IRRIGATION INFORMATION

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How to use Watermark ™ Soil Moisture Sensors for Irrigation

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This is the second of a series of three factsheets on Watermark™ Soil Moisture Sensors. The first factsheets details "How to Make a Watermark™ Sensor." This factsheet discusses how to use Watermark Soil Moisture Sensors, and the last factsheet provides additional detail about "Predicting the Last Irrigation of the Season using Watermark™ Soil Moisture Sensors."

Soil moisture sensing is an invaluable tool for understanding agronomic practices and improving irrigation water management. Soil moisture sensors provide a measure of plant available water. Sensor trends can also provide information about irrigation efficiency problems, infiltration, deep percolation, and water stress.

A cost effective and popular sensor used for irrigation is the granular matrix potential sensor or Watermark™ sensors (200SS). Tensiometers also measure the soil matric potential, however they measure it directly using a ceramic tip, gage and fluid. Watermarks are easy to use and deploy. They are comprised of two electrodes, a ceramic disk, granular material, fabric and a stainless steel mesh fashioned to form a 7/8 inch diameter cylinder and tip. They can be attached to polyvinyl chloride (PVC) tubing and placed in the soil at various depths. As water enters the granular matrix, the resistance of the electrodes changes; this change in electrical resistance is proportional to the change in the matric potential or soil tension. It is important to understand that the value reported by a granular matric potential sensor is based on electrical resistance not on a direct measure like a tensiometer. However, their simplicity, range and the maintenance free operation make them a very popular sensor for use in agricultural irrigation.

These sensors are installed in the plant row between plants. When installed the sensor equilibrates to the surrounding moisture content generally within a day. The sensor measures the electrical resistance of the ceramic material and is converted to matric potential. The range of a

Watermark™ sensor is from 0-239 kPa or centibars.

The sensors report soil water as matric potential or vacuum which is a measure of the energy that the plant exerts to draw available water from the soil, referred to as the "soil water potential." Soil matric potential is measured in pressure usually either centimeters of water, bars, or kilopascals, although several other units can also be used. Soil matric potential measurements are inherently a negative value of pressure, however it is common and appropriate to use the inverse positive term of "tension." When soil is saturated, the soil pores are full and the tension is near zero. As gravity pulls the gravitational water from the soil matrix, air is replaced creating a small amount of tension, this threshold is field capacity, typically around 15-35 centibars (1/3 bar) dependent on soil type. As plants extract water beyond field capacity, they do so until the wilting point or 1500 centibars (15 bars).

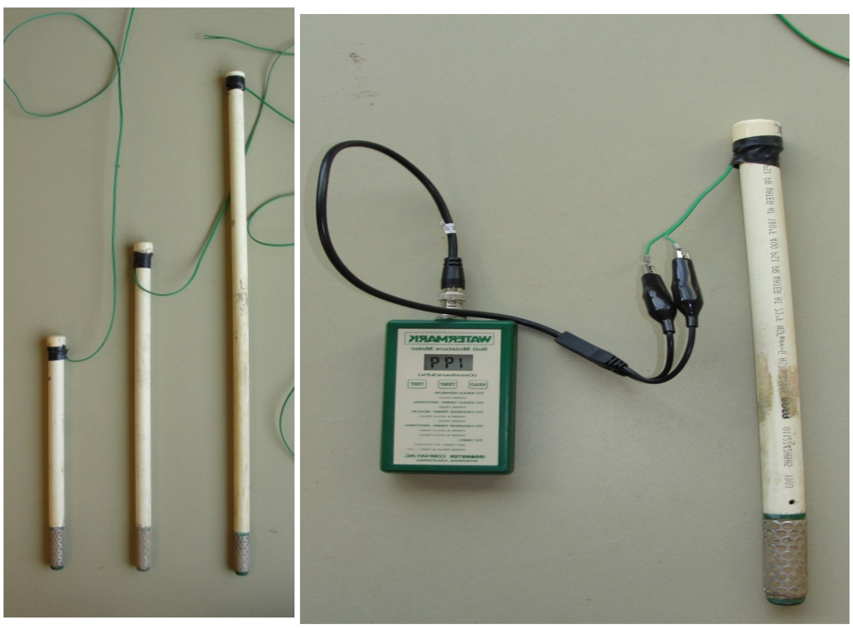

Figure 1. Manual reader and Watermark™ sensors installed on CPVC pipe for installation and different depths.

