Monitoring Soil Moisture to Improve Irrigation Decisions

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Factsheet

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Monitoring soil moisture is the key to getting the right amount of water to crops at the right time. Use this Factsheet to select the instrument best suited for the operation. Learn how to calibrate the instrument and interpret the resulting measurements.

WHY MONITOR SOIL MOISTURE?

Monitoring soil moisture can help growers manage soil moisture. Choosing the right times and the right amounts to irrigate can lead to:

- higher yields
- better product quality
- improved plant vigour
- reduction in disease
- more effective use of water (water efficiency)
- reduced irrigation costs

Water and nutrients are used most efficiently when an irrigation event applies only the amount of water the crop needs and the soil can hold. Considering the time it takes to irrigate, it makes sense to spend time taking soil moisture measurements to improve irrigation decisions.

SELECTING A MONITORING INSTRUMENT

The two main points to consider in selecting an instrument to monitor soil moisture are:

- How will the soil moisture information be used in the farm operation?
- What is the most practical way to collect the information?

Use Table 1 to review the variety of instruments available for collecting soil moisture information.

COSTS

Soil moisture monitoring costs range from $100–$3,000+ per monitoring location, depending on the type (manual versus automated) and number of instruments. Generally, one monitoring location is used per field, but multiple locations may be necessary to provide information from large fields with variable conditions or management practices. More monitoring means more information on which to base irrigation decisions. Considering the cost of irrigation (fuel and labour), it makes sense to invest in soil moisture instruments that increase the effectiveness of irrigation applications.

TIME REQUIRED

The amount of time it takes to monitor soil moisture depends on the amount of information required and whether you are using manual or automated instruments. Collect data between irrigation events and more frequently (daily) as the chosen irrigation trigger point approaches. Check data during or after an irrigation event to verify if the right amount of water was applied.

Using manual instruments requires visiting the monitoring location(s) and recording the readings. Someone already walking the fields regularly (i.e., a field scout) could do this. Making graphs of the readings takes additional time. Many of the automated instruments can be set up to send readings directly to a remote computer, and some will automatically produce graphs.

Allow time for calibrating soil moisture instruments at the start of the growing season.

Installing soil moisture monitoring equipment at the beginning of the season can take several hours, depending on the number of instruments. It is important to make this job a priority as soon as the crop is planted. OMAFRA experience shows that many growers start irrigating too late. Soil moisture monitoring can demonstrate when irrigation should begin, and, equally important, when it should end.

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Table 1. Soil Moisture Monitoring Instrument Options

Options	Instruments	How to Use
Portable "instant read" instrument		
 Irrigator taking a soil moisture reading with a TDR instrument in a lettuce field.	FDR[1] TDR[2]	This tool is best suited to growers who are walking the fields regularly and want to record measurements manually. A crop scout or other consultant can use this style of instrument to offer a soil moisture monitoring service. Multiple locations in the field can be measured.
"Bury in place" instrument with visual display in the field		
 Tensiometer with analogue output (dial reading) installed in soil in a lettuce field.	Electrical resistance blocks Tensiometer TDR, FDR, capacitance	This instrument requires growers to walk the fields regularly and record measurements manually. A consultant or scout can gather the readings and produce the data for the farm.
"Bury in place" instrument with automated data logging		
 TDR instrument about to be buried (15-cm deep hole) and wired to above-ground data logger (in an apple orchard).	Capacitance Electrical resistance blocks FDR TDR Tensiometer	The data is manually downloaded from the data logger to a home computer. Some instruments have software that automatically makes graphs of the data and interpret the results. Continuous readings allow the irrigation manager to see trends and response to rainfall and irrigation.
"Bury in place" instrument with wireless communication to a home computer		
 Solar-powered telemetry unit in a tomato field transmitting data from capacitance instrument (in access tube, under circled cap). *Photo credit: Weather INnovations Inc*	Capacitance Electrical resistance blocks FDR TDR Tensiometer	Some instruments have software that automatically makes graphs of the data and interprets the results. Some consultants offer this type of service online. Continuous readings allow the irrigation manager to see trends and response to rainfall and irrigation.
"Bury in place" instrument that automatically controls irrigation (controlling pumping plant or solenoid valves)		
 Solenoid valve on irrigation water supply pipe that is controlled by measurements from a soil moisture instrument.	Capacitance Electrical resistance blocks FDR TDR Tensiometer	Soil moisture instrument continually takes readings. When soil moisture reaches a user set trigger point, the irrigation is automatically initiated. Well suited to growers comfortable with automation.

