Researchers have been learning how to use data from weather stations, moisture sensors and other types of sensors to refine agricultural water use and tailor it to crop needs. While research systems for irrigation scheduling tend to be complex and expensive, the technology has become more available and affordable for the Green Industry through user-friendly, off-the-shelf products. Additionally, some systems allow remote access to the sensor-generated information through a cellular connection. These developments increase the utility of sensor technology at nurseries and garden centers, as well as in landscapes. Part I of this publication highlights the benefits of using soil or substrate moisture sensors and offers suggestions for successfully using these sensors. Part II illustrates how to interpret data from sensors.

**Practical Uses of Substrate Moisture Sensors**

There are several benefits to monitoring the soil or container substrate moisture level with sensors. Moisture sensors can be used to establish the normal fluctuation in moisture level from one irrigation event to the next. After a few days, a predictable cycle appears that allows rainfall and interruptions in irrigation to become obvious. For example, a moisture sensor becoming progressively drier over time indicates that the irrigation is operating incorrectly, possibly due to a problem with a controller, a leak or break in the line, or a misaligned or partially clogged sprinkler head. As a result of the disruption, water does not reach the crop. A moisture sensor can also be used to determine if the moisture content is not returning to the same anticipated level following an irrigation event, which can indicate a number of issues. For example, the
substrate may have become hydrophobic, which may be remedied by more frequent irrigation, especially during dry periods with no rain or a wetting agent may be necessary, or the plants may have grown and are deflecting water.

Moisture sensors can also be used to refine irrigation scheduling. Often, botanically related plants are placed in the same irrigation zone, but even closely related plants can require different amounts of water. For example, kousa dogwood trees use about half the water that flowering dogwoods use when grown in identical environmental conditions, and ‘Kwansan’ cherry trees harvest about two and a half times more water than yoshino cherry trees in the same irrigation zone due to their vase-shaped canopy. Installing substrate moisture sensors in two different species, whether botanically related or not, can help you determine if one is staying much wetter and needs to be relocated to a zone with less run time (Figure 1).

**Practical Uses of Soil Moisture Sensors**

A landscaper or field producer can use multiple sensors at different soil depths to refine the irrigation duration. For example, when setting up a new landscape irrigation system, sensors at different depths will give the information needed to refine run time to achieve percolation to the desired soil depth. A nursery field producer can use soil moisture sensors in the root ball and at depths above and below the root zone to ensure that their relatively long, but infrequent, irrigation schedule doesn’t put most of the applied water below the crop’s root system or that crops do not become too dry between events. A field producer can also use sensors to ensure irrigation is provided to an appropriate depth prior to digging root balls.

**Pressure Switches for Monitoring Irrigation Supply Lines**

A pressure switch can be a helpful tool, providing peace of mind to owners and garden center operators who are out of town or have entrusted an employee with watering (Figures 2A and 2B). For systems that drain and thus depressurize following each irrigation event, a pressure switch will reveal when the line is pressurized, indicating that the irrigation system can provide water. If adequate pressure is not detected during the designated run time, there may be a leak in the pipe upstream of the pressure switch or the water supply may have been physically shut off. Conversely, if the line is pressurized beyond the normal irrigation run time, the irrigation may have been accidentally left on by an employee or a solenoid valve may be stuck open. If the line is normally pressurized whether irrigating or between irrigation events, the owner can see that in the chart of pressure switch readings and be reassured that water is available when the valves open. On the other hand, if pressure is absent, the owner or manager can notify someone on-site or otherwise take steps to determine the reason. Alerts or notifications on system performance are available in some models.
Multiple Sensor Types Can Increase Utility

