Measuring Soil Moisture for Irrigation Water Management

by Hal Werner, Extension irrigation engineer

Irrigation water management requires timely application of the right amount of water. Competition for water, high pumping costs, and concerns for the environment are making good water management more important. **Managing irrigation water needs to combine a method of measuring soil moisture with some method of irrigation scheduling.**

Measuring soil moisture detects if there is a water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below the root zone. Measuring soil moisture also can build an awareness and knowledge of each irrigated field that is invaluable for planning and management.

Monitoring soil moisture levels is required for effective irrigation water management. Many tried and proven methods of estimating or measuring soil moisture are available. The method selected depends on a variety of factors such as accuracy, cost, and ease of use.

Soil Moisture Concepts and Terms

Soil moisture levels can be expressed in terms of soil water content or soil water potential (tension).

Soil water content most commonly is expressed as percent water by weight, percent water by volume, or inches of water per foot of soil. Other units such as inches of water per inch of soil also are used.

Water content by weight is determined by dividing the weight of water in the soil by the dry weight of the soil. It can be converted to percent by multiplying by 100%.

Water content by volume is obtained by multiplying the water content by weight by the bulk density of the soil. Bulk density of the soil is the relative weight of the dry soil to the weight of an equal volume of water. Bulk density for typical soils usually varies between 1.5 and 1.6.

Inches of water per foot of soil is obtained by multiplying the water content by volume by 12 inches per foot. It also can be expressed as inches of water per inch of soil which is equivalent to the water content by volume. By determining this value for each layer of soil, the total water in the soil profile can be estimated.

Soil water potential describes how tightly the water is held in the soil. Soil tension is another term used to describe soil water potential. It is an indicator of how hard a plant must work to get water from the soil The drier the soil, the greater the soil water potential and the harder it is to extract water from the soil. To convert from soil water content to soil water potential requires information on soil water versus soil tension that is available for many soils.

Water in the soil is classed as available or unavailable water. **Available water** is defined as the water held in the soil between field capacity and wilting point (Figure 1).

Field capacity is the point at which the gravitational or easily drained water has drained from the soil. Traditionally, it has been considered as 1/3 bar tension. However, field capacity for many irrigated soils is approximately 1/10 bar tension.

Wilting point is the soil moisture content where most plants would experience permanent wilting and is considered to occur at 15 bars tension. Table 1 gives common ranges of available water for soil types.

Readily available water is that portion of the available water that is relatively easy for a plant to use. It is common to consider about 50% of the available water as readily available water. Even though all of the available water can be used by the plant, the closer the soil is to the wilting point, the harder it is for the plant to use the water. Plant stress and yield loss are possible after the readily available water has been depleted.

Figure 1. Available water in the soil.

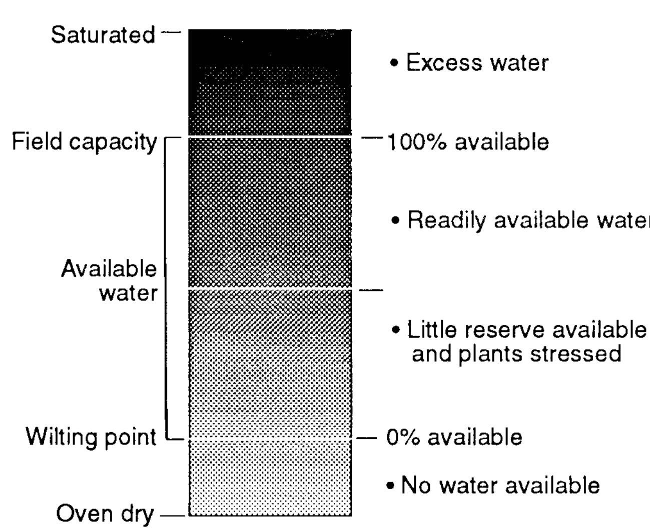


Table 1. Available water capacities for various soil types.

