A Review of Soil Moisture Sensors

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Irrigation is the most important cultural practice and most labor intensive task in daily greenhouse operation. As water resources become limited due to competition from residential and industrial uses, it is becoming even more important to increase plant production water usage efficiency. How to improve irrigation efficiency for greenhouse production is an important challenge. Keeping a watchful eye on plants to ensure they receive sufficient water on time is important. Prevention of overwatering is another aspect that can improve water usage efficiency and pest prevention. For example, a recent study reported that larvae of shore fly can be reduced if the soil moisture level is maintained around 30 percent. A similar approach can also reduce root zone diseases such as Pythium. Growing on the drier side without stressing plants is an important part of integrated pest management. Delivering water to plants automatically at the right time and right amount is a key to effective and efficient irrigation.

Knowing when and how much to water are two important aspects of irrigation. To do this automatically, sensors and methods are available to determine when plants may need water. Methods are available for estimating water supply in terms of soil moisture content, water demand in terms of evapotranspiration, and direct assessment of plants' water status. We will review a few major soil moisture sensing technologies in this article; other methods will be discussed in a following article.

There are several soil moisture sensing technologies that may benefit greenhouse plant production including tensiometer, granular matrix sensor, dielectric sensor, and heat dissipation sensor. The sensors are used to determine either water availability (i.e. soil water tension) or actual water content in soil. I will discuss their sensing principles, advantages and disadvantages, and a few application notes in the following paragraphs.

Tensiometer
A tensiometer operates like an artificial root that measures how easily plant roots can pick up water from their surrounding growing media. It operates by allowing soil water to come into equilibrium with a reference pressure indicator through a permeable ceramic cup placed in contact with the soil. Drier soil has higher tension; wetted soil has lower tension values. To control irrigation, one needs to know that water availability is better indicated by soil water tension than by water content. For example, heavy soil would hold back more water and less is available to plants, when it has same water content compared to soilless media. Therefore, higher water content is needed in the soil than in soilless media for the same water availability. On the other hand, the same tension threshold can be used for triggering irrigation events independent to potting mix types. A tension level between 2-10 kPa is generally desirable for floricultural production.

Tensiometers have several advantages. One advantage is that they are not affected by the temperature of the soil water solution or the osmotic potential (the amount of salts dissolved in the soil water), as the salts can move into and out of the ceramic cup freely. Therefore tensiometer readings are not affected by electroconductivity (EC) or soil temperature.

One often-mentioned disadvantage of the sensor is its maintenance requirement. Water in the tensiometer cavity needs frequent refilling when tensiometers are used in dry environments where the tensiometer becomes a source of water that seeps out due to drier surrounding soil. By maintaining a tension level between 0-15 kPa in our trials, our tensiometers were refilled once every three to four weeks. Refill frequency was lower when crops were maintained at lower tension (i.e. 0-3 kPa) levels. Another maintenance requirement includes algae cleaning. Algae grow whenever there is a combination of water and sunlight, and the cavity of the tensiometer does become greenish.

Tensiometers come in different sizes and tension ranges. We have used small diameter (0.5-inch) tensiometers for our 4-inch pots. Smaller tensiometers (i.e. 0.2-inch) are available from Australia (www.soilwater.com.au under "products"), if you are going to use them in pots that are smaller than 4 inches. The cost of a tensiometer is around $70.

Learning to use tools properly is critical. It is important to make sure there is a tight interface, no air pocket, between the ceramic tip of a tensiometer and the soil. Do not wiggle a tensiometer into soil; wiggling may create poor interface - push a tensiometer in using a single motion. Wet the soil first if it is too hard to push the tensiometer into the soil.

**Granular Matrix Sensor**

Gypsum block is probably the oldest sensor used to determine soil moisture content. It is low cost and easy to use. It does dissolve over time, however,
which makes it undesirable. Recently, the Watermark sensor has attracted some interest due to its relative low cost and improved performance over the standard gypsum block-type resistance-based soil moisture sensor.