Moisture sensors and pressure switches can be used in tandem. As previously described, pressure switch readings can be used to determine if the irrigation line is pressurized. If the irrigation doesn’t appear to have operated based on the pressure switch, a moisture sensor can provide information to determine if irrigation is actually necessary. For example, the pressure switch may indicate the line hasn’t been pressurized. However, checking the moisture level may reveal that a rain event hydrated the plants; therefore, an employee on-site deemed that irrigation was not needed. In another scenario, the pressure switch may indicate that the irrigation is running properly, but moisture sensor data show that the plants are getting increasingly dry. This may mean that the plants have tipped over and are not receiving the irrigation or that the irrigation sprinkler has become damaged or turned away from the crop. Recently, at one of our nursery-based research projects, the paired use of a pressure switch and moisture sensors revealed that employees were skipping weekend irrigation duties (Figures 3 and 4).

Electrical Conductivity and Temperature

Some moisture sensors have embedded electrical conductivity (EC) and temperature sensors. EC gives an indication of salt levels from fertilizer as well as the irrigation water because saltier water conducts an electrical charge more readily than less salty water. Monitoring EC can be helpful because higher salt levels are more likely to cause root burn and, consequently, plant damage. Additionally, salt-damaged roots can be more susceptible to certain root rot pathogens. Conversely, if excessive rainfall led to fertilizer salts being flushed from the root zone, rapid detection of nutrient loss will allow time to consider supplemental fertilizer options. Monitoring EC can also inform decision-making in other production situations. Salt levels that increase slowly may mean the water supply is becoming saltier or, as is more likely in Tennessee, there has been insufficient rainfall or irrigation to leach salts from the container. Using sensors to monitor for this situation, especially when overwintering container crops, can help prevent plant damage. If the salt level increases quickly, the fertilizer coating may have become damaged, such as from blending with a substrate that has sand in it, permitting the rapid release of high levels of fertilizer. Being aware of this quickly, as is possible by monitoring the EC, can allow
Types and Characteristics of Moisture Sensors

Two main categories of moisture sensors are commercially available and affordable.

**Volumetric water content**: Volumetric water content is the volume of water per unit volume of soil. Volumetric water content is usually estimated from the apparent relative permittivity of the soil, which is measured using capacitance technology. For more refined uses beyond those described in this publication, this type of moisture sensor should be calibrated for each soil or substrate.

**Soil matric potential**: Soil water potential is a measure of how available water in the soil is to plants, and it is largely a function of how tightly it is being held by the soil matrix. This is referred to as matric potential. Matric potential sensors are not dependent on soil type. So, comparing moisture levels from different soils, such as from one field or landscape to another, can be done accurately and without the need to calibrate to each substrate or soil.

**Key characteristics**: Sensor features will affect the accuracy and utility of both of these types of sensors. For example, matric potential sensors that are available currently are not ideal for soilless substrates, such as the loblolly pine bark-based substrates that are commonly used in the southeastern U.S., due to inadequate contact between the substrate and sensor. Some capacitance sensors are sensitive to salts such as those from fertilizers. Other sensors use a 70-MHz frequency to expand their utility to containers, that often have high concentrations of fertilizer salts compared with field soils, to more arid regions of the country, that tend to have saline water, and for use with reclaimed water.

Sensors are generally most sensitive to the volume immediately around the tines; however, they have a zone of influence, which is the region around the tines that can influence their measurement (Figures 5A and 5B). This region will vary with the type of moisture sensor. When a sensor used in a container has too large of a zone of influence, it may sense through the container and detect the moisture in the ground immediately below it or the low level of moisture in the air outside the container sidewall. When purchasing sensors, ask about the zone of influence and consider the range of container sizes you plan to monitor. In a field, as long as the sensor is installed deep enough, sensing relatively dry air above the soil surface is

you to apply irrigation to leach the excess salts before the crop develops visible damage.

The temperature sensor can be used to monitor root zone temperatures. Temperatures can exceed 129 °F in black plastic containers. Root zone temperature is important to monitor because roots generally stop growing at around 102 °F and die at about 122 °F, depending on the plant species. Monitoring root zone temperature allows a grower or retail garden center operator to determine if the plants need to be shaded or perhaps transitioned to white containers.
generally not a concern.

