# Soil Moisture Monitoring

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## How can soil moisture monitoring help conserve groundwater?

Knowing when to water and how much to water a crop is an important first step in conserving groundwater. Monitoring soil moisture provides information useful for determining crop water needs and scheduling irrigation.

## What are the available options in soil moisture monitoring?

One way soil moisture can be determined is by weighing a soil sample when it is collected from the field, weighing again after the sample is dried, and then calculating the difference in weight to determine the moisture level. This direct measurement method, called the gravimetric method, is accurate, but it is also destructive to soil, tedious, and time-consuming.

Consequently, other indirect methods and technologies (Figure 1) have been developed to estimate soil water levels. These technologies vary in their methods for estimating soil moisture, and as a result, can range in their performance and can be impacted by different factors (Rudnick et al., 2017).

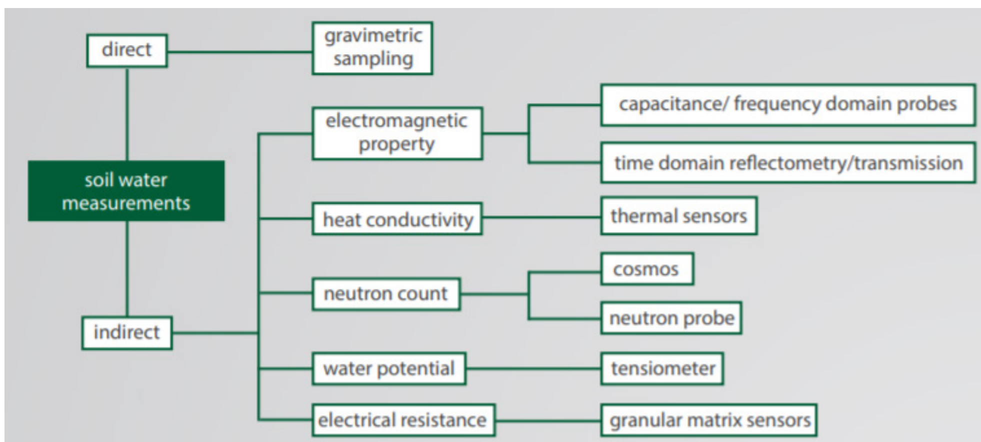


*Figure 1.* Soil water can be measured directly and indirectly (Aguilar, 2018).

## What are some recent improvements in soil moisture sensors?

Most soil moisture sensor technologies have been around for decades, but considerable improvements have occurred recently in data processing, data display, and user friendliness. These advances, combined with industry and university consultation, have increased the use of soil sensors for irrigation management decisions. However, in the most recent (2018) nationwide irrigation and water management survey, less than 25% of farms in a majority of U.S. states reported using soil moisture sensors for deciding when to irrigate (National Agricultural Statistics Service, 2019).

Another notable advancement in soil moisture monitoring is the development of sensors that spatially and remotely monitor soil water status, such as the cosmic ray probe (*Hydroinnova,* Albuquerque, New Mexico) and passive microwave reflectometry (*divirod*, Boulder, Colorado).

Advances in spatial water monitoring can help identify differences in crop water availability across the field, so that irrigation can be triggered based on field-level economic thresholds and/or the use of variable rate irrigation. Furthermore, spatial soil water status can help inform other agronomic practices, such as planting date and depth, hybrid/cultivar type, population density, and nutrient management (Rudnick et al., 2017).