[1] Frequency domain reflectometry
[2] Time domain reflectometry

Figure 1. Installing an access tube for a soil moisture monitoring instrument. *Photo credit: Weather INnovations Inc.*

Instruments that use wireless transmission technology to send data remotely to a remote computer (e.g., the farm office) may require installation by a service provider (Figure 1).

Typically, it takes a few weeks, over at least three irrigation events, to learn what the soil moisture readings mean for each field and crop and how they should affect your irrigation decisions.

PLACING THE SENSORS

Place the soil moisture sensor in a representative area of the field. If the field is not uniform, choose a location that tends to be a bit drier than average or divide the field into zones, each with its own soil moisture instrument and unique management.

Always locate sensors in areas of dense roots. Place sensors between sprinkler rows (or traveller lanes), halfway between sprinklers. For drip irrigation, place the sensor about halfway between the emitter and the outer edge of the wetting front (in an area of dense roots). For production under plastic, place the sensor under the plastic.

The primary sensor depth should be similar to the crop rooting depth (generally 15–30 cm). For deep rooted crops, two sensor depths may be needed.

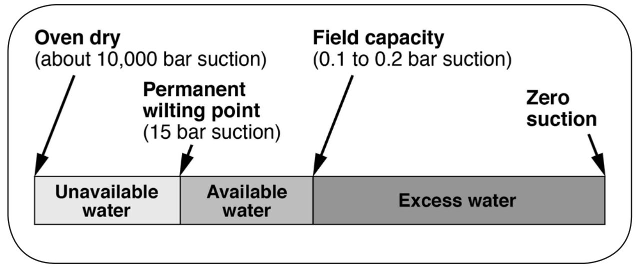


Figure 2. Availability of soil water.

Place a second sensor at the bottom of the root zone to determine if the irrigation applied is enough, too much or too little. Before and after irrigating, take note of the soil moisture. If the bottom sensor is showing lots of response to the irrigation event, less water is required. If the bottom sensor shows no response to the irrigation event, the amount of water applied is adequate or could be increased. Careful attention to the bottom sensor will prevent irrigation water and potentially nutrients from being lost to drainage tile.

UNDERSTANDING SOIL MOISTURE LEVELS AND CROP RESPONSE

Definitions

Field Capacity As much water as the soil can hold, 2 or 3 days after it has been saturated by rainfall. At this point, there is very little downward movement of soil water due to gravity and very little suction due to capillary action.

Permanent Wilting Point The amount of water remaining in the soil when the plant wilts in a humid atmosphere. The water remaining in the soil is held tightly by soil particles, and plant roots cannot absorb it.

Available Soil Water The amount of water in the soil between field capacity and the permanent wilting point. Generally, overhead irrigation should start before soil reaches 50% of available soil water. Drip irrigation should start before soil reaches 80% of available soil water (Figure 2).

Soil Texture and Soil Moisture

The amount of water available to the plants depends on the texture of the soil. The field capacity and permanent wilting points are shown in Figure 3 for various soil textures. Loam soils are usually highly valued for their consistent crop production. Note that the greatest amount of crop available water is in the loam-to-silt loam texture.

