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Timing the Final Irrigation Using Watermark™ Sensors

Chris Henry Ph.D.,
Associate Professor
and Water Management
Engineer - Rice Research
and Extension Center

P.B. Francis Ph.D.,
Professor
University of Arkansas
at Monticello

L. Espinoza Ph.D.,
Soil Scientist
Crop, Soil and
Environmental Science

M. Ismanov Ph.D.,
Program Technician -
Soils, Crop, Soil and
Environmental Science

This is the last in a series of three fact sheets on Watermark Soil Moisture Sensors. The first fact sheet provides details on "*How to Prepare, Test and Install Watermark Sensors*." The second fact sheet discusses "*How to Use Watermark Soil Moisture Sensors*." This fact sheet provides a guide to using information from soil moisture monitoring to aid in irrigation termination decisions in corn and soybean production.

Timing the final irrigation of the season can be a challenging decision for crop managers. The last irrigation should provide the water necessary to optimize yield. It should IMPROVE profitability. At times, rainfall can provide the last remaining water to carry the crop to maturity. Irrigation is unnecessary. Extending irrigation beyond what the crop requires is inefficient. It also is costly because late season pumping typically is the most expensive due to increasing depth to groundwater after a long pumping season. Prolonged irrigation also can delay harvest and exacerbate pest problems, which may reduce yield and quality.

For corn, the crop-based recommendation is to monitor ear maturity by examining the starch line development on kernels from the middle of the ear. For furrow irrigated fields, irrigation termination is recommended when starch line movement is greater than 50%, and there is adequate moisture. The final irrigation for soybeans is recommended to occur at growth stage R6 such that there is adequate moisture at R6.5.

These crop-based recommendations are helpful, but they lack precision in specifying water needs to finish the crop or how to gauge how much soil moisture is available in the root zone. This fact sheet provides a procedure to determine the amount of water available and needed to reach crop maturity. Information in this fact sheet provides a crisp answer to when to stop irrigating.

Background: Monitoring Soil Moisture and Determining Allowable Depletion

For irrigation termination decisions, one should determine crop stage and then gauge whether the soil has adequate plant available water or if additional water is needed via irrigation. The calculation (all in inches) is simply…

Plant Water Need
= Water needed to finish the crop
− Water available in the root zone - effective rainfall

If the plant water need value is positive, then irrigation or rain is needed. If it is negative, no further irrigation will provide any benefit.

Irrigation is not completely effective due to application efficiencies. Thus the amount of water that must be applied through irrigation must be adjusted for these efficiencies. The amount of water (in inches) that should be applied through irrigation is determined by dividing the plant water need by the irrigation efficiency (see Tables 4 and 5). It is not necessary to perform this calculation during the season, only for the last irrigation.

Irrigation Application Depth (inches)
= Plant Water Need (inches) ÷ Irrigation Efficiency(%)

Measurements should be made using soil moisture sensors, such as Watermark™ sensors (http://www.irrometer.com/pdf/401-Watermark-family-brochure.pdf). Other sensor types can also be used to monitor and determine the plant available water but are manufacturer specific. Users should check with the manufacturer for directions.

When making soil moisture determinations, the full rooting profile should be used. In most soil types in Arkansas, this will be 30 to 36 inches. While visual inspection of roots can be done using soil probes or shovels, generally it is most practical to utilize changes in soil moisture sensor readings to assess the effective rooting depth.

For the last irrigation of the season for both center pivots and furrow systems, it is recommended to use either a 45% or 50% allowable depletion. This will allow the crop to use all remaining soil water, and it will save on pumping costs. Using an allowable depletion of up to 60% is considered acceptable for the last irrigation, so using 50% has a factor of safety included.

