Technical Reference # 75

Soil Moisture Monitoring: Low-Cost Tools and Methods

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Irrigators who monitor soil moisture levels in the field greatly increase their ability to conserve water and energy, optimize crop yields, and avoid soil erosion and water pollution. This publication explains how soils hold water and surveys some low-cost soil moisture monitoring tools and methods, including a new generation of sophisticated and user-friendly electronic devices.

Contents

While poor irrigation practices cause a host of environmental problems, irrigation can also be a sustainable practice, at times and places where it does not deplete or degrade surface water, groundwater, or soils. In times of high energy and water costs, efficient irrigation is essential to the viability of many farms and ranches. In the next few decades, more efficient irrigation may offer the best hope of feeding the world's growing population. (Postel, 1999)

NCAT photo.

Given the importance of irrigation efficiency, it's unfortunate that irrigation water management is often presented as a series of complicated mathematical calculations that only an engineer could love. Irrigation management is nothing more mysterious than maintaining a suitable environment for growing crops, mainly by keeping soils from becoming too wet or too dry. There are many ways to achieve this goal, including some that require no calculations at all. This publication describes several ways that you can check the soil moisture levels in your fields, using your hands, inexpensive probes, or new electronic devices.

Of course, there's more to irrigation management than just checking soil moisture levels. You should follow general irrigation guidelines for the crops you are growing, and you should track crop water use (evapotranspiration) as the season goes by. These topics are not covered in this publication; your local Natural Resources Conservation Service (NRCS), Extension, or soil and water conservation district office should be able to assist you. You should also know the amount of irrigation water you are applying. (Please refer to the ATTRA publication *Measuring and Conserving Irrigation Water.*)

No one knows as much as you do about your fields, crops, and irrigation system. So adjust, adapt, or reject any suggestion in this publication that doesn't fit your situation or doesn't seem to be working. Use every kind of information you can find about how your soils and crops are responding, proceed cautiously, and test every recommendation with direct observations in the field.

ATTRA - National Sustainable Agriculture Information Service is managed by the National Center for Appropriate Technology (NCAT) and is funded under a grant from the United States Department of Agriculture's Rural Business-Cooperative Service. Visit the NCAT Web site (www.ncat.org/agri.html) for more information on our sustainable agriculture projects.

How Soils Hold Water

The water-holding capacity of a soil depends on its type, organic matter content, and past management practices, among other things.

Soils are classified into one of about a dozen standard *texture classes*, based on the proportions of sand, silt, and clay particles. Sand particles are larger than clay particles, with silt particles falling in between. For example, a soil that is 20 percent clay, 60 percent silt, and 20 percent sand (by weight) would be classified as silt loam. Other texture classes are sand, loamy sand, sandy loam, loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay.

Overwatering can

- drown crop root systems, depleting air and encouraging disease
- leach nutrients, especially nitrogen, below the root zone
- send nutrients into groundwater
- reduce root growth by cooling the soil
- cause waterlogging and salt build-up in the root zone
- reduce crop quality and yield
- waste energy and money

Coarse-textured soils have a high percentage of sand, and *fine-textured* soils have a high percentage of clay. Fine-textured soils generally hold more water than coarse-textured soils, although some medium-textured soils hold as much or more *plant-available* water than some clay soils.

Besides their texture classification, soils are also classified into *soil types* or *soil series*, based on soil-building factors such as geology, chemistry, age, and location. There are more than 20,000 named soils in the U.S. alone, with names often referring to a town or landmark near where the soil was first recognized. For example, the Houston Black series is a clay soil formed under prairie vegetation in Texas. The Myakka series is a wet sandy soil found in Florida. The full description of a soil series includes a number of layers or horizons, starting at the surface and moving downward.

