# PRACTICAL USE OF SOIL MOISTURE SENSORS AND THEIR DATA FOR IRRIGATION SCHEDULING

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# Practical Use of Soil Moisture Sensors and Their Data for Irrigation Scheduling

Good management of irrigation water will increase crop yields, improve crop quality, conserve water, save energy, decrease fertilizer requirements, and reduce nonpoint source pollution. All of these are positive benefits and help contribute to profitable crop production. Using soil moisture measurements is one of the best and simplest ways to get feedback to help make improved water man-agement decisions. However, the system installation and calibration, plus interpretation of the data from soil water sensors is often confusing or overwhelming to most busy growers. This paper doesn't attempt to compare sensors but does provide *practical* recommendations for using these instruments and interpreting their measurements for more profitable crop production.

Those who understand the basics of soil water interactions and the major differences between soil water sensors can skip these first sections and go directly to the Placement of Sensors, and the Soil Water Content and Tension-Based Sensor sections.

## Soil Water Basics

Soil water fills about 25% of the space in the soil. This water is held in the pore space, or the cracks and empty spaces between soil particles. When all of the pore space is completely filled, the soil is said to be saturated. Excess water will drain out over time to a point where the soil will hold a certain amount of water indefinitely against the downward pull of gravity. This soil water content is called *field capacity*. As a plant's roots remove water from the soil, the soil will dry out to a point where the suction or pull of the soil on the water exceeds the plant's ability to absorb water. At this point, the plant will wilt and die. This soil water content is referred to as *permanent wilting point*. The difference between field capacity and permanent wilting point is the *available water holding capacity* (AWC) of the soil (Figure 1).

Different soils have different available water holding capac-ities (Table 1). Sands can't hold very much water compared to silts and clays. A plant's rooting depth is also an impor-tant consideration. A plant with deeper roots has access to a much larger volume of soil and, consequently, to a larger reservoir of soil water to draw upon before it runs out, compared to a shallow-rooted plant (such as onions or potatoes). Applying more water than a soil can hold simply results in deep percolation: water that is lost below the root zone of the plant, along with essential plant nutrients and other soluble compounds.

At first, as the soil water is depleted from field capacity (100%

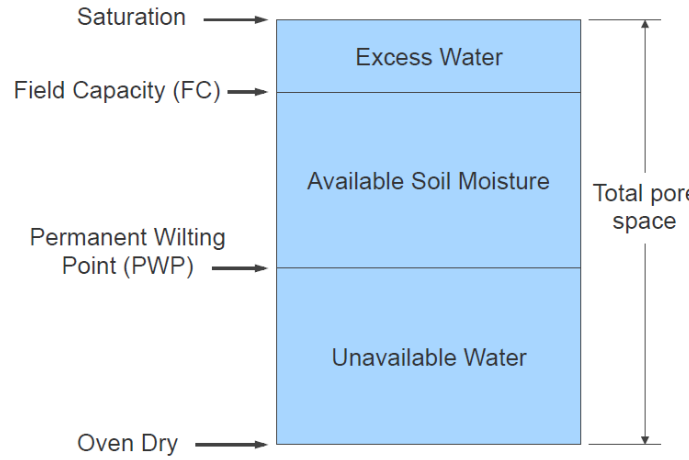


*Figure 1. The various levels of the soil water content.*

*Table 1. Ranges of available water by soil texture (PNW Irrigators Pocket Guide).*

| Soil Texture | Available Water Capacity (AWC) in/ft |
|---|---|
| Coarse Sand | 0.2–0.8 |
| Fine Sand | 0.7–1.0 |
| Loamy Sand | 0.8–1.3 |
| Sandy Loam | 1.1–1.6 |
| Fine Sandy Loam | 1.2–2.0 |
| Silt Loam | 1.8–2.5 |
| Silty Clay Loam | 1.6–1.9 |
| Silty Clay | 1.5–2.0 |
| Clay | 1.3–1.8 |
| Peat Mucks | 1.9–2.9 |

of available water) down towards permanent wilting point (0% of the available water) plant production is gener-ally not affected, but there is a point at which production drops off (Figure 2). This point is commonly chosen as a management allowable deficit (MAD). This point and the shape of this curve are different for different plants. Soil water depletion below this MAD point will result in signifi-cant yield losses.