Soil Type	Inches water per foot soil
Fine sands	0.7 - 1.0
Loamy sands	0.9 - 1.5
Sandy loams	1.3 - 1.8
Loams	1.8 - 2.5
Silt loams	1.8 - 2.6
Clay loams	1.8 - 2.5
Clays	1.8 - 2.4

Methods of Measuring Soil Moisture

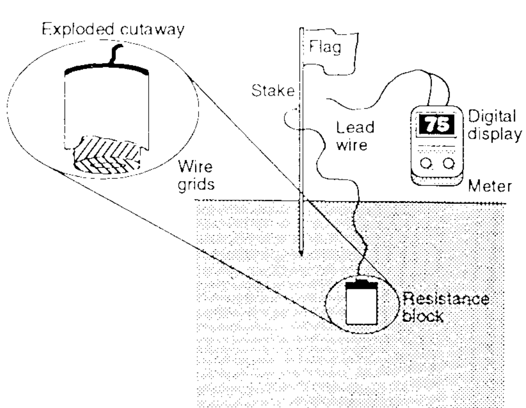
Soil moisture can be measures or estimated in a variety of ways ranging from the simple, low cost feel method to more accurate, expensive neutron probe units. For most irrigation water management applications, one of the several resistance-block types or tensiometers is recommended.

Electrical Resistance Blocks—A meter is used to read the electrical resistance of moisture blocks installed in the ground. The blocks come in a variety of configurations but generally incorporate two electrodes imbedded in a gypsum material (Figure 2). The block may be entirely gypsum or covered with a porous material such as sand, fiber glass, or ceramic. Meters are portable and are intended for use in reading a large number of blocks throughout one or more fields.

Since the blocks are porous, water moves in and out of the block in equilibrium with the soil moisture. Meter resistance readings change as moisture in the block changes which, in turn, is an indication of changes in the amount of water in the soil. The manufacturer usually provides calibration to convert meter readings to soil tension.

Proper installation is important for reliable readings. Good soil contact with the block is essential. Follow manufacturer's and Extension Service guidelines for installation and use of the blocks and meter.

Figure 2. Gypsum block and electronic digital meter.



Resistance methods are suitable for most soils, and the readings cover most of the soil moisture ranges of concern to irrigation management. The blocks tend to deteriorate over time, and it may be best to use them for only one season. Problems may occur with highly acid or highly saline soils.

Cost for the resistance block method will vary from \$4 to \$20 for each block and from \$150 to \$250 for the meter. Total cost for one irrigated field will be approximately \$180 to \$300.

Tensiometers—This is a sealed, water-filled tube with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. The tensiometer is filled with water and the porous tip is buried in the soil to the desired depth (Figure 3). Tensiometers have been called mechanical roots since they provide an indication of how hard it is for the plant to get water from the soil.

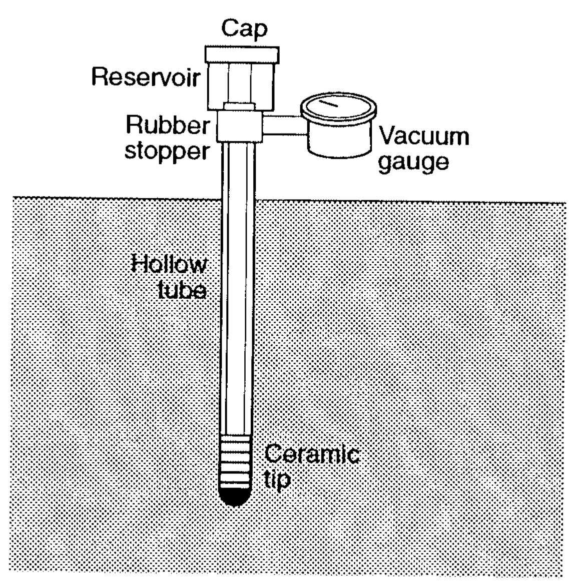
Tensiometers measure soil water potential or tension. Water in the tensiometer will come to equilibrium with water in the soil. Readings are an indication of the availability of water in the soil. Readings are in centibars (1/100 of a bar). A reading of 100 is equal to 1 bar of tension.

Tensiometers generally are effective only at less than 85 centibars of tension, because the gauge will malfunction when air enters the ceramic tip or the water in the tube separates. The usable range from 0 to 85 centibars, however, is the most important range for irrigation management.