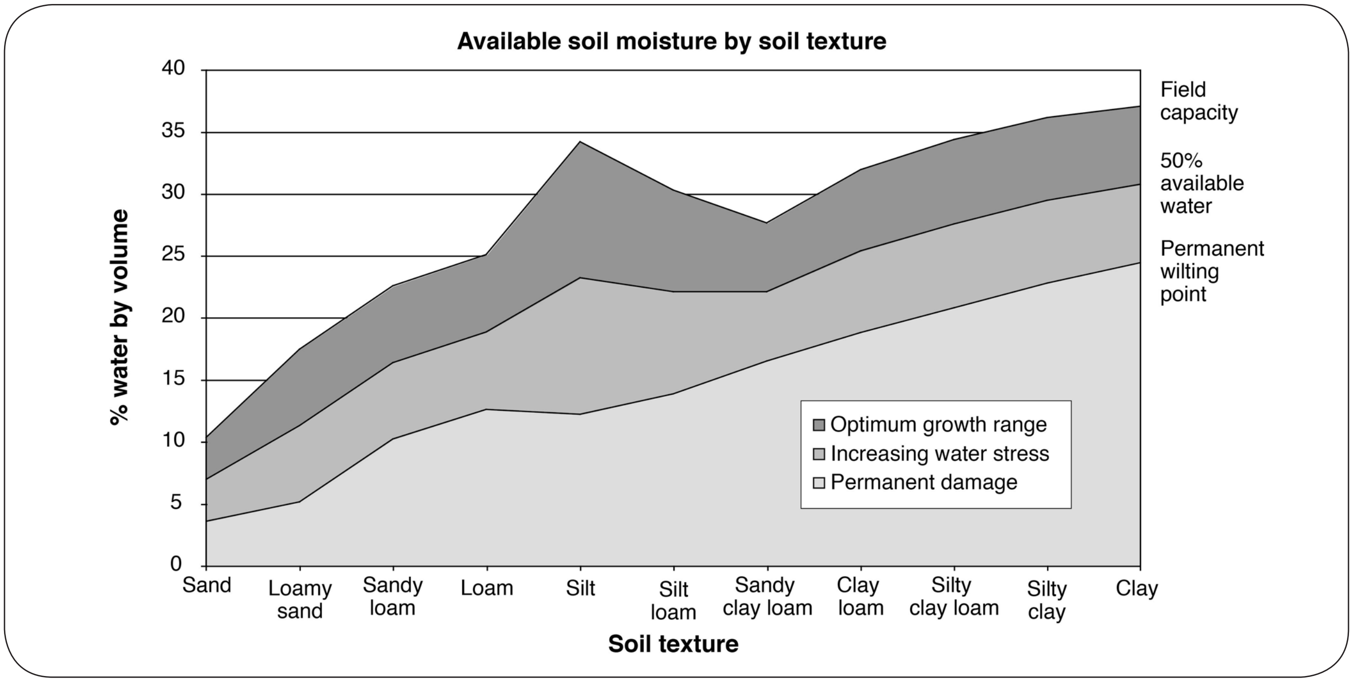


Figure 3. Available soil moisture by soil texture. Based on data from Ratliff, L.F., Ritchie, J.T., and Cassel, D.K. (1983). Soil Science Society of America Journal 47, 770(5).

INTERPRETING INSTRUMENT READINGS

Soil moisture instruments provide readings in several units, such as percent (%) water by volume, centibars or as dimensionless trends. Figure 3 provides an interpretation of soil moisture readings presented as % water by volume. Use Figure 4 to determine how much water has depleted since the last rain/irrigation (0 is wet, 100 is dry) when readings are provided in centibars.