Table 1. Plant Available Water (Inches per Foot) for a Given Soil Matric Potential or Tension (centibars) at 50% Managed Allowable Depletion

Soil Tension (cb)	Sand (1.0"/ft)	Sandy Loam (1.4"/ft)	Silt Loam with Pan (1.58"/ft)	Silt Loam (2.37"/ft)	Clay (1.6"/ft)
0	1.77	1.51	1.01	1.83	1.38
5	1.72	1.51	1.01	1.83	1.36
10	0.74	1.00	1.01	1.65	1.09
15	0.35	0.74	1.01	1.53	0.91
20	0.14	0.58	1.01	1.41	0.78
25	0.02	0.46	0.88	1.29	0.68
30		0.37	0.79	1.19	0.60
35		0.29	0.76	1.14	0.53
40		0.23	0.72	1.00	0.47
45		0.18	0.64	0.89	0.42
50		0.14	0.57	0.80	0.37
55		0.10	0.49	0.71	0.33
60		0.06	0.45	0.63	0.30
70		0.01	0.35	0.50	0.23
80			0.25	0.39	0.18
90			0.21	0.29	0.13
100			0.13	0.22	0.09
120			0.03	0.09	0.02
130				0.03	
140					

Source: Lab and model data of irrigated soils sampled and grouped from Arkansas farms.

Plant available water is dependent on soil texture. The soil in the rooting zone has an upper and lower limit of storing water available to crop plants. Water Holding Capacity (WHC) determinations have been done for groups of Arkansas soils. Table 1 shows WHC for average Watermark readings for different generalized soil textures at a 50% allowable depletion or Managed Allowable Depletion (MAD). Charts for 35% and 45% allowable depletions and in-season decision making is provided in the second fact sheet in this series. These charts provide the plant available water in inches per foot for an average soil tension value. Thus, for a one foot average reading of 45 centibars in a clay soil, there are 0.42 inches of plant available water. For an effective rooting depth of 30 inches or 2.5 feet, there are 1.05 inches of plant available water.

Four Steps to Irrigation Termination Using Sensors

Step 1. Determine crop stage and water needed to finish the crop. The amount of soil water typically required for plants to reach maturity varies with production region and system. Crop water demand for corn is provided in Table 2 based on Nebraska research, and for soybean (Table 3) based on research in Marianna, Arkansas. For corn at R5 growth stage with kernel development at ¾ milk line, the crop is approximately 7 days from maturity (black

Table 2. Crop Water Demand for Corn

Crop Growth Stage[1]	Kernel Development	Days to maturity	Water needed to mature (in*)[1]
R4	Dough	34	7.5
R4.7	Beginning dent	24	5
R5	¼ milk line	19	3.7
R5	½ milk line to full dent	13	2.2
R5	¾ milk line	7	1.0
R6	Maturity	0	0

[1]Source: Yonts, C.D., S.R. Melvin and D.E. Eisenhauer. Predicting the last irrigation of the season. Nebguide G1871. Lincoln, Nebraska. *acre-inches per acre.

Table 3. Crop Water Demand for Soybeans

Crop Growth Stage[1]	Pod and plant development	Days to maturity	Water needed to mature (in*)[2,]
R4	End of pod elongation	50-60	--
R5	Beginning of seed enlargement	40-50	10.0
R6 – R6.5	End of seed enlargement to leaves beginning to yellow	30-40	4.71
R6.5 – R7	Leaves begin to yellow	20-30	2.9
R7	Beginning maturity	10-15	0.75
R8	Maturity	0	0.27

[1]Source: A visual guide to soybean growth stages (https://coolbean.info/library/documents/2017_Soybean_GrowthDev_Guide_FINAL.pdf)
[2]Results from sap flow experiments conducted in 2017 at Lon Mann Research and Extension Center, Marianna, AR.
[3]Acre-inches per acre.

layer). That crop requires 1 inch of water in the soil profile to reach black layer. To determine amount of water needed for the final irrigation, an irrigator should determine soil water availability. If there is more than 1 inch available in the profile, then additional irrigation or rainfall is not needed (Table 2). For soybeans that have reached the R6.5 growth stage, there are 20 to 30 days left to reach maturity (depending on soybean maturity group), and at that point approximately 2.9 inches of water are needed for optimal development (Table 3).

Step 2. Determine the amount of water available in the effective root zone. It is recommended that irrigation managers deploy sensors at 6-", 12-", 18-" and 30-inch" depths to provide soil moisture information from different portions of the plant rooting zone. These depths correspond to the top, middle and lower portions of the theoretical rooting profile. The effective rooting zone can be determined from direct field sampling using a soil probe and inspecting roots. However, estimating the effective rooting depth from the sensor responses from the season is more practical. The upper 6- and 12-inch sensors represent the most active area of the rooting profile.