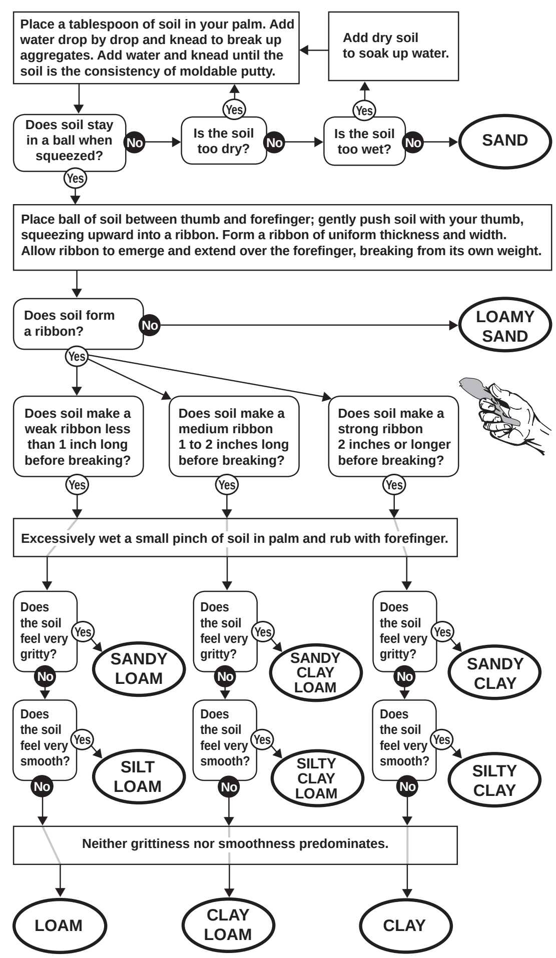
To identify the soil types or series in your fields, refer to a soil survey. Soil surveys are generally available from your local NRCS or Extension office.

As water infiltrates soil, it fills the pore spaces between the soil particles. When the pores are completely saturated, some of the water — known as *gravitational water* — percolates down through the soil profile and below the root zone. Gravitational water may take a few hours to drain away in sandy soils, or days or even weeks in clay soils.

Evaporation at the soil surface pulls water upward through capillary forces, while capillary forces also hold water around the soil particles. When a balance is reached between gravitational and capillary force, water stops moving downward and is held by surface tension in the soil – a condition known as *field capacity*.

Capillary water stored in the root zone is the most important water for crop production, but not all capillary water is available for plants to use. The water-holding force of soil, or *soil water tension*, is affected by soil texture. For example, clay soils have small pores and hold water more tightly than silt soils, with their larger pores. As soil water is depleted, the films of water remaining

Figure 1. Determining Soil Texture by the "Feel Method."



Adapted from *NRCS Irrigation Guide*, USDA Natural Resources Conservation Service, 1997.

around the soil particles become thinner, until they are eventually held in the soil with more tension than plants can overcome, and the plants begin to wilt.

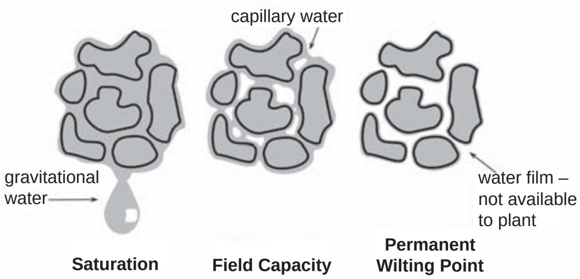


Figure 2. Saturation, Field Capacity, and Permanent Wilting Point.

Available water capacity is the amount of water a soil can make available to plants, generally defined as the difference between the amount of water stored in a soil at field capacity and the amount of water stored in the soil at the permanent wilting point.

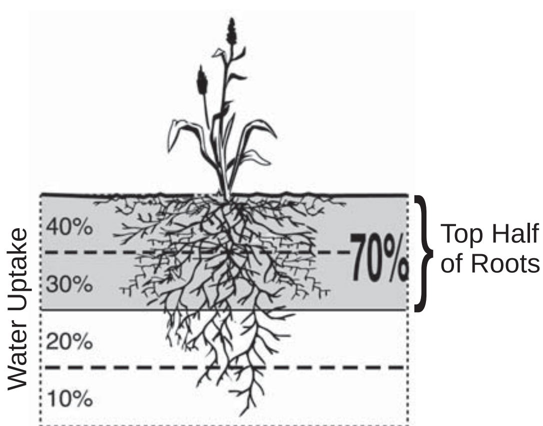


Figure 3. Effective Root Zone: the top half of the actual rooting depth, which supplies about 70% of the crop's water needs.

Plants get most of their water from the upper (shallow) portion of the root zone. The term *effective root zone* refers to about the upper half of the root zone depth, where roughly 70 percent of the plant's water is taken up.

What Soil Moisture Monitoring Method is Right for You?

In deciding when and how much to irrigate (a process sometimes called *irrigation scheduling*), all irrigators should do some kind of soil moisture monitoring. You may be surprised to learn how easy and inexpensive it has become to purchase, install, and use a state-of-the-art monitoring system. More devices are coming on the market all the time, and prices continue to fall.