## Soil Moisture Sensors

The major types of soil moisture sensors are listed in Table 2 and grouped according to the technology used to measure soil moisture. There are a variety of good publica-tions that describe the various sensors' comparative advan-tages and disadvantages and their installation procedures (Enciso et al., 2012; Shock et al., 2001; Paige and Keefer 2008; and Evett et al., 2003, 2007, and 2011). There is additional information on the installation and use of these sensors on the various manufacturers' websites.

Research continues to show that these sensors are often inaccurate, due mainly to the highly variable and complex nature of soils. However, the sensors all give trend lines that can be usable for irrigation scheduling.

Although the technologies used by each sensor type are quite different, these sensors can be roughly categorized into two groups: those that measure the soil water *content*, and those that measure the soil water *tension*. Soil water content is the actual amount of water in the soil and is most often measured as a percentage of water by volume (%) or in inches of water per foot of root zone soil depth (in/ft). Soil water tension is how hard a dry soil is pulling (sucking) on soil water and is measured using vacuum or pressure units such as pounds per square inch (psi), but is most often given in centibars (cbar).

# Placement of Sensors

## Field Location

Choose a location for each sensor that is accessible, yet away from the edge of the field. Of course, dead or dam-aged plants don't use as much water as healthy plants, so since your sensors represent the entire field, try not to damage the plants at the sensor location. In fields with variable soils, the areas with the lowest water holding capacities (typically sandy or shallow soils) will run out of water first. Therefore, to maximize production in the entire field, it is best to manage the irrigation of the whole field so that these areas don't experience water stress and the rest of the field should be fine. This often means irrigating more frequently, but in smaller amounts. If you use the same type of sensor and same area of the field year after year, then you can learn from your past years' experience without worrying that data differences are related to differ-ent soils or sensors.

## Depths

The goal with choosing a depth for each sensor is to repre-sent the soil where the majority of the plant's active roots are. Most of the active plant roots are nearer the surface where there is also evaporation water loss. Therefore, the soil nearest the surface will experience the most wetting and drying cycles. Sensors located in this area will help indicate *when* to irrigate. Deeper sensors will indicate the degree of soil water depletion and/or the depth of irriga-tion water penetration, or help give you feedback on *how much* to irrigate.