Properly installed and maintained, the tensiometer provides an accurate measurement of soil tension. It is not suitable where soil tension routinely exceeds 85 centibars. Even though portable units are available, tensiometers are normally planted or installed at one location for the duration of the irrigation season.

Tensiometers do not directly give readings of soil water content. To obtain soil water content, a moisture release curve (water content versus soil tension) is needed.

Figure 3. A typical tensiometer.



Cost for each tensiometer will be about $40 to $50. A service kit (about $30 to $50) also is recommended. Total cost for one irrigated field will be range from $200 to $400. Tensiometers will last several years with good care.

Feel Method—A soil probe is used to sample the soil profile. Soil moisture is evaluated by feeling the soil. Then a chart is used to judge relative moisture levels. It is important to sample numerous locations throughout the field as well as several depths in the soil profile.

This method is only an estimate and lacks scientific basis. Accurate measurement is not possible, but rather the method is an art developed over time with extensive use. Another measurement method such as tensiometers or resistance blocks is really needed as a reference, especially during the learning period.

The feel method requires no investment other than a soil probe. Effective use, however, does require more time and judgment than other, more quantitative methods. Do not use the feel method as an excuse to avoid using tensiometers or resistance blocks.

Portable Measuring Devices—Several types are available for estimating soil moisture. Most have electronic meters and use either resistance or capacitance technology. Some use the same principle as a tensiometer.

Portable soil moisture probes serve much the same purpose as the feel method. They provide the flexibility of being able to sample many locations throughout the field. They may be most useful in providing relative readings of moisture within or between fields rather than providing an accurate measurement of soil moisture. Another method such as tensiometers or resistance blocks is needed as a reference to calibrate the instruments.

The cost of portable soil moisture probes varies from $80 to $400.

Other Ways to Measure Soil Moisture—Other available methods of measuring soil moisture generally do not find widespread use by irrigators, largely because of cost or inconvenience. For example:

Sampling and drying involves collecting soil samples from various depths and locations in the field. Weights of the wet samples are recorded, the samples are oven dried, and dry weights are recorded. This provides values of total soil moisture. Available soil moisture and soil tension can be determined if moisture release information and bulk density are known for the soil.

This method gives an accurate measurement of soil moisture and is the basis by which all other methods are calibrated. It does not provide immediate feedback of soil moisture, it is time consuming, and it can be messy.

The neutron probe is an electronic instrument with a radioactive source that is lowered into the soil in an access tube installed in the soil. The neutron probe indicates soil moisture by detecting hydrogen in soil water. A counter reads the number of neutrons that are reflected by the hydrogen in the soil. This number is then used to calculate the moisture content.

Neutron probes require special licensing and training. The equipment is also expensive ($3500 to $6000). Installation of access tubes in the soil can be labor intensive without a power soil probe. With good calibration, the method is quite accurate and is accepted for most research work.

Time domain reflectometry (TDR) is a newer technology based on sensing the dielectric constant of the soil which is dependent on the soil moisture. The equipment consists of an electronic meter connected to two rods placed into the ground. The instrument sends an electrical signal through the soil and the rods serve as the transmitter and receiver. The unit is expensive ($6000 to $10,000).

The capacitance probe is another newer instrument. A non-radioactive probe is lowered into an access tube similar to that used by the neutron probe. An electronic meter senses the amount of moisture in the soil based on its electrical properties. Cost for the equipment is about the same as a neutron probe, but special licensing is not required.

Table 2. Crop rooting depths and soil moisture instrument placement depths.

