Measuring Soil Water for Irrigation Scheduling: monitoring methods and devices

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Rainfall is the principal source of water for North Carolina crops. However, many growers are turning to irrigation to supplement precipitation. For maximum profits, irrigation water must be applied on a schedule that makes most efficient use of water and energy.

The amount of water available to the plant from the soil determines when and how much irrigation water to apply. Thus the first step in irrigation scheduling is to measure the moisture content of the soil.

This publication provides the following information you will need for measuring soil-water:

- The types of soil-water measuring devices available
- How to select the right measuring device
- How to prepare and install these devices

Irrigation scheduling is knowing when to irrigate and how much water to apply. Effective scheduling requires knowledge about soil properties, the soil-water relationship, the crop, and the climate. Scheduling strategies are discussed in Extension Service publication AG-452-4, *Irrigation Scheduling to Improve Water and Energy Use Efficiencies.*
Not all of the water contained in the soil is available to plants. To interpret soil-water measurements and apply them to irrigation scheduling, you must be able to distinguish between the three categories of soil-water: (1) gravitational water, (2) plant-available water, or PAW (sometimes called capillary water) and (3) unavailable water. The soil-water terms related to irrigation scheduling are defined in the box on page 3. For more information on soil-water, refer to Extension Service publication AG-452-1, *Soil, Water and Crop Characteristics Important to Irrigation Scheduling*.

**Soil-Water Measuring Methods and Devices**

A variety of methods and devices can be used to measure soil-water. These include the feel method, gravitational method, tensiometer, electrical resistance blocks, neutron probe, Phene cells, and time domain reflectometer. Most of these methods and devices do not measure soil-water directly; they measure a property of the soil that can be related to soil-water status and are therefore called indirect methods. These methods differ in their ease of use, reliability, cost, and amount of labor required.

**Feel Method**

As its name implies, the feel method involves estimating soil-water by feeling the soil. This method is easy to use, and many growers schedule irrigation in this way. However, this method is entirely subjective; the results depend on the experience of the individual making the measurement. The reliability of this method is usually poor unless the operator is very experienced. The feel method is not generally recommended and should be used only as a last resort.

**Gravimetric Method**

With the gravimetric method, soil moisture is determined by taking a soil sample from the desired soil depth, weighing it, drying it in an oven (for 24 hours at 220 degrees F), and then reweighing the dry sample to determine how much water was lost. This method is simple and reliable. Unfortunately, it is not practical for scheduling irrigation because it takes a full day to dry the sample. In a sandy soil that dries quickly, irrigation may be needed before the results of the measurement are obtained. The gravimetric method is most useful for calibrating other devices for measuring soil-water.

**Tensiometer**

A tensiometer is a sealed, airtight, water-filled tube (barrel) with a porous tip on one end and a vacuum gauge on the other, as shown in Figure 1. A tensiometer measures soil water suction (negative pressure), which is usually expressed as tension. This suction is equivalent to the force or energy that a plant must exert to extract water from the soil. The instrument must be installed properly so that the porous tip is in good contact with the soil, ensuring that the soil-water suction is in equilibrium with the water suction in the tip. The suction force in the porous tip is transmitted through the water column inside the tube and displayed as a tension reading on the vacuum gauge. Soil-water tension is commonly expressed in units of bars or centibars. One bar is equal to 100 centibars (cb).
The suction at the tip is transmitted to the vacuum gauge because of the cohesive forces between adjacent water molecules. As the suction approaches approximately 0.8 bar (80 cb), the cohesive forces are exceeded by the suction and the water molecules separate. When this occurs, air can enter the tube through the porous tip and the tensiometer no longer functions correctly. This condition is referred to as breaking tension. Tensiometers work in the range from 0 to 0.8 bar. The suction scale on the vacuum gauge of most commercial tensiometers reads from 0 to 100 cb.

Tensiometers are quite affordable for scheduling irrigation. The cost ranges from $25 to $50 each, depending on length of the barrel, which ranges from 6 to 72 inches. The only other equipment required is a small hand-held vacuum pump used for calibration and periodic servicing. Tensiometers are easy to use but may give faulty readings if they are not serviced regularly.