Determining Plant Available Water (PAW): Use Table 1 and the following equation to convert readings from Watermark sensors to soil water holding capacity. The calculations are simplified by using the UAEX Arkansas Soil Sensor Calculator mobile app (available on the iTunes store).

Plant Available Water (in)
= WHC(in/ft) × MAD (%) × Effective Rooting Depth (ft)

Example: Assume the average readings from four Watermark sensors is 40 cb. For a silt loam soil with a hard pan at 50% MAD, the plant available water would be 0.72 inches/ft, as read from Table 1. If the effective root zone is 3 feet, then the calculation would be:

PAW = 0.72 in/ft x 3 ft = 2.4 inches of plant available water.

If this were a corn field, checking back to the information listed in Table 2, the PAW calculation would indicate that no further irrigations will be required because only 2.2 inches of water are needed to mature the crop. If this were a soybean field at R6 (Table 3), then the 2.4 inches PAW calculated value indicates that an addition irrigation would be required.

Step 3. Account for any potential rainfall that may occur before the crop matures. If rainfall occurs, this amount (depth) can be added to the water balance. For example, if 0.5 inches of water are needed to finish the crop, and that much or more falls on the field without runoff, then no additional irrigation need be applied.

Step 4. Determine the irrigation need. If rainfall does not provide enough to finish the crop, then a last irrigation is necessary. The irrigation need is the difference between what is available in the soil and what is needed.

Table 4. Typical Irrigation Efficiencies for Arkansas Systems

	Irrigation Efficiency Range	Irrigation Efficiency Most Common in Arkansas
Furrow Irrigation	60-80%	70%
Center Pivot	65-85%	80%
Micro-Irrigation	85-95%	90%

Irrigation is not 100% efficient. Losses may be due to tail water runoff and deep percolation, or there may be uneven infiltration along the row. All of the water applied to a crop does not reach all of the plants equally. Furrow irrigation systems generally are only about 60-70% efficient, and center pivot systems are between 65-85% efficient depending upon condition and sprinkler package (Table 4). If the crop needs 1.0 inch of water to finish, and the irrigation system is only 70% efficient, then 1.4 inches of water (1 ÷ 0.7 = 1.4) are needed to provide that inch of water. Also, if only 1.0 inch of water is needed to finish out a furrow irrigated crop, then reduce the irrigation time or depth accordingly (flush) rather than apply a full irrigation. This should be adequate to provide an inch of water to the lower reach of the field.

For sprinklers, the irrigator should adjust the percent run time based on the pivot's operation chart to match the application depth needed. Run time calculations should also account for irrigation efficiency. Irrigation application efficiency is defined as Ea = (volume of delivered to the crop/volume of water applied) x 100. A simplified net irrigation equation is below.

$$\text{Applied Irrigation Depth (in)} = \frac{\text{(Plant Water Need (in)}}{\text{(Irrigation System Efficiency (\%)}}$$

Thus, to apply an inch of irrigation, using an irrigation system that is 70% efficient, it is necessary to apply 1.4 inches.

Table 5. Applied Irrigation Depth (in) Needed for Plant Water Needs for Different Irrigation Efficiencies

Plant Water Need (in)	Irrigation Efficiency (%)		
	70%	80%	90%
0.5	0.7	0.6	0.6
1.0	1.4	1.3	1.1
1.5	2.1	1.9	1.7
2.0	2.9	2.5	2.2
2.5	3.6	3.1	2.8
3.0	4.3	3.8	3.3

Full Example

Readers are encouraged to use the mobile app designed for phones and tablets, "Arkansas Soil Sensor Calculator" (available on the Apple App Store, and an Android version is available on the Google Playstore) to determine the water available in the profile. If the amount available is more than is needed, no additional irrigation is necessary. The difference is the net irrigation required.

Crop Stage: Corn at R5 with the starch line at 50% and rooting depth of 3 ft.
Watermark sensor readings: 40, 63, 60, and 85 cb for 6-, 12-, 18- and 30-inch depths.
Irrigation and soil: Furrow irrigated field with clay soil.
Rainfall: 0.15 inches rainfall occurred within 12 hours of making the readings.
Managed Allowable Depletion (MAD): 50%

Step 1. Determine crop stage and water needed to finish the crop. Amount of water needed to finish the corn is determined from Table 2 = 2.2 inches.