- Unless you are a scientific researcher, don't get too hung up on accuracy or precision. Methods and devices will give slightly different readings, but almost all will track moisture trends similarly. So choose a method that works for you, take the exact readings with a grain of salt, and pay more attention to the trends and changes you are seeing over time.
- Consider the limitations imposed by your irrigation system, and choose a method that gives you information you can use. As a general rule, the greater your control over the rate and frequency of water applications, the more sophisticated and detailed the information you can use.
- Consider your soils and crops. Some devices work better in coarse soils than in fine soils, some devices work better with annual crops than with perennial crops, and so on. High-value crops will often justify a more expensive monitoring system than low-value crops.
- Consider what's convenient for you. Some devices are portable while others are hard-wired in place. Some devices give you "raw" data, and others do the calculations for you or display readings in a graph. Some devices require cables that may interfere with tillage.
- Be realistic in your expectations. Soil moisture measurement, even with the advent of ever-more-accurate devices, is still an art as much as a science. Soil sensing and measuring devices don't substitute for the judgment, observation, and local knowledge that good irrigators acquire over time.

The methods below are arranged roughly in order of cost, from least expensive to more expensive. All work just fine if they are used properly and diligently.

Related ATTRA Publications

The Montana Irrigator's Pocket Guide

Drought Resistant Soils

Sustainable Soil Management

Soil Management: National Organic Program Regulations

Alternative Soil Amendments

Table 1. Determining Soil Water Content by Feel and Appearance

Coarse	Moderately Coarse	Medium	Moderately Fine and Fine	% of Available Water Capacity (AWC)
Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles and free water forms on surface.	Exceeds field capacity – runoff & deep percolation.
Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.				100% – At field capacity
Tends to stick together, forms a weak crumbly ball under pressure.	Forms weak ball that breaks easily; does not stick.	Forms a ball and is very pliable; sticks readily if relatively high in clay.	Ribbons out between thumb and finger; has a slick feeling.	70 – 80% of AWC
Tends to stick together. May form a very weak ball under pressure.	Tends to ball under pressure, but seldom holds together.	Forms a ball, somewhat plastic; sticks slightly under pressure.	Forms a ball; ribbons out between thumb and finger.	50 – 70% of AWC
For most crops, irrigation should begin at 40 to 60% of AWC. Crop-specific guidelines are available from NRCS or Extension.				
Appears to be dry; does not form a ball under pressure.	Appears to be dry; does not form a ball under pressure.	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls up under pressure.	25 – 50% of AWC
Dry, loose, single-grained flow through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily breaks down into powder.	Hard, baked, cracked; sometimes has loose crumbs on surface.	0 – 25% of AWC

Adapted from *NRCS Irrigation Guide*, USDA Natural Resources Conservation Service, 1997.

Direct Inspection

The least expensive methods rely on digging up soil samples in the field and then inspecting, feeling, or weighing and drying them.

Feel and Appearance Method

Take walnut-sized soil samples from various locations and depths in the field, appropriate to your crop's root zone. Then use the table above to estimate the soil water content of your samples. With practice and diligence, the feel and appearance method can be accurate enough for most irrigation management decisions. A soil probe, auger, or core sampler is far superior to a shovel, especially for retrieving deep soil samples.

Hand-Push Probe

You can use a hand-push probe (sometimes called a *Paul Brown Probe* or *Brown Moisture Probe*) to determine the depth of wetted soil and also to retrieve soil samples. These extremely useful probes cost less than $50 and are among the fastest and easiest ways to check moisture anywhere in your fields.

To determine the depth of wetted soil, push the probe vigorously into the soil by putting your weight on the handle *without turning*. The probe will stop abruptly when it reaches dry soil. (Rocks and gravel will also stop the probe, but these are easily detected by a metallic click.) Check the mark on the probe shaft to determine the depth of the wetted soil.

To obtain a soil sample, twist the probe after pushing it into the ground. The probe will be full of soil when you pull it up. Then use either the "feel and appearance" method or gravimetric weight method to estimate soil moisture.

Figure 4. Soil Sampling Tools

Gravimetric Weight Method

The gravimetric method involves weighing soil samples, drying them in an oven, weighing them again, and using the difference in weight to calculate the amount of water in the soil. While too time consuming to be used for day-to-day management decisions, this highly accurate and low-cost method is often used to calibrate other tools. Your local Extension or NRCS office may be able to provide instructions for this technique, or you can find the instructions on the Internet.

Meters and Sensors

More sophisticated devices measure some physical property that is correlated with soil moisture. Some portable sensing tools are pushed directly into the soil or into an access tube implanted in the soil. Other systems rely on buried sensors that are either hard-wired to a fixed meter or else have long attached wires (electrodes) that are left above-ground and hooked to a portable hand-held meter.

