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Soil Moisture Measurement and Sensors for Irrigation Management

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Water is a limited resource in Utah's semi-arid climate. The demand on Utah's water supply continues to rise with a rapidly expanding urban population. Crop irrigation is the largest water use in Utah, accounting for about 80 percent of annual diversions. Proper irrigation management has a positive effect on water use, plant health, and crop yields.

The use of soil moisture sensors helps growers with irrigation scheduling by providing information about when and how much to water. This provides for efficient use of water; enough to meet crop needs without applying excess or too little water. Excessive irrigation increases the cost of production from additional pumping costs and fertilizer lost to runoff and leaching. It can also decrease yields from waterlogging and leaching of soil nutrients. Excessive runoff can sometimes be harmful to the environment if fertilizers and pesticides moved to sensitive environments. Under-watering results in plant stress which can reduce yield and crop quality. This fact sheet introduces several soil water monitoring options that, when used correctly, can help growers avoid over and under watering. The use of soil moisture sensors requires an understanding of soil moisture depletion, available soil water, and irrigation application.

Soil Water

Understanding some basic terms, definitions and concepts will help you make irrigation management choices. Below are some general soil moisture definitions:

- *Saturation*: At saturation all pore space in the soil is filled with water, no air. Most agriculture soils have between 40 and 50 percent (4.8 to 6 inches per foot) voids (pore space) that are filled with water and/or air.
- *Field Capacity*: Soil water content after water has drained by gravity. Field capacity of most agriculture soils ranges between 20 and 45 percent by volume (2.4 to 5.4 inches per foot).
- *Permanent Wilting Point*: Soil water content when plants or crops cannot obtain water from the soil. Permanent wilting point ranges between 7 (sand) and 24 (clay) percent by volume (0.8 and 2.9 inches per foot) for most agriculture soils.
- *Available (Usable) Water*: The soil water content between field capacity and permanent wilting point. Although plants can utilize the water, plant stress occurs as soil water content approaches permanent wilting point.
- *Allowable Depletion*: The soil water content available to crops without causing stress that impacts yield or crop quality. The allowable depletion is dependent on crop type, crop growth stage, and climate. Allowable depletion can range between 25 percent of available water for crops very sensitive to small changes in soil moisture to over 50 percent of available water for crops that are less sensitive to water stress.
- *Dry Bulk Density*: The oven-dried weight of soil in a known volume of field-extracted sample (e.g., using the sample length and diameter from a sampling tube).
- *Soil Porosity*: The pore volume of soil divided by the total volume of a soil sample.

The total amount of water a soil can hold (soil water holding capacity) is affected by soil type, soil structure, and organic matter. There are three basic soil particles: sand (large particles), silt (medium particles) and clay (small particles). Many soils have a mixture of these particle types. Loam soils have a mixture of all soil particles, and may have a high percentage of a particular soil particle size (e.g., sandy loam, clay loam, silt loam, etc.) Sandy soils generally have lower porosity and larger particles (and therefore larger pores), resulting in fairly rapid drainage and low water holding capacity. Sandy soils need to be watered more frequently than finer-textured soils. Silt soils have a medium drainage rate and infiltration rate. Clay soils drain slowly, have a low infiltration rate, and higher field capacity as a result of smaller pores and larger porosity. Clays and silts have similar available water-holding capacity. Good soil structure (clusters of soil particles) helps improve infiltration rate, drainage, and available water holding capacity. Depending on soil type, some soil moisture monitoring devices are more effective than others and this should be considered when choosing a sensor.

Soil Water Monitoring

There are several ways to monitor soil water, with varying costs and accuracy. Although it is common for growers to estimate soil moisture by feel, appearance, or time between irrigation events, soil moisture can be more accurately and effectively monitored using a variety of commercially available soil moisture monitoring systems. The effectiveness of the monitoring system is dependent upon proper placement and installation. The sensors or sampling should be in locations that represent the overall field, garden, or landscape. Avoid placing sensors where there are variations due to shade, nearby structures, or at the top of a hill or bottom of a depression. Since there is significant variation across fields, it is recommended that several sensor locations be used for large fields. Consider soil type, plant distribution, and irrigation when placing the sensors or sampling.