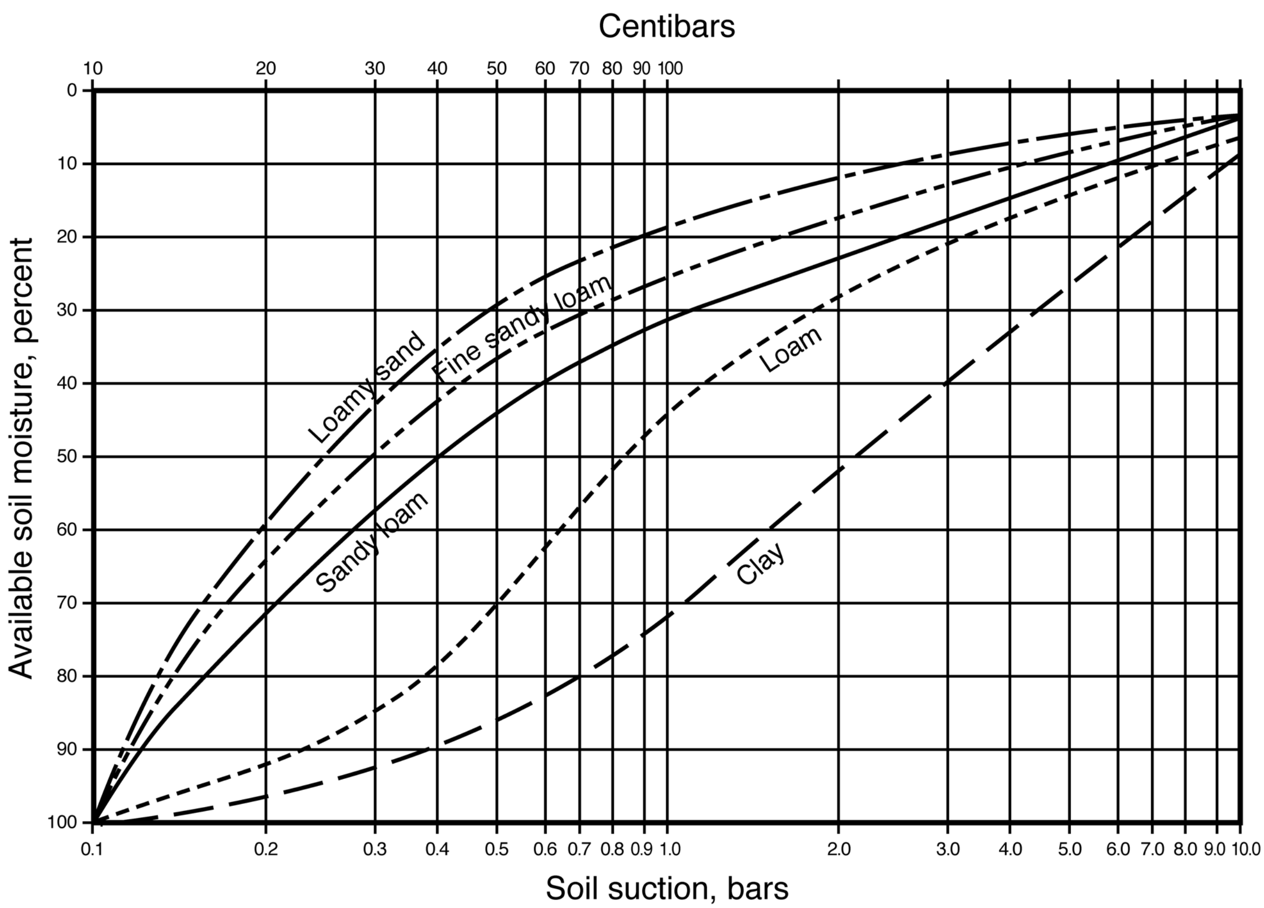
Calibration is important for interpretation but even more critical for those instruments that just display trends.

> **Example:** A sandy loam soil has 90% available soil moisture at a soil moisture tension of 13 centibars and at 50% available soil moisture at a soil moisture tension of 40 centibars.

OMAFRA experience suggests that overhead irrigation be triggered before 50% of available soil water is depleted and drip irrigation be triggered before 20% of available soil water is depleted (i.e., at 80% available water).

Know the field capacity and permanent wilting point of your soil (using the charts or through in-field calibration or laboratory analysis). Choose how much depletion to allow. Begin irrigation when the field hits this trigger point.

With all instruments, graphs of the soil moisture are used to analyze the data for trends. An irrigation event or significant rainfall will cause the soil moisture to spike. Following an irrigation event, the soil moisture can drop quickly, depending on the crop growth stage. As the soil dries out, the soil moisture will continue to drop more slowly. This is an indication that it is more difficult for the plant to take water out of the soil and that further irrigation is needed. Instruments that provide continuous measurements (log data or transmit to a computer) are best suited to this analysis.