> **"Having a soil probe in each of our irrigated circles has definitely saved us money. How we manage water on our farm using the probes and residue helps keep nutrients in the root zone, preventing money we've spent on them from leaching or washing away."**
> **Tim Franklin, Producer, Goodland, KS**

### What are some general tips in selecting a soil moisture sensor?

When selecting a soil moisture sensor for an intended use, it is important to understand how each sensor works in order to compare advantages and disadvantages among sensor options. In addition to sensor accuracy (Rudnick et al., 2016), the following factors should also be considered:

- convenience - easy to install and maintain
- financial costs
- remote access capability
- product support
- susceptibility to influencing factors
- number of sensors required
- sensor spacing, volume, and response time
- integration with other weather-based and plant-based moisture sensors and data

It may be advantageous to install sensors at multiple soil depths (Figure 2). Shallow soil depths may be dry, but water may be available at deeper depths where crop roots are actively growing. Tremendous insight can be provided by observing sensor responses over time at various depths, including: the extent and depth of root growth, infiltration depth of irrigation and precipitation, soil field capacity (water retained in a freely drained soil about two days after wetting), and possible evidence of over- or under-irrigation.

> **"There is no ideal soil water content sensor. They all have their advantages and disadvantages. The best sensor for your application is the one that gives you what you care about most. There are a lot of good sensors available, and if you understand what the sensor is really measuring, then it becomes easier to compare them and make the best choice for your application."**
> **Soil Sensor Manufacturer, Logan, UT**

Another consideration is understanding how a sensor and any accompanying technologies express soil moisture levels (centibars, percent volumetric water content, index values) and how these values should relate to irrigation schedules. Figure 2 (below) demonstrates one app display example that expresses moisture levels as soil water tension, which is a measure of the force necessary for plant roots to extract water from the soil. Higher soil water tension means soils are drier.

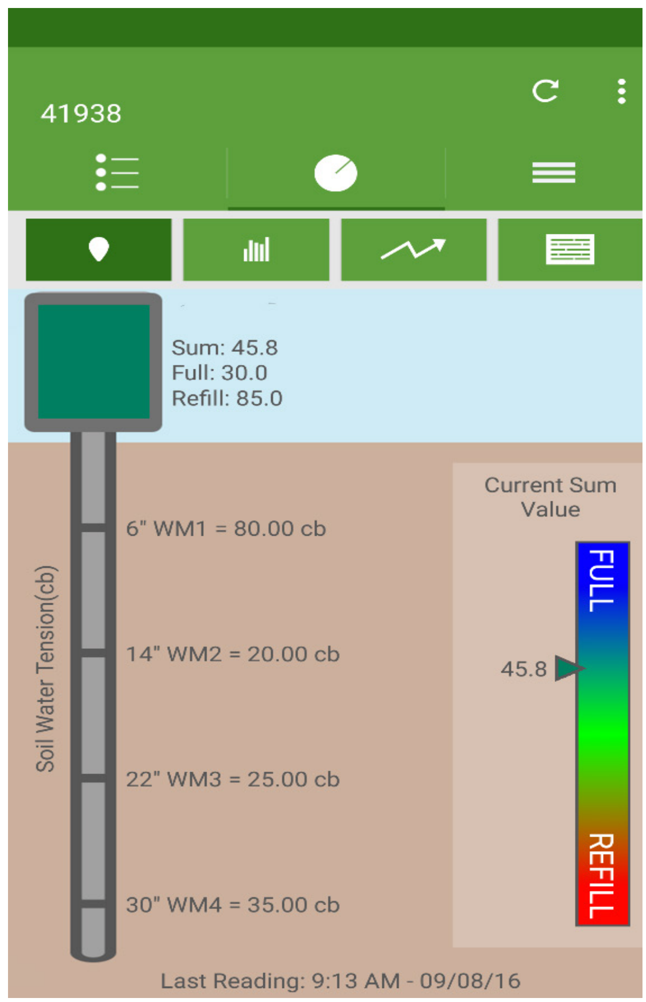


*Figure 2. Example of a mobile phone app display expressing soil moisture in two ways: (left) as soil water tension (centibars) at various soil depths and (right) with a color scale "Full-Refill" graphic (AgSense, 2020).*