Sensors need to be properly installed and have good contact with the soil. After installing the sensor, firmly pack the soil around it, avoiding excessive compaction. When placing sensors or access tubes in a growing crop, care should be taken not to injure plants at the installation site. If the crop is grown on plastic mulch, place the sensor under the plastic for readings that reflect what the plant roots are experiencing. Bury sensors in the root zone of the crop (typically in the top 12 to 18 inches). For row crops, sensors should be installed 2 to 3 inches away from the plant row.

The six common soil monitoring systems are: gravimetric, porous blocks, neutron probes, dielectric sensors, tensiometers, and heat dissipation. The systems provide indirect measurements (measure a property of the soil water and then calibrate to a soil water term) of soil water except for the gravimetric method. Porous blocks, dielectric sensors and tensiometers can be set to record automatically and even trigger irrigation. Each of these monitoring systems is briefly discussed below.

Gravimetric: The gravimetric method is a direct measure of soil moisture and does not require expensive sensors (Photo 1). It involves collecting soil samples and accurately weighing them before (wet weight) and after (dry weight) oven drying. The gravimetric method also requires knowing the dry bulk density of the soil to convert gravimetric water content to volumetric, i.e., weight-based to depth-based. The inches water per inch of soil is found by the weight-based water content times the dry bulk density of soil). While it is accurate and fairly simple, the laboratory equipment required is a limitation for many growers. Additionally, readings are not instantaneous since you must wait for soil to dry completely (a 24-hour process). Gravimetric or volumetric soil moisture describes the total soil water but an understanding of allowable depletion is needed to understand what is actually available to plants.

Photo 1. 5-foot soil probe than is incrementally hammered into ground to extract soil samples.

***Porous blocks*: This common method uses some sort of porous block (gypsum, fiberglass, ceramic) (Photo 2). The blocks are buried in the soil at rooting depth and water moves in or out until equilibrium is reached with water in the soil. Electrodes in the block record the electrical conductivity of the block, which is assume to be equal to that of the soil. This reading is used to estimate volumetric soil moisture. They are simple to install, cost $30 to $50, and are easy to maintain. However, they are temperature sensitive, sometimes do not re-wet after drying out, and have a slow reaction time to what is actually happening. They do not work well in sandy soils, where the water drains too quickly for the block to reach equilibrium. Also, the electrical conductivity of the soil is increased by salts, so fertilizers added to the field may result in incorrect readings. Gypsum blocks provide a buffer against soil salinity changes, helping to get a more accurate reading, but the block dissolves over time. Most gypsum blocks are good for 3 to 5 years.

Photo 2. Installation of porous blocks and data logger using electrical conductivity of the block in equilibrium with the soil (Watermark).

Figure 1 shows data from a porous block soil moisture measurement device in a safflower field. The data shows irrigation events on June 12, July 1, and July 16 (the more negative the matric potential value, measured in centibars (cb), the drier the soil). August and September had rain events to keep the soil moisture at an adequate level for full crop production. The deeper soil layers were being depleted in August and September.