Adapted (with permission) from the *BC Trickle Irrigation Manual,* BC Ministry of Agriculture and Food, Irrigation Industry Association of British Columbia (T.W. Van der Gulik)
Note: 1 kpa = 1 centibar; 100 centibars = 1 bar

Figure 4. Relationship between available soil moisture and soil moisture tension in different soil textures.

Graphs based on the soil texture are used to determine the need to irrigate (Figures 3 & 4), however, a simplified "in-field" calibration is superior. Soak the area around the soil moisture instrument and take a reading 24 hr later (the drainage time required is longer for fine textured soils such as clays). This reading is the field capacity (maximum). The permanent wilting point (minimum) is assumed as approximately 50% of the field capacity (maximum). The permanent wilting point (minimum) is refined by analyzing the readings over the season (or by sending an undisturbed soil core sample for laboratory analysis to determine the permanent wilting point).

A variety of soil moisture monitoring instruments can help collect accurate data. Select the instrument that best suits the farm operation (Table 2).

Table 2. Comparison of soil moisture monitoring tools

Simplicity of use	Reliability	Measurement units	Range of soil types	Manual infield reading	Potential for automation	Portability	Observations	Cost
Tensiometers								
✓✓	✓✓	centibars	most, except clays	yes	yes	Buried for crop season but moveable from season to season	• proper installation critical to ensure good contact between porous tip and soil • requires maintenance to refill water columns and regular checking of units • if the sand is coarse, a special unit is required	**$** usually two units at two different depths
Electrical resistance blocks (gypsum blocks)								
✓✓✓	✓✓	centibars	most, except clays, gravel, very coarse sand or peat	yes – need hand-held digital reader	yes	Buried for crop season but moveable from season to season	• installation generally easy but depends on soil type • requires some calibration with soil type • sensitive to salt levels • low maintenance • not very sensitive at high soil moisture • lifespan ~3 years+ • readings are affected by soil temperature (0.6% per degree Celsius)	**$$** meter + individual units, usually two units at two different depths
Dielectric sensors: TDR (time domain reflectometry), FDR (frequency domain reflectometry), capacitance								
✓ depends upon unit used	✓✓	volumetric soil moisture (%) or trends comparison	all, but clays may pose some problems	some yes, some no	yes	Various, depending on the model: • portable • buried for crop season • can move between permanently placed access tubes	• sometimes difficult to insert probes in dry conditions • professional installation of access tubes may be required • FDR — sample volume is 25-cm diameter around probe	**$$$** cost has come down in recent years

See the Irrigation page at www.ontario.ca/omafra for additional information on soil moisture instruments and soil moisture monitoring service providers.

COMMON SOIL MOISTURE MONITORING INSTRUMENTS

Tensiometer

The tensiometer reads the soil water tension or suction, in centibars. The higher the tension, the drier the soil. The tensiometer is made of a closed plastic tube with a ceramic tip attached to one end, and a vacuum gauge with an air-tight seal at the other end. The tube is filled with water and sealed. When the ceramic tip comes to equilibrium with the surrounding soil, the gauge registers the soil water tension.

Install tensiometers carefully to ensure that the ceramic tip is in contact with the soil. Use a soil sampling tube to drill a hole to the proper depth. Partially fill the hole with a slurry of soil and water. Gently, push the tensiometer into the hole until it reaches the bottom (Figure 5). Do not touch the ceramic tip, as the grease from fingers can interfere with the water movement across the ceramic tip/soil interface.

Routine maintenance is important. The liquid in the tube must be refilled and air bubbles removed with a hand pump. Some newer models have lower maintenance requirements. Record readings manually from the analogue or digital display or connect instruments to data loggers or communications equipment and send the data to the farm office computer (Figure 6). Use the graph from Figure 4 to interpret the readings from the tensiometer.

Figure 5. Tensiometer ceramic tip inserted into a 2.5-cm diameter hole in soil.