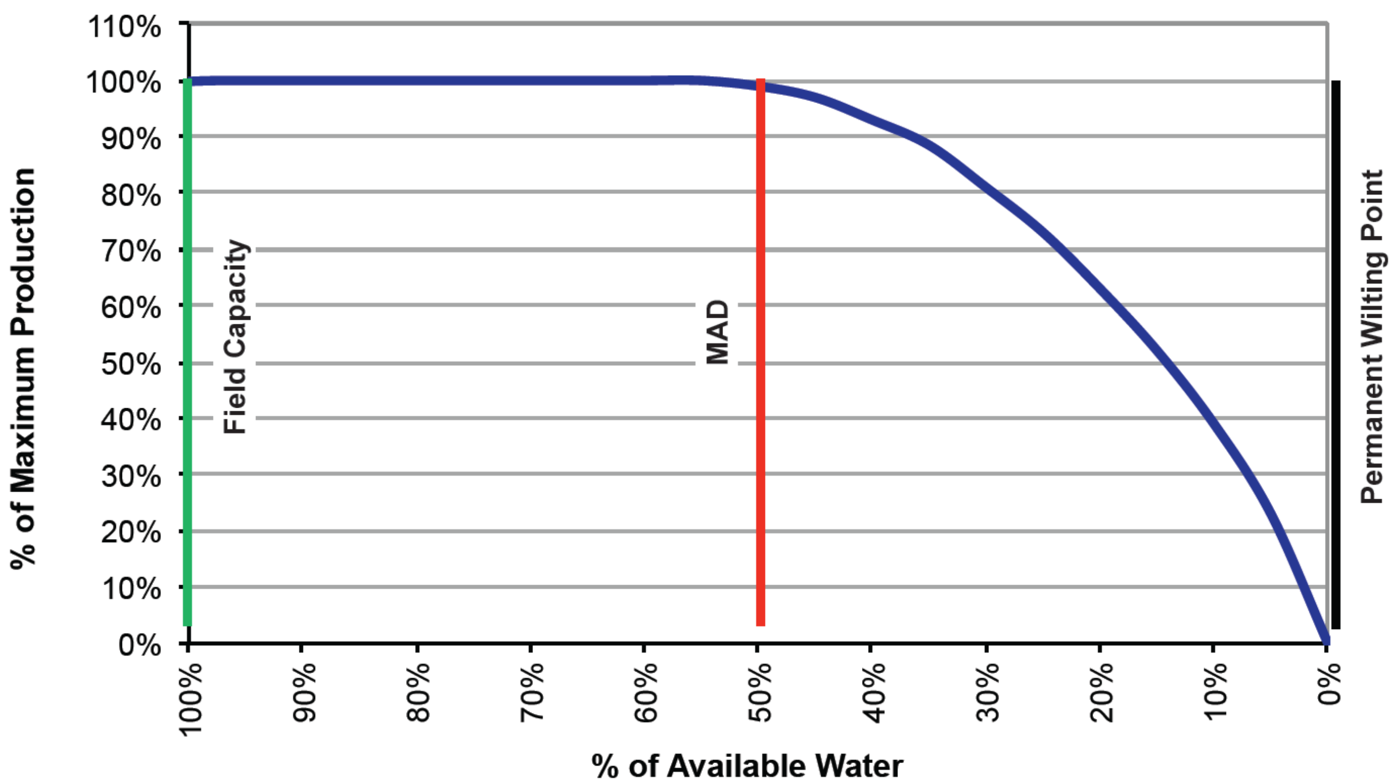


*Figure 2. A generalized curve shape showing how plant production (growth) is affected by soil water stress.*

*Table 2. Major types of soil moisture sensors and their relative advantages and disadvantages.*

| | Sensor Type | Advantages | Disadvantages |
|---|---|---|---|
| *Soil Water Content* | **Neutron Probe** (Campbell Pacific Nuclear; CPN) | Accurate. Repeatable. Samples a relatively large area. One sensor for all sites and depths. | Government-required paperwork and regulations. Can't leave in field due to radiation issues. Relatively expensive (about $4,500). |
| | **Time Domain Transmissivity** (Acclima, Gro-Point) | Less expensive ($110/sensor). Easy to log data. | Samples small area. |
| | **Capacitance Sensors** (Enviroscan, Echo Probes, Acclima, Vernier, etc.) | Easy to set up to log and/or transmit data. Low maintenance. | Highly affected by soil conditions immediately next to the sensor. High variability. More expensive ($300–$1,200/system). |
| *Soil Water Tension* | **Tensiometers** | Less expensive ($80/sensor). | Maintenance issues. Need to protect from freezing. Work best on coarse textured soils. |
| | **Granular Matrix Sensors** (Watermark) | Inexpensive ($40/sensor). Easy to log data electronically. | Highly variable output. Less accurate. Sensitive to temperature and soil salinity. |

When using only one sensor per site, place the sensor in the middle of the root zone or at ½ of the root depth. Two sensors per site should be placed at about 1/4 and 3/4, or 1/3 and 2/3, of the root zone. With three sensors, the shallowest sensor should be placed about 4 – 6 inches deep, then the next one at 1/2 – 2/3 of the root zone depth, and the last one towards the bottom of the root zone.

## *Number of Sensor Sites*

Adding additional measurement sites in the various parts of a field can help the grower understand what is hap-pening in the various parts of a field. Also, additional sensors can help average out some of the field and sensor variability to give a more representative average. In gen-eral, the greater the variability, the more monitoring sites are required to find a representative average. However, a single site located in the correct spot (see above) can help improve irrigation management immensely.