Crop	Rooting Depth (Ft)	Soil Sensor Depth (In) Shallow	Deep
Corn	3 - 5	12 - 18	24 - 36
Alfalfa	4 - 6	18	36
Soybeans	2 - 3	12	24
Potatoes	2 - 3	12	24
Small grains	3 - 4	12	24
Field beans	2 - 4	12	24
Sugar beets	2 - 4	12	24
Pasture or grass	1 - 2	12	18 - 24
Sorghum	3 - 4	12 - 18	24 - 36
Turf and lawns	1	6	12
Annual vegetables	1 - 2	6 - 12	12 - 18
Small fruits	1 - 2	6 - 12	12 - 18
Asparagus	2 - 3	12	18 - 24

Using Tensiometers and Resistance Blocks in the Field

Placement in the Soil —To best determine moisture conditions for the full soil profile, place sensors in the root zone. For soils without restrictive layers, about 70% of the roots are in the top 50% of the root zone. Table 2 gives normal rooting depths for common crops along with recommended placement depths. Remember, these are the rooting depths for mature crops. Root development progresses at a similar rate to top growth. Install sensors early enough in the season to make them useful for scheduling any irrigation.

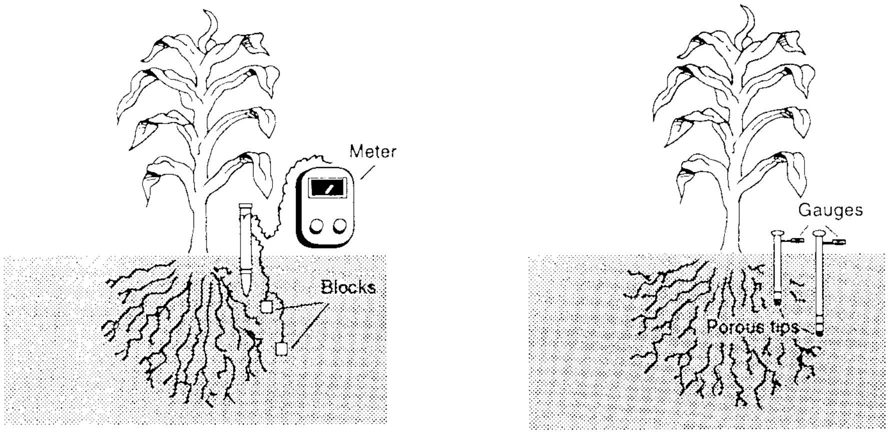


Figure 4. Placement of soil moisture sensors in the root zone.

Install at least two sensors at each site except for shallow-rooted crops or shallow soil underlain by gravel. Place the sensors at 1/3 and 2/3 of the crop rooting depth (Figure 4). For example, with corn, sensors would be placed at about 12 to 18 inches and 24 to 36 inches.

Use the shallow sensor to judge when to start irrigating. Use the deep sensor to determine how much water to apply. If readings of the deep sensor rise faster than the shallow sensor, apply more water with each irrigation. If readings of the deep sensor remain wet, then there is more chance for deep leaching of water and nutrients.

For row crops, place the blocks or tensiometers between plants in the row. Avoid locations where field or irrigation equipment could damage the sensors. Select a uniform area and make an

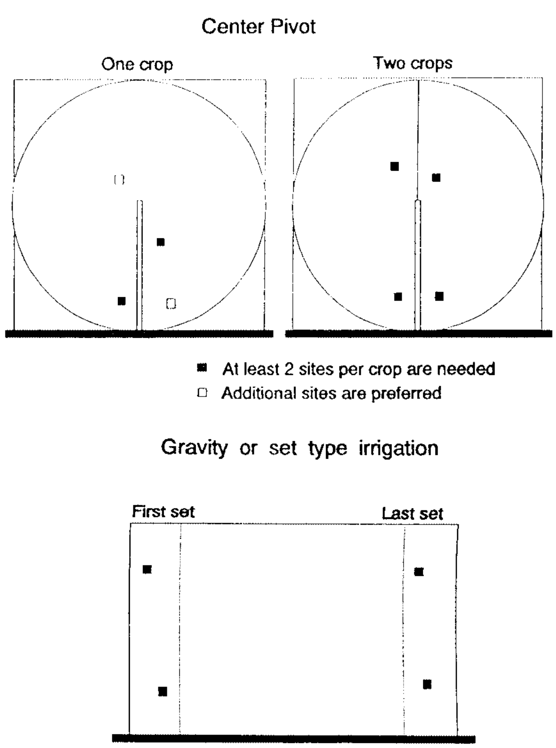


Figure 5. Locating soil moisture sites in the field.

effort not to disturb or compact the soil near the sensors.