Step 2. Determine the amount of water available in the effective root zone. The average of watermark readings is 62cb [(40+63+60+85)÷ 4 = 62 cb]. It is assumed the rooting depth is 3 feet because all the sensor readings moved during the season, and the irrigation manager used a shovel to visually inspect roots. From Table 1, for a clay soil at 60 cb the plant available water per foot is 0.30 inches per foot. PAW = 0.30 x 3 ft. = 0.90 inches. This is the plant available water in the effective rooting zone.

Step 3. Account for any potential rainfall that may occur before the crop matures. There were 0.15 inches of rainfall that occurred after the readings were taken, so the total plant available water is 0.90 inches + 0.15 inches = 1.05 inches of plant available water (PAW).

Step 4. Determine the irrigation need. The irrigation need is 2.2 inches. PAW is 1.05 inches. The difference between PAW and the amount of water needed is (2.2 - 1.05) = 1.15 inches. So, for this example, another irrigation is necessary to meet crop water demand. This furrow irrigation system is at least 70% efficient, so the depth to apply is 1.65 inches of water to get 1.15 inches (1.15 ÷ 0.70 = 1.65 inches). If a normal irrigation is 2 inches, irrigation can be reduced after the advance has occurred about 20% earlier than a normal irrigation to finish the corn crop.

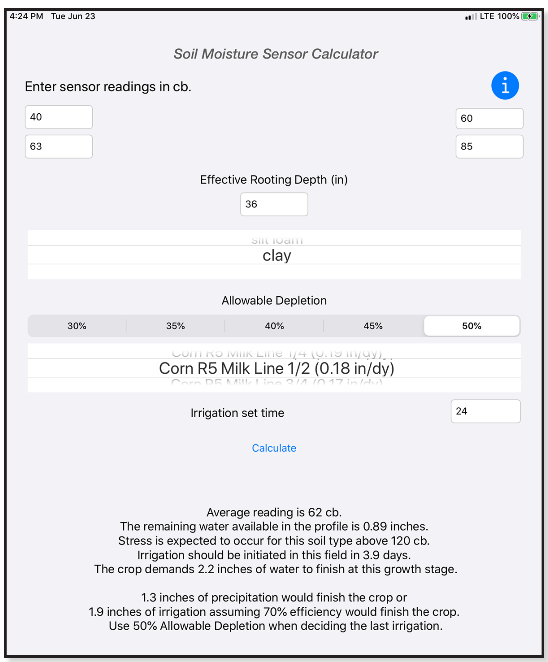

Figure 1. Apple version of Arkansas Watermark Tool, Soil Sensor Calculator result for the example. The app does all of the calculations except adjusting for rainfall. The app can be downloaded at the Apple App Store.

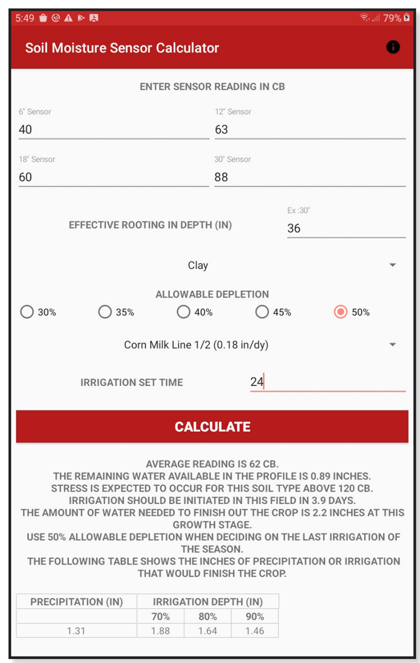

Figure 2. Android version of Arkansas Soil Moisture Sensor Calculator result for the example. The app does all of the calculations except adjusting for rainfall. The app can be downloaded at the Google Play Store.

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DR. CHRIS HENRY, is an associate professor and Water Management Engineer with the Rice Research and Extension Center in Stuttgart. **P.B. FRANCIS**, is a professor with the University of Arkansas at Monticello. **L. ESPINOZA**, is a soil scientist with the department of Crop, Soil and Environmental Science. **M. ISMANOV**, is a program technician with the department of Crop, Soil and Enviromental Science. FSA59-PD-4-2020N