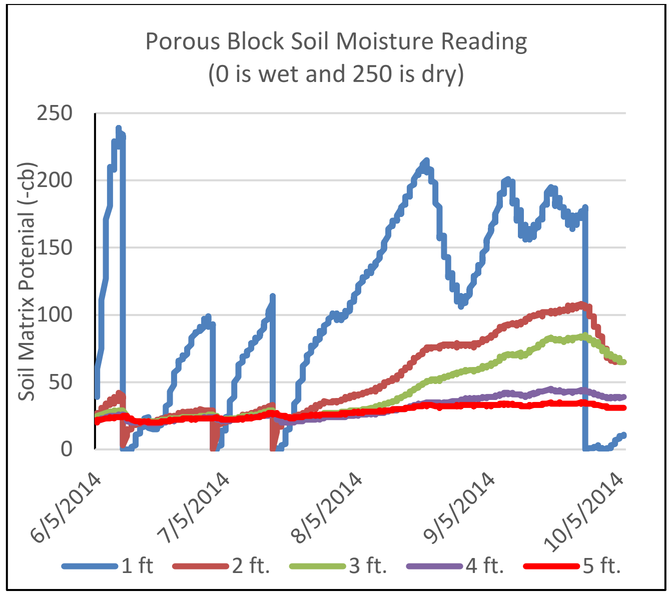

Figure 1. Soil Moisture Reading (electrical resistance reading in a porous probe scaled to represent soil matrix potential in centibars) for an irrigated safflower field.

Neutron Probes**:** A neutron probe involves lowering a radioactive source and receiver into monitoring holes (long, narrow access tubes) installed throughout the field. Neutrons are emitted and slow down when they collide with hydrogen in the soil water (H_2O). The slowed neutrons are measured and correlated to water content. Neutron probes are accurate when properly calibrated, are not influenced by salts, have a large radius of measure, and can take measurements at many depths. However, they are expensive ($10,300), pose a radiation hazard (require certified personnel), and can be difficult to calibrate and install. Measurements close to the soil surface are not as accurate because neutrons escape to the atmosphere and are not reflected back to the instrument.

Dielectric Methods**:** These probes sense dielectric properties of soil and water to monitor soil moisture. They typically consist of two or more electrodes inserted into the soil (Photo 3 and 4). Most are not affected by salts and temperature and are fairly easy to install. They may not give accurate readings in clay and organic soils where soil-specific calibration is needed. The sensors send an electromagnetic signal into the soil and measure properties of the signal. Good contact with the soil is crucial for gaining an accurate reading. There are several measurement approaches relying upon the dielectric properties of the soil, including Time Domain Reflectometry (TDR) and Frequency Domain (FD) sensors. Some capacitance probes are portable and can be insert in access tubes to get many readings from one sensor.

Photo 3.Probe in an access tube using dielectric properties of soil (Sentek Diviner 2000).

Photos 4. Example of sensor relying on dielectric properties of soil (Stevens Hydra Probe)

Tensiometers**:** A tensiometer is a water-filled tube designed to simulate a plant root. A porous cup is buried in the soil with a negative pressure (vacuum) gauge is at the other end (Photo 5). As the soil dries, water is pulled out of the tensiometer making the pressure reading more negative, which indicates decreasing soil moisture. The more negative the reading, the less water there is in the soil. Once irrigated, soil water re-enters the cup and the pressure becomes less negative. They are easy to read and cost about $80 to $100. Tensiometers are sensitive to conditions in a relatively large soil volume and are easy to install and maintain. Continuous recording of data is possible using a pressure transducer but gauge-based instruments are well suited for periodic manual readings. The range of measurement is somewhat limited to wet conditions common in irrigated agriculture and good soil contact is critical for accurate readings. Tensiometers also require frequent maintenance and can have a slow response time. Tensiometers are not suited to heavy-textured clay soils that swell nor to very coarse sandy soils. For irrigation management, the tensiometer reading needs to be correlated to the soil moisture content to know how much water has been extracted and needs to be replaced by irrigation.

Photo 5. Tensiometer being installed in soil with the porous cup on the installation end of the tensiometer (Irrometer).

Heat Dissipation**:** The basic principle behind using heat transfer to estimate soil moisture is that dry soil transfers heat faster than wet soil. During heat input to the sensor matrix in contact with the soil a temperature sensor monitors the heat dissipation. Soil moisture is calibrated to differences in soil temperature measurements over a given period. Heat dissipation is usually accomplished using a block sensor similar to a porous conductivity block. The blocks require similar maintenance to conductivity blocks and low power heaters are used that utilize direct current batteries for power.