Soil Moisture Blocks

The most common sensors, *electrical resistance blocks*, work on the principle that water conducts electricity. The wetter the soil, the lower the electrical resistance and the better the block conducts electricity. The two most common types of electrical resistance blocks are *gypsum blocks* (with a life of as little as one year but a cost of only $5 to $15 apiece) and *granular matrix sensors* (lasting three to seven years or more and costing $25 to $35 each). Freezing can cause cracking and premature aging in gypsum blocks, but will generally not hurt granular matrix sensors.

Electrical resistance blocks work by absorbing water from the surrounding soil. They need to be buried carefully, with snug soil contact and no air pockets—something that may be difficult to achieve in coarse or gravelly soils. Over the past several years, the National Center for Appropriate Technology (NCAT) has installed hundreds of granular matrix sensors. We have found the number-one problem to be poor soil-to-sensor contact, usually in coarse or gravelly soils.

Gypsum blocks. NCAT photo.

Granular matrix sensor. NCAT photo.

When burying any soil moisture sensing device, minimize soil compaction and disturbance to the surrounding soil and canopy cover. Your goal is to install each sensor in surroundings that are representative of the field.

Electrical resistance blocks may be read either with a data logger (see below) or with a portable hand-held meter. Hand-held meters, costing $150 to $600, generally either give electrical resistance readings in ohms or else convert resistance to *centibars.* (See text box below.)

Hand-held meters have their advantages. You don't need to bury cables in the field. And because the meter is portable, you can check moisture at an unlimited number of sites, wherever your soil moisture blocks are buried.

A disadvantage of hand-held meters, though, is that each monitoring site must be marked in some way, so you can find the electrodes in the field and hook them to the meter.

A common indicator of soil moisture is *soil water tension*

Some soil moisture monitoring instruments give *volumetric* readings — moisture per foot or per inch of soil — while other instruments indicate the level of soil water tension. Soil water tension is usually measured in centibars (cb), where a centibar is 1/100th of a bar, and a bar is roughly equivalent to one atmosphere of pressure. Centibars measure the force that a plant must exert to extract water from the soil. As the plant works harder to remove water, the centibar number increases. So larger centibar numbers mean drier soil.

Soil water tension levels mean different things in different soils and so — unfortunately — there is no simple way to translate centibar readings into water volumes or vice versa. Depending on soil texture, for example, field capacity may be between about 10 and 33 cb. Coarse soils (such as sands and sandy clay loams) have released 50 percent of their available water by the time soils have dried out to 40 to 50 cb. On the other hand, many clay and silty soils still retain more than 50 percent of available water at 80 cb.

Another disadvantage is the challenge of wading through crops (sometimes tall and wet) to your monitoring sites. Also, the meters seem expensive for what they do. For roughly the cost of a hand-held meter you could purchase a sophisticated data logger offering graphical display, automated moisture readings, and many other features.

Considering the high cost of the hand-held meters, you may be tempted (as we were) to measure resistance with an ordinary ohm meter. Unfortunately, this doesn't work. Ohm meters use DC power, which polarizes the soil moisture blocks and causes readings to fluctuate wildly. The meters made specifically for use with soil moisture blocks convert DC power to AC, avoiding polarization and giving stable readings.

Thermal dissipation blocks, a less-common alternative to electrical resistance blocks, work on the principle that dry objects heat up faster than wet objects. These porous ceramic blocks contain small heaters and temperature sensors. They cost $35 to $50 apiece, with meters costing $150 to $600.

Tensiometer. Photo courtesy The Irrometer Company.

Tensiometers

A tensiometer is an airtight, water-filled tube with a porous ceramic tip on the end that is placed in the soil, with a vacuum gauge on the other end that protrudes above the ground. Tensiometers measure soil water tension and display the reading on the vacuum gauge in centibars (cb). These devices work best in the range of 0 to 80 cb, making them better suited to coarse soils than fine soils. A coarse soil at 80 cb might cause severe crop stress, whereas a fine soil such as clay might still contain more than half of its available water capacity at 80 cb.

Tensiometers are fairly easy to use but must be serviced regularly by filling with water and using a pump to pull a vacuum. If the soil becomes too dry, tensiometers can lose soil contact, requiring re-installation. Depending on length—from 6 to 48 inches—they cost $45 to $80. Because they are easy to install and remove, tensiometers are well-suited to cultivated fields and annual crops where buried blocks or cable would be awkward. They are also often used in orchards.

Tensiometers measure moisture tension at the depth where the tip is located. To use two tensiometers as simple irrigation "on-off" indicators, install one at the center of the effective root zone and another one just below the effective root zone (i.e., at approximately one third and two thirds of the total root depth). Use the shallow tensiometer as an indicator to start irrigating and use the deeper one as an indicator to stop irrigating.