A small zone of influence also can be challenging in some situations. In the instance of a newly planted crop with roots that have not grown beyond their original root ball and into surrounding substrate, the sensor may detect amply moist substrate around the roots, yet the liner’s roots may be dry because they have exploited all available water within the original root mass. The wet-dry cycle from daily irrigation likely will still be apparent, but the moisture level reported may dramatically overestimate the moisture level within the root zone. To monitor an irrigation system, installing sensors in containers with plants that are established, commonly referred to as “rooted in,” can be a straightforward approach.

**Sensor Number**

The number of sensors to use and where to position them in relation to the root zone are common questions that arise when using sensors for the first time. Unless the container is larger than approximately a #10 or #15 container, usually one sensor per container is sufficient to monitor whether or not the irrigation system is working correctly. To monitor the system, multiple sensors are best utilized by installing them in a range of plant species representing high and low water users, or in several different irrigation zones, as opposed to using more than one sensor per container. If a species is particularly valuable or sensitive, installing a sensor in more than one plant can provide additional validation of the substrate moisture content.

**Sensor Placement**

Sensor placement may be important during experiments or when using sensor data to control irrigation by actuating a solenoid valve. But, it is less critical when simply monitoring irrigation systems. First, consider the container size and zone of influence. Then, position the sensor midway between the top and bottom of the container. If placed too low, the sensors will detect water in the perched water table at the bottom of the container and potentially moisture below the container, which can mask the irrigation cycle and cause the sensor reading to overestimate the wetness of the container. If placed too close to the surface or the sidewall, the sensor reading may overestimate the dryness of the container. In general, placement is not critical for ensuring a system is operating correctly each day because the wet-dry cycles will be evident. Install sensors before going out of town and monitor their readings for several days or longer to determine how well they detect changing moisture conditions. For field production and landscapes, the use of irrigation and plant size determine the placement. For example, if you are planning to dig a field-grown 24-inch ball, the irrigation should reach at least 14.4 inches (minimum ball depth is 60 percent of a 24-inch diameter root ball). A sensor installed at 15 inches should help determine if the wetting front has moved to that depth.

**Sensor Installation and Removal**

Sensors should be handled carefully so as not to scratch or otherwise damage the surface of the tines. Bent tines will affect measurement accuracy. Some sensors can crack at the overmold where the cable joins the sensor body (Figure 6). Reinforcement for the overmold can be fashioned to prevent damage. Take care to install the sensors deep enough so that the overmold is well below the soil or substrate surface to protect it. Just
Additionally, metal rods or conduit used to stake trees or other metal will affect the sensor’s electromagnetic field. A sensor can be installed vertically or horizontally. For horizontal installation, dig an area slightly deeper than where the sensor will be installed. At the depth intended for the sensor, remove the vertical soil face so that undisturbed soil is exposed. Install the sensor into the undisturbed soil covering the entire length of the tines. Backfill and carefully pack the soil to achieve the previous bulk density. Take care not to put a strain on the sensor body or overmold.

For a vertical installation, auger a 3-inch diameter hole to the depth the sensor will be installed. Push the sensor into the undisturbed soil at the bottom of the hole. If the hole is too long to reach, a narrow diameter PVC pipe can be used to push the sensor into the soil. Cut a small groove in one end to catch the sensor and thread the cable through the PVC. After installation, remove the PVC pipe and connect the cable to the data logger or handheld reader. Backfill, taking care to return the soil to the previous bulk density. If the hole is more than a foot or so deep, backfill using the soil from the deepest part of the hole first since it may have different physical properties.

Matric potential sensors do not have tines. To install, the weight of the cable can create enough strain for the plastic to crack.