# Soil Water Content-Based Sensors: (Capacitance, Neutron Probe, Gravimetric)

Sensors that read the soil water content are more useful for irrigation management than those that just give soil water tension. This is because they can indicate both *when* and *how much* water to apply, while a soil tension sensor can only indicate *when* to irrigate.

Remember that the soil water content measurement must be multiplied by the depth of soil in the root zone that the measurement represents (whether in inches or feet), to give the total amount of water in that soil depth. For example, if you have one sensor that represents the soil in a 2-foot-deep root zone and it reads 3.5 inches/foot then the total water is 3.5 x 2 = 7 inches of water in that 2-foot depth of soil. If, in the same example, the measurement is given in % by volume, 31% in this case, then the reading would be 0.31 x 24 = 7.4 inches of water (2 ft = 24 inches of root depth).

Soil water content measurements are much more meaning-ful for irrigation scheduling when they are compared to field capacity. This is because the difference between the current soil water content and the soil's field capacity is the soil water deficit—the maximum amount of water that can be applied without wasting water to deep percolation past the bottom of the root zone. This difference is how much water should be applied at the next irrigation event.

The easiest way to get an estimate of your soil's field capac-ity is to simply use the sensor to take a measurement at a time when you are confident that the soil is at field capac-ity, or full of water, yet the excess water (Figure 1) has had time to drain through. Possible good times to take these measurements are early in the spring as soon as soil thaws (assuming adequate soil moisture recharge over the win-ter), or 12 to 24 hours after a heavy irrigation. For heavier soils, you may need to wait longer for the free water to drain through to lower soil layers.

Using your sensor to measure field capacity helps compen-sate for the need to calibrate most sensors to that particular soil since the absolute value of field capacity is less impor-tant than the sensor's repeatability, or ability to give the same number at that soil water content in the future. It also helps avoid the costly and labor-intensive laboratory methods of determining field capacity for that soil.

It is helpful to have an estimate of the soil water content at which the plants will begin to experience water stress so that this point can be anticipated and avoided. This can be estimated from the previously *measured* field capacity, the soil's available water capacity (AWC), and the recommend-ed management allowable depletion (MAD) from table val-ues. A range of AWCs by soil texture were given in Table 1 (see http://websoilsurvey.nrcs.usda.gov for a more accurate estimate for your area), while rooting depths and suggested MAD points for various crops are given in Table 3. Multiply the soil's AWC number by the crop rooting depth to get the total amount (inches) of water that is held in the soil between field capacity and wilting point.

***Table 3. Suggested management allowable deficit (MAD) points and typical rooting depths for various crops. Actual values may differ due to restrictive soil layers or other site differences.***

| Crop | MAD (%) | Rooting Depth (ft) |
|---|---|---|
| Alfalfa | 55 | 4 |
| Asparagus | 50 | 4 |
| Beans | 40 | 2.5 |
| Blueberries | 50 | 3 |
| Carrots | 50 | 2 |
| Corn | 50 | 3 |
| Grapes | 50 | 3.5 |
| Green Beans | 50 | 2 |
| Hops | 50 | 4 |
| Mint | 35 | 2 |
| Onions | 40 | 1.5 |
| Pasture/Clover | 50 | 2.5 |
| Peas | 50 | 1.5 |
| Potatoes | 30 | 1.5 |
| Raspberries | 50 | 3 |
| Safflower | 50 | 4 |
| Spring Grains | 50 | 3 |
| Strawberries | 50 | 1 |
| Sugar Beets | 50 | 3 |
| Sweet Corn | 40 | 3 |
| Tree Fruit | 50 | 3.5 |

## Example 1: Set-Up

I am growing tree fruit in a fairly uniform and deep silt loam soil. I noted from Table 3 that tree fruit has a 4-foot root depth and I buried two capacitance probes that mea-sure soil water content at ¼ and ¾ of the root zone depth, or at 1 ft and 3 ft deep. I used these probes to take a soil water content measurement early in the spring, one day after a heavy rain when I was confident the soil was at field capacity, and got 32% at the 1-foot probe, and 29% at the 3-foot probe. The field capacity of the soil is determined by multiplying the measurement by the depth of soil that each sensor represents:

(probe measurement) × (depth of soil measured) = 0.32 x 24 inches = 7.7 inches of water in the top two feet, and

(probe measurement) × (depth of soil measured) = 0.29 x 24 inches = 7.0 inches of water in the bot-tom two feet, for a total of 7.7 + 7.0 = **14.7 inches** of water that can be held at field capacity in the 4-foot root zone (Figure 3).

From Table 1, I estimate that the available water holding capacity (AWC) of my silt loam soil is 2.1 inches per foot. Therefore in the 4-foot-deep root zone, the soil can hold

(AWC × soil depth) = 2.1 in/ft x 4 ft = 8.4 inches of water.

Therefore, the soil's wilting point should be close to (field capacity – [AWC × soil depth]) = 14.7 – 8.4 = **6.3 inches** of water (Figure 3).

For tree fruit the MAD is 50% (per Table 3). There-fore I would only allow 50% depletion of the 8.4 inches of available water, or (50% × available water) = 0.5 x 8.4 in = 4.2 inches, before irrigating.

The water stress point would be at

(field capacity – MAD volume) = 14.7 – 4.2 = **10.5 inches** of total water (Figure 3).

I now have my boundary lines! I want to keep the soil water content between the field capacity line and the MAD line (sometimes referred to as the refill point). Now my periodic soil moisture readings give me very useful infor-mation.

## Example 2: Mid-season

Later in the season if I take readings and get 19% in the top sensor and 29% in the bottom sensor:

0.19 x 24 inches = 4.6 inches of water in the top two feet, and

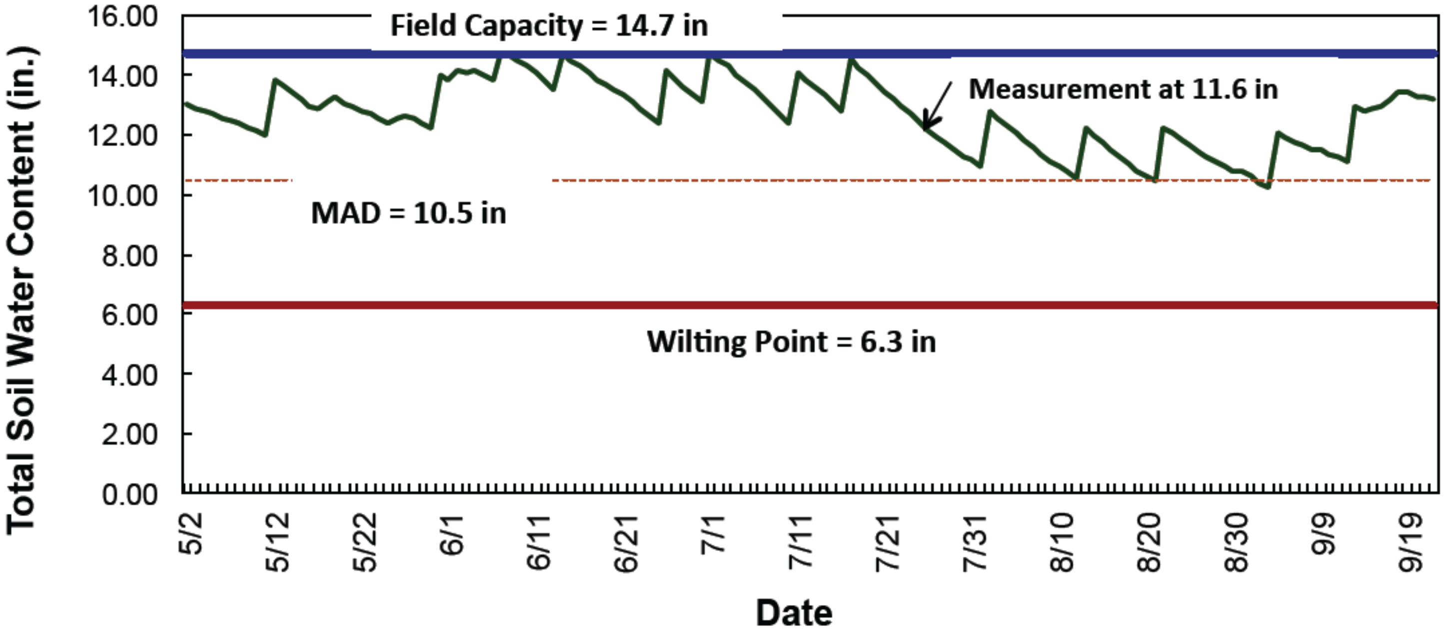


*Figure 3. Soil water contents over time from the above examples (1 and 2).*

0.26 x 24 inches = 7.0 inches of water in the bot-tom two feet shows a total of

4.6 + 7.0 = **11.6 inches** of water in the root zone.

Then I know that the soil water deficit is the differ-ence between field capacity and my measurement:

(field capacity – measured water content) = 14.7 – 11.6 =**3.1 inches** of water.

Thus, 3.1 inches is the maximum amount of water that I can apply before losing some water (and nutrients) to deep percolation. I also know that there is 11.6 – 10.5 = 1.1 inches of water that can be further depleted in the soil before I reach MAD and water stress begins to cause lost production in my fruit trees.

Plant and soil observations should also be used as feedback to refine these estimates over time. For instance, if in the above examples I saw the first signs of tree water stress at a measured 11.0 inches of water in the root zone instead of my estimated MAD at 10.5 inches, I would re-draw the MAD line at 11 inches and be sure to irrigate before that point in the future.

Using this method, the absolute accuracy of the sensor is less important because the sensor is just compared to itself. Also, the soil moisture measurements throughout the season now take on meaning because we can determine the soil water deficit (field capacity minus the current reading) and the amount of water that can be depleted before water stress occurs. Good irrigation managers will maintain the water content well between field capacity and this stress point.

## Tension-based soil moisture sensors: (GMS, Tensiometers)

When using tension-based soil moisture sensors, a soil's field capacity, wilting point, and maximum depletion point are less relevant because it is difficult for the lay person to compare these to the soil water tension measurement. A soil that is full of water will have a measured soil water tension near zero. As a starting point, fruit trees and vines should be irrigated before they reach 40–50 centibars. For regulated deficit irrigation (such as for wine grapes), this could be increased to 80 centibars.

Since these measurements can be inaccurate and soil-spe-cific, refine your limits using crop observations over time. For example, note the measured soil water tension at the earliest indications of water stress (this will appear first in sandier or shallow soil areas) and be sure to irrigate before you reach that water stress point again in the future. Also take some readings right after an irrigation event. If the sensor near the bottom of the root zone goes to zero, then it's possible you put too much water on and lost water and nutrients to deep percolation. If the bottom sensor shows no movement at all, apply a little more water next time to push water a bit deeper. Use this type of trial-and-error method to make the soil water tension measurements more meaningful over time.

## Additional Recommendations for All Soil Moisture Sensors

- Avoid creating an easy flow path for water down to the sensor during the installation process.
- Flag the sensor in the field so that it can be easily found each time.
- Graphical representation of the data helps greatly with data interpretation, so graph your results.
- Use soil water measurements with irrigation sched-uling tools such as Irrigation Scheduler Mobile (weather.wsu.edu/is/) for much better water man-agement.
- Keep measurement records and record your obser-vations. Correlate readings with observations. Compare these to past years.
- Stay away from both the field capacity point (potential over-irrigation and water and nutri-ent loss to deep percolation), and the water stress (MAD) points, if possible.
- Realize that soil and sensors have a lot of vari-ability. You are only measuring at one point in the field, so look around as you monitor to see what else may need to be adjusted.
- Be patient and stick with it. It may take a year or two before you are good at interpreting your sensor readings.

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