Table 2. Irrigation Guidelines Based on Centibar Readings

Reading	Interpretation
0-10 cb	Saturated soil
10-20 cb	Most soils are at field capacity
30-40 cb	Typical range of irrigation in many coarse soils
40-60 cb	Typical range of irrigation in many medium soils
70-90 cb	Typical range of irrigation in heavy clay soils
> 100 cb	Crop water stress in most soils

Adapted from *Watermark Soil Moisture Sensors*, The Irrometer Company, Riverside, CA.

Data Loggers

Soil moisture data loggers are typically battery-operated devices, permanently mounted on a post and hard-wired to buried electrical resistance block sensors. At regular intervals (generally every several hours), the data logger sends a current through each sensor, measuring electrical resistance. The measurements are converted into soil moisture readings and stored in memory. Data loggers with a graphical display show several days or weeks of readings in a bar graph, allowing you to see recent soil moisture trends at a glance on the screen. Depending on their features, soil moisture data loggers may cost $60 to $500, not including sensors or cable.

The arrival of low-cost soil moisture data loggers on the market in the late 1990s was great news for irrigators. A major advantage of data loggers is that no matter how busy you get, the monitor automatically checks and records your soil moisture. The monitor is normally mounted on a conveniently-located post at the edge of the field or near the control panel of a center pivot, eliminating the need to walk into the field or find electrodes amidst foliage. A disadvantage is that a limited number of sensors (typically 6 to 15) can be connected to the monitor. Installation generally also requires running cable from the data logger to each sensor. When feasible, such as in perennial crops, burying the cable is recommended.

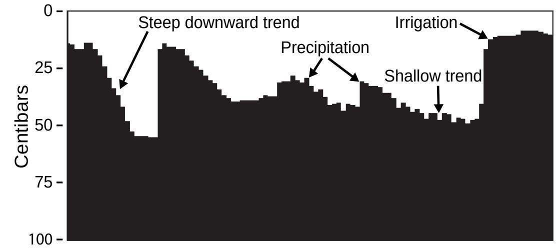


Figure 5. Data Logger Graphical Display.

Between 2000 and 2004, NCAT helped install around 100 soil moisture data loggers at farms and ranches in Montana. Data logger installation is not particularly difficult, and the headaches mostly relate to the cable. We saw dozens of faulty splices, cables chewed by livestock and wildlife, cables damaged by machinery during tillage and hay cutting, cables melted when the owner was burning weeds, cables melted by lightning, and (on one memorable occasion) a cable snagged by a passing car.

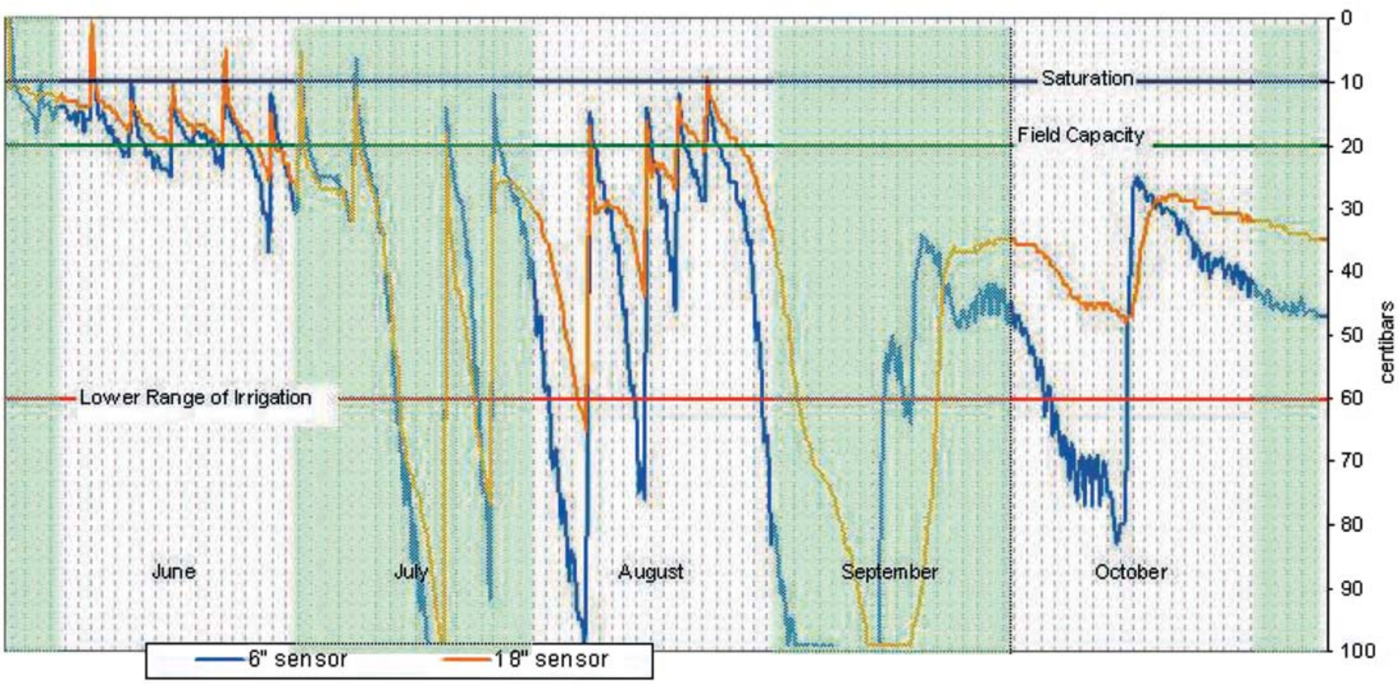
Besides displaying recent moisture readings, soil moisture data loggers store several months or years of data, which may be downloaded and viewed in graph form.