Electrical Resistance Blocks

These units measure soil water tension in centibars, similar to tensiometer readings. They measure the electrical resistance to current flow between electrodes embedded in a material resembling fine sand, surrounded by a synthetic porous material.

Carefully install electrical resistance blocks to ensure that the blocks are in contact with the soil. Use a soil sampling tube to drill a hole to the proper depth. Partially fill the hole with a slurry of soil and water. Push the block into the hole until it reaches the bottom, leaving the attached wires above the soil surface (Figures 7 and 8). Replace the soil above the block, and firmly pat it into place. Flag each unit for easy access. In the field, attach a hand-held digital reader to the wires to read the data. The wires may also be connected to a data logger or communications equipment and sent to the farm office computer.

Figure 6. Digital tensiometer wirelessly transmitting data to a remote computer. *Photo credit: Hortau Inc.*

Figure 7. An electrical resistance block being inserted into a hole in the soil. Wires from a buried electrical resistance block are connected to a digital hand-held reader.

Figure 8. An irrigator takes soil moisture readings using a digital hand-held reader connected to wires from a buried electrical resistance block, which protrude from the soil.

Figure 9. A TDR is positioned at the bottom of a hole, approximately 30 cm deep, in an apple orchard.

Install the sensors in the soil, to any depth, in groups of two. Because they require good contact with soil, they are not suited to gravelly, sandy or peat soils. Use the graph from Figure 4 to interpret the readings.

Dielectric Sensors

Time Domain Reflectometry (TDRs)

Time domain reflectometry is a relatively new way to measure soil moisture. Probes inserted into the soil measure the velocity of electromagnetic waves in the soil (Figure 9). These waves are slowed by soil moisture. The measurements are very accurate, and the equipment comes factory-calibrated. Because soil texture also influences the velocity of the waves, these units are not practical in soils with high clay content.

The disadvantage to TDR technology is that complex electronics and expensive equipment are required, as well as some in-field calibration.

Portable TDR sensors give almost instant readings and may be shaft mounted or hand-held (Figure 10). Take care when inserting the probes, as the equipment is calibrated based upon a set distance between the electrodes. If the electrodes become bent, measurements may not be accurate. Some come with internal data loggers that allow automated recording of the soil moisture values in the field.

Bury non-portable types of TDR instruments in one place for the duration of the growing season. Wires from the instrument protrude above the ground and can be read with a portable meter, connected to a data logger or connected to communications equipment and sent to the farm office computer.

Figure 10. An irrigator pushes a TDR soil moisture probe attached to a waist-high insertion handle into the soil in an asparagus field. An instantaneous reading is taken and the probe is removed.

Frequency Domain Reflectometry (FDRs)

Frequency domain reflectometry is similar to time domain reflectometry.

Capacitance-Based Instruments

Capacitance-based technology has been gaining in popularity because instruments are now available and provide continuous readings, but they are primarily used in research trials due to the expense. Current capacitance probes are designed for installation in a fixed location in the field for the entire season. They are compatible with high levels of automation and/or telemetry. Cost often limits the number of capacitance probes used. Careful site selection with the probe is critical to ensure representative information for the field monitored.

Figure 11. An irrigator lowers a capacitance probe with multiple monitoring depths into an access tube.

Many capacitance probes are used by installing a waterproof access tube and inserting the probe into the tube (the tubes are generally installed in permanent locations that are not moved from year to year). Numerous moisture-sensing points may be fixed along the length of the probe to give readings at various depths specific to your crop roots (Figure 11).

Some capacitance probes are buried directly in the ground with wires protruding above the ground. These are read with a portable meter, connected to a data logger or communications equipment and sent to the farm office computer.

SUMMARY

Soil moisture monitoring can help growers efficiently use and apply water and nutrients. All soil moisture instruments provide data that help a grower make good decisions about how much water to apply and when to apply it. The right soil moisture monitoring instrument for the farm is one that suits the management style of the grower. If it suits the grower, it will get used, and the data will inform the irrigation decisions.

See the Irrigation page at www.ontario.ca/omafra for additional information on soil moisture instruments and soil moisture monitoring service providers.

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