Soil water content of soils varies by texture, soil organic matter and compaction. Therefore, field capacity and the soils ability to hold water vary and must be determined for each installation. In general, clayey soils contain smaller pores and have a greater ability to retain moisture in the matrix because it takes more energy to extract the water from the matrix. In sandy soils, the pore spaces are large and since water is easily extracted from large pores, less water is available once the pores have been emptied.

Watermark sensors are best used by gluing them to PVC or CPVC pipe at several depths to represent the rooting zone of the crop. The use of the rubber washer help seal the sensor to the soil has been found to improve potential problems from installation. Press the washer down tightly and place soil on top of the washer to provide a good seal. The seal prevents water from migrating down to the sensor between the soil and PVC interface. An overly conservative threshold is 60 centibar average in the profile for silt loams and clays and 20-35 cb for sandy soils. Experience has shown that 80-100 centibars is also safe in silt loam and clay soils. These are guidelines for most row crops except furrow irrigated rice. For furrow irrigated rice, the effective rooting depth is much less than row crops (near 20 inches), and recommendations are still being developed, but maintaining the 4" and 8" sensor at less than 40 cb has worked well in on-farm demonstrations. Additional recommendations on furrow irrigated rice is available in the factsheet "Furrow Irrigated Rice." However, use of the mobile app or the tables below should be used to calculate available water rather than timing irrigation from a threshold. More information about using sensors to schedule irrigation is available at www.uaex.edu/irrigation. For information about how to construct and install sensors see the factsheet on "How to Make a Watermark™ Sensor."

The use of 6, 12, 18 and 30 inch deep sensors is recommended for soybeans, peanuts, corn and cotton. For furrow irrigated rice, 4, 8, 12 and 18 inches is recommended. The 6, 12, 18 and 30 inch spacing has proved to be a very reliable and representative spacing for Arkansas silt loam soils. The 6 and 12 inch represent the top foot, where most of the water movement takes place. Using two sensors for the top foot of the profile provides redundancy, good resolution, and minimizes sensor to sensor variation. Also many times the 12 inch sensor is near a tillage pan, which can create some erroneous readings. The 18 inch sensor represents the second foot of the profile and the 30 inch sensor represents the third foot. Sensor installation at 36 inches is also acceptable, but at this depth sensor extraction in some soils can be challenging. This arrangement also allows for good representation of the profile should one sensor fail or readings are questionable. The soil moisture profile can still be estimated with the other three. Another configuration is 6, 12, and 24 inches, representing the profile down to 30 inches. This can also work well, but loss of one sensor, especially the 24 inch makes it difficult to rely on the sensors to schedule irrigation. Scheduling irrigation with only two sensors is not recommended.

Interpretation of the 30 inch sensor should be done with caution. In most situations this water is available but severe compaction has been observed to limit water movement. Less often this subsoil is replenished, so irrigators should use this available water before the end of the season. However, early subsoil moisture depletion before the reproductive stages indicates inadequate irrigation. If available subsoil water remains unchanged it generally indicates either a pan, a fragipan, or excessive irrigation. Users should monitor trends to observe water use patterns during the year and use their observations to establish acceptable thresholds for their particular situations. As long as sensors are showing movement, plants are extracting water. When this movement stops, plants are not extracting water, this is likely due to excessive or deficit soil moisture conditions. When above field capacity, air is pushed out of the soil matrix, roots are starved for oxygen and cannot extract soil water. This can often be seen when rain follows an irrigation. It may take several days for enough air to re-enter and for transpiration to resume. Sensor responses will flat-line in these situations indicating plants are experiencing (too much) water stress.
The rate of change of a tension is non-linear. Near field capacity, tension is low near 33 cb, and

plants can extract water easily and water is plentiful. Tension may only change a few centibars in a day when at peak water demand. As soil tension increases above 90 cb in silt loam and clay soils tension may change 5-10 cb in a day when experiencing peak water demand. Sensor trends may have a steep slope and then gradually flatten out indicating that extraction is decreasing and the plants are accumulating stress units. When this occurs it is the maximum allowable depletion for that soil type and situation.

Another trend that is commonly observed in sealing soils, is that as irrigation is applied, the sensor responses do not change much or level out after an irrigation. While sometimes sensors responses will go to zero centibars, soils that seal restrict water entry and the sensor responses will decrease or level out rather than show saturated conditions. This is normal and indicates infiltration issues. Soil management practices such as winter cover crops, deep tillage, reduced tillage, no-till, gypsum may help improve water infiltration in soils.