## What are the general limitations of soil moisture sensors?

In general, the limitations of soil moisture monitoring for irrigation management include challenges in correctly selecting, installing, and maintaining sensors in order to provide an accurate and representative picture of soil moisture status across a producer's operation. Addressing these limitations involves determining:

- adequate number of sensors (or measurements)
- where to install sensors
- representative sensing volume
- adequate sensor response time
- reasonable soil moisture "full" and "refill" levels

Soil moisture sensor accuracy can be affected by several factors including temperature, salinity, and soil texture. In addition, although some sensors may report moisture levels to the nearest hundredth of an inch, producers should evaluate irrigation applications to the nearest tenth of an inch, reflective of the overall application accuracy irrigation systems can achieve due to variation across the entire system.

Users wanting precise volumetric water data are recommended to be cautious of sensors that by design (such as operating physical principles, electromagnetic frequency., etc.) are predisposed to high sensitivity to microscale differences in soils (Lo, et al., 2019).

## How can soil clay content impact soil moisture sensor accuracy?

Clay particles increase the specific surface area of a soil and can affect the calibration of electromagnetic soil water sensors, including reflectometers.

In a recent study, two soil moisture sensors - the Acclima TDR315 and the Campbell Scientific CS655 - were laboratory calibrated for five Nebraska soils with clay content ranging from 5 to 49%. Especially with the CS655, the accuracy of the manufacturer's calibration was found to worsen as clay content increased. A simple, user-friendly correction for clay content was successfully developed for these two sensors. This approach might also be applicable to similar sensors in clayey soils (Singh et al., 2019).

A 2019 study in the Southern High Plains also found that site-specific calibrations were useful in improving accuracy of a capacitance probe - the PR2/6 Profile Probe (Delta-T Devices) - in clay loam soils on perennial grasslands (Dhakal, et al., 2019).

Unfortunately, site-specific calibrations can be challenging and time consuming to perform, and it is recommended that users consult their local extension office and/or consultant for support. Nevertheless, users can monitor sensor readings and how they respond to wetting and drying events to identify important thresholds, such as field capacity or "full" after a heavy rain.

**Soil moisture monitoring is one of three available methods** to estimate crop water needs: 1) soil-based, 2) weather-based, and 3) plant-based (Figure 3).

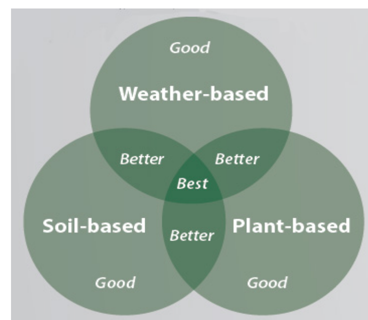


*Figure 3. Using more than one method of estimating crop water needs can provide greater confidence in estimating soil moisture* (Aguilar, 2018).

## How can soil-based information work together with other crop water estimation methods?

Irrigation scheduling tools that use water balance models based on weather information can work together with soil moisture sensors. While models can provide acceptable irrigation requirement estimates, their errors can accumulate through the growing season. Using occasional soil moisture measurements within the growing season to correct weather-based water balance models can be an effective approach to take advantage of both technologies (Andales, 2019).

> **"Soil water sensing should be integrated with other water management technologies for the best results. We should always try to avoid using a single technology to manage irrigation... Nothing can substitute going out into the field and seeing what is going on."**
>
> **Dr. Robert Schwartz, USDA-ARS Soil Scientist, Bushland, TX**

## Conclusion

Soil moisture monitoring is one widely recognized tool to help better determine crop water needs, estimate effective precipitation, and schedule irrigation. Although soil moisture monitoring should not be expected and solely relied upon to provide a high degree of precision and accuracy in all scenarios, moisture sensors can still prove to be a useful tool by combining feedback with other tools and observing crop response.

An understanding of both the possibilities and the general limitations of using soil moisture sensors is necessary to provide the maximum benefits in meeting crop production goals and conserving water.

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