Comments from Data Logger Users

Below are a few representative comments from interviews with NCAT's 2000-2004 soil moisture data logger project participants. (The names are fictitious.)

Jim Clinton intensively grazes grass pasture, which he waters frequently and for short periods. After he installed a soil moisture data logger, he checked it daily and called

Figure 6. Soil Moisture Graph Generated by a Data Logger, Showing an Entire Irrigation Season.



Soil Moisture Data Logger. NCAT Photo.

it "one of the best things to come along for a long, long time." Jim quickly became convinced that he was overwatering. He had been running five- to six-hour sets through the growing season, switching to eight-hour sets during hot weather. In his second year with the monitor, he ran two-hour sets in the spring, three-hour sets through May, and four- to five-hour sets when it got hot. He told us, "Soil moisture has always been the missing link... The meter said that six hours was all we needed. Even if it started out at 90 centibars, we got down to 10 centibars within six hours."

After Chester Hendricks installed a soil moisture monitor, he looked at it "every day, at least, and sometimes two or three times per day." He told us that he bases most of his decisions on careful observation of the crop, and he called the data logger "a tool to manage the crop along with visual observation of the crop... It's a tool, but so is looking at the crop." Chester believes that the monitor definitely made a difference to his total production. During an exceptionally hot and dry summer, he "didn't let the crop get hurt" by the hot dry weather, and enjoyed excellent yields, "one of our best crops ever." Chester was surprised that evapotranspiration rates skyrocketed once the plants started getting taller. "An 18-inch crop pulls a lot more moisture than when the plants are smaller and younger." He was also impressed by "how much effect wind and humidity make on depletion of soil moisture.... Unbelievable." He saw some tremendous moisture drops take place in just a four to six hour period.

NCAT photo.

George Adams told us that his irrigation practices didn't change much during his first year using a data logger. The device did give him a much better idea, though, how the water was moving down through the soil profile. He said, "The year before I wasn't getting water deep enough. This year I wanted to saturate it then let it go longer between passes to let the water go deeper, by slowing down the pivot. Yield was fantastic." In subsequent years, George has monitored soil moisture in the spring and started irrigating earlier. He told us that he sees the device as useful for limited-water situations: "Instead of trying to water everything, I can set priorities for short water supplies."

Three years of using a soil moisture data logger have not caused John Jefferson to make major changes to his water management methods, but have confirmed his belief that he is not overwatering and is making good use of water. He told us that the monitor has helped him save water during spring rains and late June snowstorms. "We saved two to three days of watering because the ground was wet after a late snow," Jefferson says. At prevailing electricity rates, he saved about $100 in these three days alone.

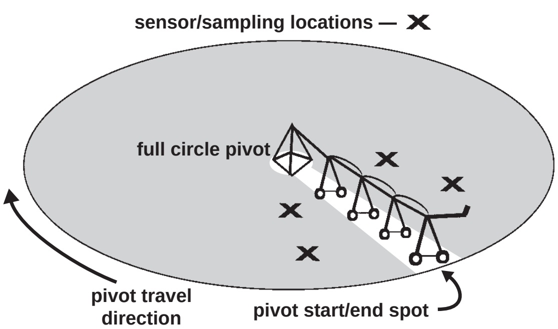
Tips on Placing Moisture Sensors

- It's generally not practical to monitor every part of the field, so install sensors in average soil and slope areas. Avoid field edges and unusually wet or dry areas.
- For mature trees, place sensors well away from the trunk but inside the drip line (canopy diameter).
- The question of how deeply to maintain soil moisture is a management decision, depending on crop and growth stage, soil conditions, and other factors. In general, though, management should focus on the effective root zone; i.e., the upper half, where plants take up most of their water.
- For three-foot or deeper effective root depths, you may want to place sensors at three depths; e.g., in the top,

middle, and deepest third of the total root depth.