In addition to soil matric potential sensors, there are many other types of sensors. The most common are dielectric, total domain reflectometry and capacitance (frequency domain) probes. Generally these are used in conjunction with a telemetry system of some sort so the cost is much higher than Watermark™ sensors. These sensors typically report volumetric water content. The sensors generally use the dielectric properties of soil and water to correlate sensor signals to water content. Capacitance sensors report relative values and calibration of the resulting values, while they may be called volumetric water content, are not absolute. Thus capacitance sensors require calibration at every location and soil type to actual response of the crop and water content. Therefore, irrigators should use the trends to determine field capacity and stress levels and manage between the reported values for the sensor. Shallowing of the trend in water content in a layer, is an indication of water stress by the crop. Saturation can often be seen after a significant rainfall, where the upper soil layer is brought to a high water content and then equilibrates to field capacity after gravity draws the free water from the matrix. This usually occurs within a few hours to a day. Once stabilized, this should represent field capacity for the sensor. When stress is observed in a soil layer by shallowing of the moisture content change, this indicates the lower threshold for all of the sensors. Thus once these points are observed and recorded, the irrigator can maintain an average soil water content within this zone. This is applicable to all types of sensors including Watermarks™.

Mobile Application

A mobile app is currently available on the Apple App store. It is strongly recommended to use the mobile app with Arkansas crops, soil types and Watermark™ sensors. Search for the "Arkansas Soil Sensor Calculator" on the Apple App Store. Use of the app simplifies the calculations and water retention curve information provided in this factsheet and simplifies irrigation decision making. An Android version of this app is not available.

Effective Rooting Depth

To effectively use Watermark™ sensors, one must know what the effective rooting zone. Sheffield and Weindorf, 2008 report effective rooting depths for crops in Louisiana. Irmak and Rudnick (2014) report effective rooting depth for crops in Nebraska. One main challenge when moving from a calendar scheduling method (or a very frequent, shallow application depth schedule) to a sensor based scheduling method is that when ample water in the upper root zone, to plants during the vegetative stage, they may not develop a deep rooting system. This may depend on soil, environmental conditions and crop varieties. It is also important to keep in mind that the most effective roots at extracting water and nutrients from the soil are very small and fine and difficult to visually see. Simply pulling up a plant from the soil may only reveal the very large root masses. Use Table 1 and visual observations of the sensor changes to gage the effective root zone to use for scheduling irrigation. Heavy rains early in the season, compaction and tillage pans, and fragipans can limit rooting depth, so using sensors can be used to judge the effective root zone where water is being depleted.

Table 1. Effective Rooting Depths

Crop	Effective Rooting Depth[1] (inches)	Effective Rooting Depth[2] (inches)
Corn	40	36-48
Cotton	55	
Soybeans	40	24-36
Rice	20	
Sorghum	40	36-48
Bermuda Grass	6-18	

[1] *Sheffield, R.E., and D.C. Weindorf, 2008. Irrigation scheduling made easy using the 'look and feel' method. LSU AgCenter Ext. Pub., Baton Rouge, LA.*

[2] *Irmak, S., and D.R. Rudnick, 2014. Corn soil-water extraction and effective rooting depth in a silt-loam soil. Univ. Nebraska Ext. Pub. G2245, 4 pp.*

It is recommended to interpret sensor reading at 18-24 inches or 1.5-2 feet early in the season for corn, cotton and soybeans when the plants are small and in the vegetative stages, unless a pan or other restrictive layer shows the subsoil is not being depleted. Often it is not until the reproductive stage that the 2-3 ft sensor depths show depletion.

Allowable Depletion or Managed Allowable Depletion (MAD)

There are three critical points in the soil water balance, Saturation, Field Capacity and the Permanent Wilting Point. Field capacity is defined as the point at which all of the water the soil can hold after gravity takes effect (gravitational water is removed). When soil is saturated, water is taking the place where air occupies part of the soil matrix when at field capacity. This occurs at near 33 centibars in silt loams and clays, but is soil texture specific. When the soil matric potential reaches 1500 centibars, plants wilt permanently and death occurs. The difference between field capacity and wilting point is called total plant available water.