Summary

There is a wide range of methods available to monitor soil moisture. When selecting a sensor, consider the advantages and disadvantages as well as what will work with your soil. Maintenance, skill level, and cost should also factor into your decision. If you live in an area that has low water availability or if water is expensive, investing in a monitoring system can lower water use and reduce costs and improve yields. Table 1 is a summary of the methods. While porous blocks have been commonly used in farmer's fields, prices of multi-function sensors such as the Time Domain Reflectometry instruments are now priced in the same range as porous blocks and have many advantages. The multi-function instruments can provide accurate estimates of soil moisture by volume, and measure soil temperature and soil water salinity (electrical conductivity), additionally they are less sensitive to salinity and temperature.

Table 1. Summary of soil water measurement methods used for irrigation scheduling.

Method	Type of Measurement	Installation	Quality of Measurement	Costs
Feel Method	Visual and sensory	None, but require soil sampling for each measurement.	Based on experience of individual	Labor
Gravimetric	Direct measurement	None, but require soil sampling for each measurement.	Accurate measurement can be used for calibration of other methods.	Labor, drying oven, and scales
Tensiometer	Soil water matrix potential	Sensors installed at beginning of cropping season	Requires calibration to soil water content. Generally higher maintenance than other options.	$80/unit (2 to 3 per site).
Porous Block	Electrical Resistance of a porous block in contact with the soil	Sensor installed at beginning of cropping season (multiple years for perennial crops)	Requires calibration to soil water content. Sensitive to temperature and soil salinity.	Data logger/reader $500 to 1,000, then $40 per sensor (2 to 5 per site).
Neutron Probe	Neutron thermalization as a function of water content	Access tube at beginning of cropping season (multiple years for perennial crops)	Estimates water in a larger area than most soil measure methods. Requires calibration to soil water content.	Neutron Probe ($10,000), plus $15 per access tube. Regular dosimetry analysis and record keeping
Frequency Domain Probe	Electromagnetic soil capacitance as a function of water content	Sensors installed or access tubes (multiple years for perennial crops)	Is accurate after calibration to soil water content. Is relatively insensitive to soil water salinity levels.	Data logger or reader $500 to $3,000, then $280+ per sensor (2 to 5 per site). Access tube installation kit $2,600.
Time Domain Reflectometry Probe	Electromagnetic soil capacitance as a function of water content	Sensors installed or portable probe or access tube (multiple years for perennial crops)	Is accurate and relatively insensitive to normal soil water salinity levels.	Data logger/reader $1,000 to 3,000, then $100 per sensor.
Heat Dissipation	Uses heat buffering capacity of soil and thermal conductivity of soil water.	Sensors installed at beginning of cropping season (multiple years for perennial crops)	Requires calibration to soil water content. Is quite accurate and relatively insensitive to soil water salinity levels.	Data logger/reader $500 to $3,000, then $155 per sensor (2 to 5 per site).

1) Gravimetric (percent water by weight) is considered direct measurements of soil water. All others are indirect, measuring a property of the soil water.
2) Gravimetric and the feel method require sampling, all other methods are in-situ with buried sensors or an access tubes.

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Websites for manufactures of soil moisture sensors. The list below is not all inclusive, and is not meant to specifically endorse or discriminate against any one manufacture.

- http://www.irrometer.com/
- https://www.campbellsci.com/soil-science
- http://www.stevenswater.com/soil_moisture_sensors/index.aspx
- http://www.decagon.com/products/soils/volumetric-water-content-sensors/
- http://www.sentek.com.au/products/soil-moisture-triscan-sensors.asp
- http://www.sentek.com.au/products/enviro-scan-probe.asp
- http://cpn-intl.com/503-elite-hydroprobe/
- http://www.imko.de/en/products/soilmoisture/mobile-trime-meters

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