Sensors can be installed through the soil or substrate surface or through a slit cut in the container sidewall. Sensors installed through the sidewall should be secured with wide, weatherproof tape. Positioning sensors through the container sidewall will likely cause the sensor to detect air within the zone of influence, which will lower the reported moisture level (Figure 5B). Either a vertical or horizontal orientation of the tines is suitable for monitoring an irrigation system because the large changes in moisture level are what is important. A sensor installed through the sidewall will require more careful removal, while one installed through the surface of the substrate is extracted more easily. However, hand weeding, pruning and other tasks may be performed more easily with an installation through the container sidewall. When using tines that are flat as opposed to round, position the narrow aspect parallel to the surface of the soil or substrate so as not to create a rain or irrigation shadow.

Field Installation and Removal Techniques
For the most accurate results, a sensor should be installed in undisturbed soil. Air pockets or excessively compacted soil will distort the measurement accuracy. Additionally, metal rods or conduit used to stake trees or other metal will affect the sensor’s electromagnetic field. A sensor can be installed vertically or horizontally. For horizontal installation, dig an area slightly deeper than where the sensor will be installed. At the depth intended for the sensor, remove the vertical soil face so that undisturbed soil is exposed. Install the sensor into the undisturbed soil covering the entire length of the tines. Backfill and carefully pack the soil to achieve the previous bulk density. Take care not to put a strain on the sensor body or overmold.

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Matric potential sensors do not have tines. To install,
wet a handful of soil removed from the hole into which the sensor will be installed and form it into a ball (Figure 7). Press the ball around the sensor before installation to ensure good contact between the soil and sensor. If installing the sensor into a borehole, mix a soil slurry just to the point that it is pourable, fill the hole with the slurry, and install the sensor to ensure good soil contact. When a sensor is no longer needed, carefully excavate it; do not pull on the cable to remove it as the wires within the cable can break. Between installations, sensors should be stored so that the tines do not become scratched or otherwise damaged. Sensors should be placed out of direct sunlight and high temperatures when not in use.

### Sensor Safety and Care

In retail locations especially, locate sensors in areas that will not be subject to foot traffic, as the cables may present a trip hazard, and make employees aware of their presence. In landscapes and nurseries, marking cables can help prevent damage, such as from a mower. Bright flagging tape or field flags can help make the cables more visible, and brightly colored wire loom or PVC pipe can be used as a protective conduit. Sensor wires can be threaded through the conduit and then buried for longer term use.

Take care that rocks, debris or other material do not become wedged between the tines as that can affect readings and damage or break a tine. Even gritty or sandy soil has the potential to damage the surface of certain sensor tines after repeated installations and removals. Do not force a sensor into the ground. Wet the soil to soften it if it is too hard for the sensor to penetrate.

Rodents can be attracted to electrical wiring and often chew cables. This not only damages the cables but can cause the system to have a short circuit and malfunction. Rodent damage may be avoided by securing cables in the air or by shielding cables with wire loom or sections of polyethylene irrigation tubing. Minimizing the length of exposed cables may also help reduce damage. In locations where rodents are a known problem, it is also advisable to place sensors in more exposed, well-lit areas. Try to limit rodent habitat and

**FIGURE 7:** To properly install a matric potential sensor, wet soil is formed into a ball and pressed around the sensor just prior to installation (shown), or a soil slurry is poured in the borehole.
food sources and place traps on the property to reduce the rodent population.

**Conclusion**

Sensors, especially those with cellular connections, allow for greater monitoring and decision-making, even from a distance. Whether you run a large corporate nursery or have a small mom and pop operation, adopting sensor-based technology can help monitor irrigation systems and troubleshoot problems. Using these tools and the information they provide can help prevent plant health problems, reduce crop losses and detect leaks and other problems quickly.

**Acknowledgements and Additional Reading**


http://digitalpubs.ext.vt.edu/vcedigitalpubs/3312473486515986/ MobilePagedReplica.action?pm=2&folio=1#pg1


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