Allowable Depletion or Managed Allowable Depletion is the percent or point in the plant available water that is available to plants before potential yield limiting stress occurs. It is a percent of the total plant available water the soil can hold. At least half of the total plant available water is held as a reserve.   The other half or less, referred to as the allowable depletion, is used to store and use water for plants. Once 50% of the total plant available water is used by plants, stress may begin to accumulate because it takes more effort for the plants to extract water from the soil. For center pivots where planned application rates are near an inch of water, a more conservative allowable depletion is used, such as 30-35% is recommended. This provides a buffer or additional margin of safety should an unexpected delay occur. Also there is less water applied and so the soil only needs to be depleted just enough to store the irrigation event and any potential rainfall. For furrow irrigation system, a higher allowable depletion should be used. In furrow irrigation application depths should be between 2-3 ac-inches/ac. Thus more soil storage is needed to store this amount of water and smaller irrigation applications are not possible. Thus for furrow irrigation system an allowable depletion of 40-50% is recommended.   For the last irrigation of the season a 50% allowable depletion should be used. Allowable depletion can range between 30 and 50%, use an allowable depletion that provides enough margin of safety for the irrigation system but also allows enough room to store an irrigation and any potential rainfall. For example, a furrow irrigation system that has limited capacity should use a lower allowable depletion. A center pivot irrigator could use a 40% allowable depletion is there is a strong chance of rain in the near future or has a machine with a short turn time.

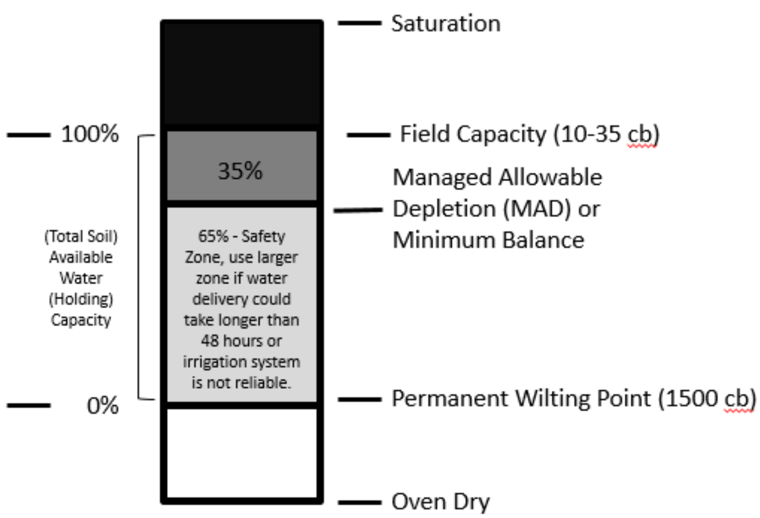

Figure 2. Total Plant Available Water and the relationship between Saturation, Field Capacity, Permanent Wilting Point, and Allowable Depletion. Shown is a 35% Allowable Depletion.

Determining Plant Available Water

There is a known relationship between the soil water content and soil matric potential. It is different for every soil type and varies by region. Relationships have been developed and generalized for many of the soil types in Arkansas. Use Tables 1 and 2 to convert Watermark™ reading for the effective root zone and allowable depletion desired for the conditions present. First average the Watermark™ readings for the effective root zone. Second, determine the plant available water for the soil type and average sensor reading. Take this value times the effective rooting depth in feet. The result is the plant available water in inches in the profile. For example, for a corn crop on a silt loam soil with a pan, where the 6, 12, and 18 inch sensor read 10, 25, and 55 centibars. Take the average (10+25+55 / 3 = 30 cb) of the readings. Using Table 2, read 30 cb for the silt loam soil with a pan, to find 0.72 in/ft. Multiply 0.72 in/ft times the effective rooting depth for corn of 2 feet (0.72 x 2.0 ft = 1.44 inches). This is the amount of plant available water in the profile for an allowable depletion of 45%. Table 3 shows the available water for a 35% allowable depletion. Table 4 shows the plant available water for an allowable depletion of 50%. Plants exposed to an average tension in the effective rooting zone at higher levels than 50% allowable depletions are expected begin to accumulate stress. While some sensors will exceed these levels, the average soil tension for the effective root zone should not reach these levels. Visual observation should be used with sensor readings to confirm that the readings align with plant progress. Soil moisture within a field can be variable and placement of the soil sensors cannot always be assumed to be representative of the field they are being used to monitor. Confirm readings by sampling the soil profile (using a slide hammer) and the feel method when in doubt.