The principle of operation is that the resistance of a electrodes-embedded porous block is proportional to its water content. Thus, the wetter a block is, the lower the resistance measured across two embedded electrodes. Advantages of this sensor are its ease to use and low cost. Unfortunately, its application is best for lower soil moisture (i.e. > 10 kPa) sensing. In addition, any change in soil conductivity not related to moisture (such as adding fertilizer) will also be detected. In other words, the fertilization scheme will affect "soil moisture" readings. In addition, calibration for an individual growth mix is necessary to establish a relationship between the electrical resistance reading and soil water content. An alternative is to use it for relative measurements.

**Dielectric Sensor**

Dielectric constant is a measure of how easy a medium can conduct electrical signal, dry soil has lower dielectric constant than that of moist soil. Sensors have been developed to determine soil moisture content from measured dielectric information. Examples of this sensor type include Flori by Netafim, ECH2O by Decagon, and ThetaProbe by Delta-T. This type of sensor uses an oscillator to generate an AC field which is applied to the soil to detect changes in soil dielectric properties linked to soil water content. The cost ranges from $100 to $500. Higher end sensors (i.e. ThetaProbe) use a swept frequency rather than single frequency for more robust determination of soil moisture.

One advantage of this type of sensor is it gives an almost instantaneous reading. Growers can do a quick check of root zone moisture content without having to wait, as is the case with tensiometers and Watermark sensors. The quick sensor response time is also an asset for precision water delivery using demand-based, automated irrigation systems. The quicker water status can be detected, the easier it is to make control decisions for meeting a crop's water needs. Another major advantage of this type of sensor is its maintenance requirement; very little or no maintenance is required.

Disadvantages, on the other hand, include its susceptibility to influences by temperature, salinity, and soil property, especially for systems operating lower than 20 MHz frequencies. For example, when temperature and EC levels are changed, the sensor may give you different readings even if the moisture level remains the same. Therefore, before you use this type of sensor for different growing media, temperature settings, or fertilization programs, it is best to do some testing first to establish the relationship between sensor output and actual soil moisture content. An irrigation system can then be turned on or off
based on a predetermined sensor output that was measured at the desired soil moisture content of a given cultural system (including soil type, EC, and root zone temperature).

Similar to application notes for tensiometers, the sensor readings are heavily influenced by moisture content and air gaps in the soil volume near the sensing probes. It is extremely critical to have good contact between sensor and soil for a reliable estimation of soil moisture.

**Heat-Dissipating Sensor**

In a heat-dissipating sensor, the temperature in a porous block is measured before and after a small heat pulse is applied to it. The amount of heat flow from the pulse-heated point is mostly proportional to the amount of water contained within the porous material. That means a wet material will heat up slower than a dry one. This rise in temperature (or the cooling) is measured with an accurate temperature sensor located at the sensor tip and calibrated to the soil water content of the medium.

Advantages of this type of sensor include 1) sensor output is independent to EC value and 2) small size. Their operating principle is similar to gypsum block sensors, except they measure thermal conductivity rather than electrical conductivity; and hence, the conductivity of the water is not an inherent problem. Small (3/16- x 2-inch) probes (DRW probe) have been used for a number of irrigation research projects. It is not clear if this sensor is commercially available in the United States, even though commercial applications have been reported in Australia and the United Kingdom. Smaller sensors of this type have been developed for the NASA space research program to measure growing media water content. The small sensor size may work very well for propagation, where precise water management is even more critical than in production environments. As for disadvantages, its commercial availability is unknown, and it does have a larger power requirement compared with other sensor types.

**In Summary**

Among the sensors we have reviewed, tensiometers and dielectric sensors are the best currently available for today's floricultural applications, but heat-dissipating sensors hold promise for the future. These sensors can be used to determine absolute or relative water status in soil. But remember, readings from even the best sensors are only reliable if they are used properly. To ensure the sensors can give dependable information, good contact between the sensor probe and the soil is a must. Therefore, air pockets around the sensor probes must be avoided to ensure authentic readings. It is also important to work with these probes in your production environment, especially the dielectric types, to "standardize" their readings with your crop's needs. With
these simple guidelines, moisture sensors can serve as a cornerstone of your automated irrigation system.