Identify the depth of the sensors to insure correct recording by the person reading them during the season. Mark the locations well using flags or stakes. When using blocks, identify the lead wires and attach them to the stake.

Location in the field— Select at least two sites in each field (four is preferable), one near the start of the irrigation cycle and one near the end of the irrigation cycle. Use two sites for each crop where more than one crop is in the same field (Figure 5).

Where there is more than one soil type, place sensors in the predominant soil types. Avoid locations that are low areas, tops of hills, beneath the coverage of the end gun of a center pivot, under the first tower of a center pivot, near the edges of fields that may get uneven irrigation, or any other area that is not representative of the field.

Put each site where it will be accessible from a road or trail. It is very important to place sensors where they can be found easily for reading, especially as the crop matures. Put markers or flags in the row and on the side of the held. Reduce foot traffic around the sensors to minimize soil compaction. Do not locate the sites too far from field roads so that extra effort is required to find and read the instruments.

Scheduling with Soil Moisture Instruments

Soil moisture measurement is an integral part of any irrigation scheduling program. Soil moisture readings can be used by themselves to schedule irrigations, but they are most valuable when used in combination with other methods of scheduling such as a simple checkbook method or a computer model. Soil moisture readings can determine initial soil moisture balances and update those balances throughout the irrigation season.

Where the soil moisture readings are the basis for scheduling irrigations, take readings at least once every two days. Where the readings are used to update other scheduling methods, reading once or twice per week may suffice. Record all readings (Figure 6). The soil moisture readings, along with rainfall and irrigation amounts and crop condition, can help in management and future planning.

Soil moisture instruments measure current moisture levels in the soil and cannot predict future readings. It is possible for soil moisture readings to change rapidly during high water-use periods, from one day to the next, for example. Crop water use can be especially high on hot, windy days. Unless all of the field can be irrigated in one day, start irrigations before the sensors call for water.

Use soil moisture readings to schedule irrigation so the irrigation cycle can be completed before crop stress occurs. Table 3 gives

Figure 6. Example form for soil moisture and irrigation records.

Field number ______________ **Crop** ________________________________ **Year**________

Date	Rainfall	Irrigation	Site #1 Shallow	Site #1 Deep	Site #2 Shallow	Site #2 Deep	Comments

guidelines for irrigating using tensiometers and resistance blocks. Starting irrigations early is important during periods of high water use or critical growth stages to prevent excessive depletion of the soil moisture reserve. Since most irrigation systems do not have enough pumping capacity to keep up during times of high water use, the soil water reserve helps get through those periods.

During periods of lower water use and after rainfall, it is especially important to monitor the soil sensors. Stop irrigation when both the shallow and deep readings indicate the soil moisture is near field capacity.

Because crop demands and sensitivity to water stress are often lower early and late in the season, it may be possible to deplete more soil moisture at those times without loss of crop yield. This will allow more effective use of rainfall and minimize leaching of chemicals and nutrients below the root zone. Irrigation water application may be terminated after it is determined that adequate soil moisture reserves are available for the crop to mature.

Summary

Soil moisture readings are useful to determine how much water is available for the crop, when to start irrigating, and how much water to apply. Soil moisture monitoring can help conserve water and energy, minimize pollution of surface and ground water, and produce optimum crop yields. Efficient scheduling of irrigation water applications gives the highest return for the least amount of water.

Table 3. Soil tension readings for available soil moisture.

Soil Type	Field Capacity	Start Irrigation*	Optimum Range**	Reading at 50% Depletion
Loamy sand/sandy loam	10 - 15	20 - 30	30 - 50	45 - 60
Loam/silt loam	10 - 20	30 - 40	35 - 55	50 - 70
Clay loam/clay	15 - 25	35 - 45	40 - 60	60 - 100

* Start irrigation values are readings when irrigation should be started to complete most irrigation cycles before stress occurs in the field.

** Optimum range is the soil moisture range in which crop stress is minimized and yields are optimized. It may be desirable to deplete soil moisture beyond these readings both early and late in the growing season.

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1000 copies printed by CES at a cost of $.21 each. July 1992; updated April 2002.