- For effective root zones of two feet or less, place sensors at two depths.
- Place a sensor below the root zone for shallow-rooted crops (including grasses), or in the lower quarter of the root zone for deeper-rooted crops, as a way of detecting deep percolation and overwatering.
- For center pivots, monitor a few sprinkler diameters from where you normally start the pivot, in the direction of pivot movement. Also monitor a few sprinkler diameters before the spot where you normally stop the pivot.

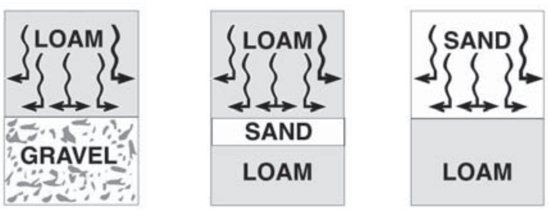
Figure 7. Soil Monitoring Sites Under Pivot.



Changes in soil texture act as a temporary barrier to water movement.

Fine soil overlying a coarse soil, or vice versa, must become very wet before water will move down through the subsoil. Under these conditions, the overlying soil holds up to three times as much water as it would in more uniform soils. If you have distinct layers of soil, you may want to monitor soil moisture in each layer separately.

Figure 8. Water Movement in Stratified Soils.



(Adapted from *NRCS Irrigation Guide*, USDA Natural Resources Conservation Service, 1997.)

- Avoid the inner part of a pivot circle (inside the first tower), which tends to be wetter than the rest of the circle.

Other Tools and Techniques

In 2006, the tools below are generally more expensive and best suited to high-value crops, large farms, and scientific research. In some cases, though, high-tech features are becoming available at affordable prices. It's hard to predict the future of this highly competitive and rapidly changing market.

Remote sensing systems ($1,000 and up) use buried sensors wired to a nearby transmitter that sends readings to a receiver, usually a data logger connected to a computer. These systems are often called "wireless." Although this term is slightly misleading, it's true that the cable connections between the sensors and transmitter are typically quite short. The big advantage of these systems is that they allow large farms to monitor soil moisture in several fields from a single computer, without going into the field.

Time domain reflectometers (TDR) send an electromagnetic wave along two parallel rods or stiff wires inserted in the soil, measuring the "dielectric constant" of the soil. TDR instruments range in price from about $500 to $4,400.

Frequency domain reflectometers ($475 to $900) use high-frequency radio waves pulsed through the soil from a pair of electrodes.

Infrared thermometry is based on the principle that the temperature of a plant's leaves is related to its transpiration rate. *Infrared satellite imagery* to detect crop stress is under research.

Conclusion

Soil moisture monitors, especially the new generation of electronic devices, show you how water is moving through your soils, with a precision and vividness that most irrigators have never seen before. The effect can be startling — almost like having an x-ray machine that allows you to look beneath the surface of the soil. With the cost of sophisticated monitoring systems dropping into the range of a few hundred dollars, many of these devices are rapidly paying for themselves in the form of crop yield improvements, energy savings, water conservation, and peace of mind.

On the other hand, soil moisture monitors don't "tell you when to irrigate." You'll still need to develop guidelines for your own crops and soils, and there is no substitute for the experience, subtle observations, and judgment that make someone a good farmer.

References

Postel, Sandra. 1999. **Pillar of Sand**. Worldwatch Books, New York. 313 pages.

USDA-Natural Resources Conservation Service. 1997. **NRCS Irrigation Guide**. Natural Resources Conservation Service, Washington, DC. 702 pages.
www.wcc.nrcs.usda.gov/nrcsirrig/irrig-hand books-part652.html

Further Resources

NCAT Publications

Installing and Using the AM400 Soil Moisture Monitor. 2004. By Mike Morris and Vicki Lynne. National Center for Appropriate Technology, Butte, MT. 17 pages.

Detailed instructions for installing and using the AM400 soil moisture data logger, including maintenance, troubleshooting, downloading data, and advanced settings. To request a free print or electronic copy, call 800-411-3222 (toll-free).

The Montana Irrigator's Pocket Guide. 2003. By Mike Morris, Vicki Lynne, Nancy Matheson, and Al Kurki. National Center for Appropriate Technology, Butte, MT. 161 pages.

A take-to-the-field reference to help irrigators save energy, water, and money, including guidelines for water management, equipment maintenance, and handy conversions and formulas. Get a free printed copy by calling 800-346-9140 (toll-free).