Tensiometers are best suited for use in soils that release most of their plant-available water (PAW) at soil-water suctions between 0 and 80 cb. Soil textures in this category are those that consist of sand, loamy sand, sandy loam, and the coarser-textured range of loam and sandy clay loam. Many clayey and silty soils still retain over 50 percent of their plant-available water at suctions greater than 80 cb, which is outside the working range of a tensiometer. Tensiometers are not recommended for clayey and silty soils unless irrigation is to be scheduled before 50 percent depletion of the plant-available water, which is the normal practice for some vegetable crops such as tomatoes. Methods for preparing and installing tensiometers are discussed later in this publication.
Figure 2. Schematic of an electrical resistance block and meter. The block is buried in the soil at one-half the effective root depth. With the proper calibration curve, the meter reading can be related to soil moisture.

**Electrical Resistance Blocks**

Electrical resistance blocks consist of two electrodes enclosed in a block of porous material, as shown in Figure 2. The block is often made of gypsum, although fiberglass or nylon is sometimes used. Electrical resistance blocks are often referred to as *gypsum blocks* and sometimes just *moisture blocks*. The electrodes are connected to insulated lead wires that extend upward to the soil surface.

Resistance blocks work on the principle that water conducts electricity. When properly installed, the water suction of the porous block is in equilibrium with the soil-water suction of the surrounding soil. As the soil moisture changes, the water content of the porous block also changes. The electrical resistance between the two electrodes increases as the water content of the porous block decreases. The block's resistance can be related to the water content of the soil by a calibration curve.

To make a soil-water reading, the lead wires are connected to a resistance meter containing a voltage source. The meter normally reads from 0 to 100 or 0 to 200. High readings on the scale
(corresponding to low electrical resistance) indicate high levels of soil-water, whereas low meter readings indicate low levels. Electrical resistance blocks are fairly inexpensive, costing from $3 to $12 each. A portable, hand-held resistance meter costs $250 to $300 and can be connected to read many different blocks in turn.

Because of the pore size of the material used in most electrical resistance blocks, particularly those made of gypsum, the water content and thus the electrical resistance of the block does not change dramatically at suctions less than 0.5 bar (50 cb). Therefore, resistance blocks are best suited for use in fine-textured soils such as silts and clays that retain at least 50 percent of their plant-available water at suctions greater than 0.5 bar. Electrical resistance blocks are not reliable for determining when to irrigate sandy soils where over 50 percent of the plant-available water is usually depleted at suctions less than 0.5 bar. Methods for preparing and installing electrical resistance blocks are discussed in a later section.

<table>
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<tr>
<th>Soil-Water Terms Used in Irrigation Scheduling</th>
<th>Definition</th>
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<tr>
<td><strong>Tension, Suction</strong></td>
<td>A measure of the adhesive forces by which soil retains water. Tension is a measure of negative pressure (suction) relative to the prevailing atmospheric gauge pressure of zero.</td>
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<td><strong>Bar</strong></td>
<td>Unit commonly used in irrigation scheduling to express soil-water tension.</td>
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<tr>
<td><strong>Saturation</strong></td>
<td>Condition in which all soil pores are filled with water. At saturation, soil water tension is zero.</td>
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<td><strong>Field Capacity (FC)</strong></td>
<td>The soil-water content after the force of gravity has drained or removed all the water it can. Usually 4 to 5 days after rainfall, field capacity is considered the upper limit of plant-available water. When measured under field conditions it is equivalent to a soil-water tension of approximately 0.1 bar.</td>
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<td><strong>Gravitational Water</strong></td>
<td>Water in the soil that is free to drain or move by the force of gravity. Gravitational water is the volume of water in the soil between saturation and field capacity. This water is not usually used by plants.</td>
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<tr>
<td><strong>Capillary Water</strong></td>
<td>Water retained in soil pores after gravitational water has drained or that is held loosely around soil particles by surface tension. Most of the soil-water available to plants is capillary water, but not all capillary water is available to plants.</td>
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<td><strong>Permanent Witting Point (PWP)</strong></td>
<td>The soil-water content at which healthy plants can no longer extract water from the soil fast enough to recover from witting. The permanent witting point is considered the lower limit of plant-available water. At this point, the soil-water tension is considered to be 15 bars.</td>
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<td><strong>Plant-Available Water (PAW)</strong></td>
<td>The amount of water held in the soil that is available to plants, the difference between field capacity and the permanent witting point.</td>
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<td><strong>Unavailable Water</strong></td>
<td>Water in thin, tightly held films around soil particles, not available to plants.</td>
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<tr>
<td><strong>Depletion Volume</strong></td>
<td>The amount of plant-available water removed from the soil by plants and evaporation from the soil surface.</td>
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<tr>
<td><strong>Allowable Depletion Volume</strong></td>
<td>The amount of plant-available water that can be removed from the soil without seriously affecting plant growth and development.</td>
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</table>
**Neutron Probe**

