed after use; in agriculture, this can refer to the water that is transpired by plants or evaporated from the soil surface.

**dielectric constant** – The measure of the ease in which a wave of electromagnetic energy can move through the soil; also known as “dielectric permittivity.”

**dielectric permittivity** – See “dielectric constant.”

**evaporation** – The process in which water is vaporized (which is a change from the liquid to the gas phase) and lost to the atmosphere.

**evapotranspiration** – The sum of evaporation and plant transpiration of liquid water released to the atmosphere as a vapor; also known as “ET.”

**field capacity** – The amount of water a soil can hold after allowing for 2-3 days of drainage under normal conditions.

**gradient** – The difference in magnitude of some property (such as water surface elevation) along a defined path.

**granular matrix sensors** – A set of electrodes in a granular matrix material, usually quartz. The matrix is enclosed in a semipermeable membrane and is protected by a mesh, usually made of stainless steel. Gypsum is embedded in the matrix as a salinity buffer. Changes in soil electrical conductivity are analogous to soil matric potential.

**gravimetric** – The properties of water based a unit of weight (g/kg) as compared to the weight of dry soil.

**groundwater** – Water that is stored below the Earth’s surface. This generally can be considered water in underground aquifers as well as moisture in the soil.

**hydraulic conductivity** – A measure of the ability for water to move through a soil. This is dependent on mineralogy, porosity, and degree of saturation for a given soil.

**in situ** – A term used to describe something that takes place in its natural environment.

**irrigation** – A controlled process where water is applied; it is generally applied to soil for crop use.

**irrigation controller** – A device that is programmed to turn irrigation on and off at specific times and maintain specific flow rates that are predetermined by the operator.

**leaching** – Infiltrated water moving down through the soil profile before it can be used by plants.

**lysimeters** – Devices that measure the water in soil pores at a given location in the soil profile. This gives a leaching value and can be used to calculate evapotranspiration.

**matric potential, soil matric pressure** – A negative pressure or suction head that is read by the instrument. Soil matric potential reflects the ability of the soil to either retain or move water as a result of adhering to the soil or or suction exerted by pores. In this publication, matric potential is used synonymously with water potential, since it is commonly used by suppliers. Matric potential is thought to be the dominant force affecting water potential in soils (which is the sum of osmotic, gravitational, and matric potential); however, the majority of soil moisture sensors cannot distinguish between water potential and matric potential.

**microirrigated** – Localized irrigation that provides water to a small area as opposed to a broadcast irrigation. An example of microirrigation would be drip irrigation.

**neutron probe** – A device that measures soil water content by releasing neutrons from a radioactive source at high speeds in a soil. When the neutrons hit other particles with similar masses ( $H^+$ ), the neutrons slow down. This results in a neutron “bubble” or “cloud” in the soil. Because water is the primary source of  $H^+$  in soil, the density of this neutron cloud can be related to the percentage of water in the soil.

**osmotic pressure** – Used when evaluating two solutions — one with salts, the other without; water will flow from the latter to the former. This gradient or pressure differential is known as osmotic pressure.

**permanent wilting point** – Soil water potential that, when reached, plant wilt becomes irreversible. This is generally considered to be  $-1.5$  megapascal (MPa) or 145 pounds per square inch (psi).

**permittivity** - The degree of resistance to an electromagnetic field traveling through a medium such as soil.

**plant-available water** – The difference between field capacity and permanent wilting point at any given depth in a soil.

**pores** – Void spaces between soil particles that have a given affinity for water and gas exchange based on size and location.

**porosity** – The void space within a soil solid matrix that is filled with either water or air.

**real time** – When a measure can be observed at any time because data is constantly being collected, as opposed to being collected periodically.

**root zone** – The depth of the soil that is occupied by plant roots.

**runoff** – Water that originates from landscapes during rain events that does not infiltrate into the ground. As it collects, runoff flows along the ground surface.

**soil minerals** – The solid, nonorganic particles in a soil, usually classified by the diameter of the particle as gravel, sand, silt, or clay.

**soil moisture sensor** – One of many devices that is used to measure water content of a soil by various methods.

**soil psychrometers** – A meter that measures temperature changes and relative humidity change as a sample dries out to yield a water potential for a given soil sample.

**soil texture** – The composition of soil based on its particle sizes. According to the U.S. Department of Agriculture’s classification, soils are classified as sands (larger than 0.05 mm), silts (0.002-0.05 mm), and clays (smaller than 0.002 mm).

**soil type** – The lowest unit in the natural system of soil classification; a subdivision of a soil series and consisting of or describing soils that are alike in all characteristics including the texture of the A horizon or plow layer; in Europe, roughly equivalent to a great soil group. (Source: Soil Science Society of America’s Glossary of Soil Science Terms, available at <https://www.soils.org/publications/soils-glossary>.)

**soil water content** – The amount of water in the soil. This can be measured on a percent volume basis (volumetrically) or a percent weight basis (gravimetrically).

**species** – A group of similar biological organisms that are capable of interbreeding.

**suction head** – The tension at which water is held in a soil.

**tensiometer** – A sealed tube filled with water, with a ceramic porous material on one end, and a pressure gauge on the other. Pressure in the tube, over time, will become equivalent to the matric potential of soil outside the tube.

**volumetric** – A measurement in which the water in a soil is described by the percent volume of the space that the water is occupying.

**water use** – Includes all aspects of water being used, including agricultural, commercial, industrial, and residential.

**water use efficiency** – Defined in this publication as the percentage of applied water used by the intended plant.

**weighing lysimeter** – A device that assesses soil moisture content by differential mass.

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