Water and Energy Conservation with the AM400 Soil Moisture Monitor. 2004. By Mike Morris. National Center for Appropriate Technology, Butte, MT. 15 pages.

Summarizes four years of NCAT research on the AM400 soil moisture monitor. To request a free print or electronic copy, call 800-411-3222 (toll-free).

Other Publications

Soil Water Monitoring with Inexpensive Equipment. 2000. By Richard Allen, University of Idaho, Kimberly, ID. [four papers]
www.kimberly.uidaho.edu/water/swm

Reviews and research on low-cost soil moisture monitoring equipment.
Hard copy available from
Kimberly Research and Extension Center
University of Idaho
3793 North 3600 East
Kimberly, ID 83341
208-423-4691

Tensiometer Use in Irrigation Scheduling. 1997. By Mahbub Alam and Danny H. Rogers. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS. 6 p.
www.oznet.ksu.edu/library/ageng2/l796.pdf

Tensiometer installation, use, and troubleshooting.
Hard copy available from
Production Services/Distribution
Kansas State University
26 Umberger Hall
Manhattan, KS 66506-3404
785-532-5830

Measuring Soil Moisture. 1998. By Blaine Hanson and Steve Orloff. University of California, Davis, CA. 34 p.
http://gwpa.uckac.edu/05.htm

Good discussion and comparison of soil moisture measuring devices, although slightly dated and does not include data loggers.
Hard copy available from
Cooperative Extension Office
Department of Land, Air and Water Resources
113 Veihmeyer Hall
University of California
Davis, CA 95616
530-752-1130

Web sites

NRCS Irrigation Page
USDA-Natural Resources Conservation Service
www.wcc.nrcs.usda.gov/nrcsirrig

A comprehensive source for irrigation reports, guides, statistics, photos, and links.

The Soil Water Content Sensor discussion group
www.sowacs.com
Moderated by Bruce Metelerkamp

An e-mail discussion list and archives, with discussions and reviews of all kinds of soil moisture monitoring devices, concentrating on automated electronic sensors that can be continuously logged with data loggers.

An Internet search under "soil moisture monitoring" (or similar key words) will yield hundreds of additional Web sites offering products, reviews, and guidelines.

Suppliers

Hundreds of companies make and sell soil moisture monitoring equipment. Listed below are a few representative sources of equipment mentioned in this article.

Art's Manufacturing & Supply, Inc.
105 Harrison Street
American Falls, ID 83211
800-635-7330 (toll-free)
www.ams-samplers.com

Source of soil probes, bucket augers, and other irrigation equipment.

Ben Meadows Company
2589 Broad Street
Atlanta, GA 30341
800-241-6401 (toll-free)
www.benmeadows.com

Campbell Scientific, Inc.
815 West 1800 North
Logan, UT 84321-1784
435-753-2342
www.campbellsci.com

Source of data loggers and weather stations.

Davis Instruments Corp.
3465 Diablo Ave.
Hayward, CA 94545
510-732-9229
www.davisnet.com

Source of weather stations and wireless soil moisture monitoring systems.

Delmhorst Instrument Company
51 Indian Lane East
Towaco, NJ 07082-1025
1-877-DELMHORST (toll-free)
www.delmhorst.com

Source of gypsum blocks and hand-held soil moisture meters.

Gempler's
P.O. Box 44993
Madison, WI 53744-4993
800-382-8473 (toll-free)
www.gemplers.com

Source of soil moisture sensors, probes, tensiometers, and other irrigation equipment.

Irrometer Company, Inc.
P.O. Box 2424
Riverside, CA 92516
909-689-3706
www.irrometer.com

Source of Watermark granular matrix soil moisture sensors, hand-held soil moisture meters, tensiometers, soil moisture data loggers, and other soil moisture monitoring equipment.

Isaacs and Associates, Inc.
3380 Isaacs Ave.
Walla Walla, WA 99362
800-237-2286 (toll-free)
www.isaacstech.com

Source of remote soil moisture monitoring systems.

M.K. Hansen Company
2216 Fancher Boulevard
East Wenatchee, WA 98802
509-884-1396
www.mkhansen.com

Manufacturer of the AM400 soil moisture data logger.

Soil Moisture Equipment Corporation
801 S. Kellog Ave.
Goleta, CA 93117
805-964-3525
www.soilmoisture.com

Source for soil augers, soil moisture sensors and meters, tensiometers, time domain reflectometers, and other soil moisture monitoring equipment.

Soil Moisture Monitoring: Low-Cost Tools and Methods

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This publication is available on the Web at:
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or
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