The neutron probe uses a radiation source to measure soil-water. An empty tube (access tube) with a 2-inch inside diameter must be installed vertically in the soil at each field location where the soil-water is to be measured. When properly calibrated, the neutron probe is easy to use, reliable, and accurate, but it is expensive ($3,000 to $4,000 per unit). One of its advantages is that soil-water measurements can be made easily at different depths in the soil profile. Because of its cost, a neutron probe is not as practical as other methods for on-farm use. It may be a viable option for operators with large acreages of irrigated land. At present, it is used by some irrigation consultants to perform the technical tasks required to schedule irrigation.

**Phene Cell**

The Phene cell works on the principle that a soil conducts heat in relation to its water content. By measuring the heat conducted from a heat source and calibrating the conductance versus water content for a specific soil, the Phene cell can be used reliably to determine soil-water content. Because the Phene cell is placed at the desired soil depth, a separate cell is needed for each depth at each location to be monitored. A cell costs about $100, and the instrument required to measure the heat dissipation costs an additional $1,000. For irrigating small acreages, the total cost of using the Phene cell is less than that of the neutron probe. For large acreages, the neutron probe may be more cost effective.

**Time Domain Reflectometer**

The time domain reflectometer (TDR) is a new device developed to measure soil-water content. Two parallel rods or stiff wires are inserted into the soil to the depth at which the average water content is desired. The rods are connected to an instrument that sends an electromagnetic pulse (or wave) of energy along the rods. The rate at which the wave of energy is conducted into the soil and reflected back to the soil surface is directly related to the average water content of the soil. One instrument can be used for hundreds of pairs of rods. This device, just becoming commercially available, is easy to use and reliable.

The TDR is expensive, costing nearly $8,000 per unit. Although it is probably too expensive for scheduling irrigation (except for very large operations), it may become the preferred device in the future.

**Selecting the Right Device**

When cost, ease of use, and reliability are considered, tensiometers and electrical resistance blocks are usually the most practical devices for measuring soil-water in North Carolina. For best results, tensiometers and electrical resistance blocks must be properly installed, maintained, and calibrated for the primary soil types in each field. Installation Focusedes for tensiometers and resistance blocks are described in the next section. The gravimetric method can be used to calibrate tensiometers and electrical resistance blocks on the farm. Calibration procedures are given in Extension Service publication AG-452-3, *Calibrating Soil-Water Measuring Devices*. 
Preparing and Installing Measuring Devices

Tensiometers

Before a tensiometer is installed, the porous tip should be soaked in water overnight. The tube should then be filled with boiled (air-free) water, and the gauge and tip should be tested using a small, handheld vacuum pump (available from tensiometer manufacturers). The vacuum pump should also be equipped with a vacuum gauge. It is used to create a vacuum in the tensiometer.

After the porous tip of the tensiometer is saturated, attach the vacuum pump to the top of the tensiometer with the cap removed. Use the pump to evacuate air from the tensiometer barrel. The vacuum gauge reading on the pump and on the tensiometer should be the same. Furthermore, this reading should remain constant for several seconds, indicating that air is not leaking through the porous tip.

If tension cannot be maintained, the tip or barrel has probably been damaged or cracked. The most common cause of failure is a crack in the porous tip resulting from rough handling. A cracked tip allows air to enter the barrel so that tension forces in the soil are not correctly transmitted to the gauge. Tips, seals and gauges can be replaced by the tensiometer manufacturer.