Table 2. Plant Available Water for in (in/ft) for Soil Types versus Watermark™ Readings in centibars at a **45% MAD (furrow).**

Tension (cb)	Sand (1.0 in/ft)	Sandy Loam (1.4 in/ft)	Silt Loam with Pan (1.58 in.ft)	Silt Loam (2.37 in/ft)	Clay (1.6 in.ft)
0	1.72	1.44	1.03	1.71	1.30
5	1.67	1.44	1.03	1.71	1.28
10	0.69	0.93	0.93	1.53	1.01
15	0.30	0.67	0.93	1.41	0.83
20	0.09	0.51	0.93	1.29	0.70
25		0.39	0.80	1.17	0.60
30		0.30	0.72	1.07	0.52
35		0.22	0.73	1.02	0.45
40		0.16	0.64	0.88	0.39
45		0.11	0.56	0.77	0.34
50		0.07	0.49	0.68	0.29
55		0.03	0.42	0.59	0.25
60			0.37	0.51	0.22
70			0.27	0.38	0.15
80			0.18	0.27	0.10
90			0.13	0.17	0.05
100			0.05	0.10	0.01

Table 3. Plant Available Water for in (in/ft) for Soil Types versus Watermark™ Readings in centibars at a **35% MAD (pivots).**

Tension (cb)	Sand (1.0 in/ft)	Sandy Loam (1.4 in/ft)	Silt Loam with Pan (1.58 in.ft)	Silt Loam (2.37 in/ft)	Clay (1.6 in.ft)
0	1.62	1.30	0.87	1.47	1.14
5	1.57	1.30	0.87	1.47	1.12
10	0.59	0.79	0.77	1.29	0.85
15	0.20	0.53	0.77	1.17	0.67
20		0.37	0.77	1.05	0.54
25		0.25	0.64	0.93	0.44
30		0.16	0.56	0.84	0.36
35		0.08	0.57	0.79	0.29
40		0.02	0.49	0.64	0.23
45			0.40	0.54	0.18
50			0.33	0.44	0.13
55			0.26	0.36	0.09
60			0.21	0.27	0.06
70			0.11	0.14	
80			0.02	0.03	

Table 4. Soil Tension where no readily Plant Available Water Remains (50% allowable depletion)

	Sand (1.0 in/ft)	Sandy Loam (1.4 in/ft)	Silt Loam with Pan (1.58 in.ft)	Silt Loam (2.37 in/ft)	Clay (1.6 in.ft)
Stress level (centibars)	25	70	123	134	120

Determining the Next Irrigation

The water use by crop growth stage for corn and soybeans is shown in Tables 5 and 6. Once the amount of water in the profile has been determined, use these Tables to determine crop water use. Divide the available water in the soil by the daily crop water use to determine when the plants will consume the available water. Next subtract the time for the irrigation set. If rainfall occurs after readings were taken, add effective rainfall to the plant available water. Effective rainfall is the depth of rainfall that infiltrated into the field. The depth of effective rainfall is highly variable and is a function of the depth and intensity. Generally, it is assumed that small storm events of less than half an inch are completely retained. The more intense the precipitation event the more runoff occurs and less of the rainfall is captured by the soil.

$$Days\ to\ initate\ irrigation = \frac{Plant\ Available\ Water\ (in) + effective\ rain\ (in)}{Daily\ crop\ water\ use\ (\frac{in}{dy})} - Irrigation\ set\ time(dy)$$

For example, given no rainfall, if the plant available soil water is 2.14 inches and crop water use is 0.25 inches per day, irrigation will need to be completed by (2.14 inches / 0.25 inches per day = 8.5 days). If 48 hours is required to complete the irrigation then irrigation needs to be initiated in 6.5 days.

See the factsheet "Predicting the Last Irrigation of the Season using Watermark™ Soil Moisture Sensors" to determine the last irrigation.

Table 5. Daily Corn Water Use by Growth Stage

Growth Stage	Crop Water Use (inches per day)
V12-V16	0.20
VT	0.21
R1 Silking	0.25
R3 Milking – R4 Dent	0.33
R5 Full Dent	0.25

Source: http://extension.missouri.edu/scott/documents/Ag/Irrigation/Corn-Irrigation-and-Water-Use.pdf

Table 6. Daily Soybean Water Use by Growth Stage

Growth Stage		Crop Water Use (inches per day)
Late Vn	Late Vegetative stages	0.20
R1 to R3	Flowering to beginning pod	0.20
R4 to R6	Pod development to pod fill	0.25-0.35

Source: http://extension.missouri.edu/scott/documents/Ag/Irrigation/Soybean-Irrigation-and-Water-Use.pdf