After the vacuum pump test has been completed, the rubber seal in the cap should be tested. Fully assemble the tensiometer and place it on a table or surface so that the porous tip is exposed to the air. Water will begin evaporating from the tip. Within a few minutes, the tension reading on the gauge should begin to increase. If it does not, the rubber stopper in the cap is not providing a good seal and should be replaced. Otherwise, the tensiometer is ready for installation. It should be transported to the field with the tip submersed in a container of water or wrapped in a moist cloth so that tension is not broken before installation.

A probe slightly smaller than the diameter of the porous tip (for example, a steel rod, broom handle, or tube) is used to make a hole in the soil for the tensiometer. The depth of the hole should be about 1/4 to 1 inch less than the actual depth for the porous tip (Figure 3). Pour 1/4 cup of water into the hole to moisten the soil at the bottom. Insert the tensiometer and gently push it down to the desired depth, usually one-half the effective root zone depth. To ensure good contact between the soil and the porous tip, push the tip into the undisturbed soil just below the depth created by the probe. After the probe has been installed, the soil and porous tip usually reach equilibrium within 24 hours, and the instrument is then ready to use.
Field experiences with tensiometers have been mixed. When properly installed and maintained, tensiometers are reliable. Unsatisfactory results are usually caused by inadequate maintenance. Sandy soils, which are best suited for tensiometers, have low levels of plant-available water. In coarse, sandy soils the water content may decrease from field capacity to less than 20 percent of the plant-available water within three days. At this depletion rate, tension can exceed 80 cm within three days, breaking the water column (tension). The soil may then appear dry and the crop may show visible signs of stress. Because tension was broken and the tensiometer is no longer functioning correctly, however, the gauge shows a low tension (high soil moisture). Thus the irrigator concludes that the tensiometer is unreliable. Tensiometers should be read every day (sometimes twice a day in very sandy soils) until you obtain a feel for how fast the soil dries after rainfall or irrigation.

Whenever tension is broken, the tensiometer must be serviced. This includes refilling the instrument with boiled water and checking it with the vacuum pump. Adding a little food coloring to the boiled water makes it easier to see whether water is still present in the tensiometer. Air bubbles in the water column tend to collect at the top of the barrel and appear clear compared to the colored water. The water column should always be free of air bubbles, and water should always be stored in the reservoir. It may be necessary to add water to the reservoir during the season even if tension is not broken.
**Electrical Resistance Blocks**

Like tensiometers, electrical resistance blocks should be soaked overnight before they are installed in the field. A soil probe should be used to make a hole to the desired installation depth. The hole should be slightly larger than the moisture block so the block slips in easily. After placing the resistance block in the hole, backfill the hole with a thick soil slurry using soil from the installation depth. Since fine-textured soils do not dry as rapidly as sandy soils, resistance blocks do not need to be read as frequently as tensiometers. Normally, three to four readings per week are adequate.

The electrical resistance of soil-water is affected by substances dissolved in the water. The exchange of water between the soil and the block over the course of the irrigation season may gradually alter the electrical resistance of the block and eventually alter the calibration. This is not a serious problem in North Carolina soils unless highly saline water is used for irrigation. Since electrical resistance blocks are inexpensive, however, new calibrated blocks should be installed at the beginning of each growing season.

**Positioning Soil-Water Measuring Devices**

If tensiometers or electrical resistance blocks are used, at least one device should be located in each of the major soil types in the irrigated field. For most soils irrigated in North Carolina, the effective root depth is about 12 inches. The soil-water measuring device should therefore be installed to a depth of 6 inches. In soils with a dramatic textural change within 12 inches of the soil surface, such as a loamy sand surface texture overlying a sandy clay loam, one device should be installed in the center of the effective root zone portion of each layer.

Soil-water measuring devices should be installed in the plant row. Install them as soon as possible after planting so that roots will grow around them and water extraction will resemble natural field conditions. Flag each device so that it can be easily found in the growing crop. Mark the end of each row containing a device.

**Technical Assistance**

Soil-water can be measured reliably by several different devices. Success results from selecting a device that is appropriate for the soils and crops being irrigated and that you feel confident in using. Your county Agricultural Extension Service and Soil Conservation Service personnel are available to help with these irrigation decisions. They are familiar with soil-water measuring devices and have received training on their proper use.