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Irrigation Scheduling Strategies When Using Soil Water Data

Using Soil Water Sensor Conversion Charts for Watermark Sensors

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Introduction

Deciding when to irrigate and selecting how much water to apply per irrigation are longtime challenges. Soil water data can assist in applying enough water to produce top yields while minimizing water use and pumping costs. This is accomplished by providing information on the amount of water stored in the crop root zone and the distribution of water throughout the soil profile. These data help determine how long crops can go before irrigating and the depth of water the root zone can hold at the time of irrigation. Starting in early August, soil water data can also help decide how much water from rain and irrigation will be needed until the crop matures.

Soil water monitoring equipment can generate ample management data; however, without effective strategies to analyze the information, it has limited value. Scheduling decisions require data analysis and interpretation.

The irrigation scheduling strategies and procedures described in this publication are designed to help Nebraska irrigators quickly and accurately plan their irrigation timing and application amounts. Each technique has its own advantages and disadvantages. They can be used as stand-alone methods or in combination with one or more of the other methods. Users should take time to understand the methods and then select the one that suits their individual situation and/or personal liking. Many irrigators use all four techniques sometime during the year depending how accurate they need to be during a particular crop growth stage and the amount of time available to make the decision.

In addition, Soil Water Sensor Conversion Charts have been developed to assist in interpreting data from devices that measure soil water tension, such as Watermark® sensors. The charts enable various approaches to utilizing soil water data to help make accurate scheduling decisions when growing deeper-rooted crops such as corn or soybeans.

The strategies presented start with the simplest, progressing through the more detailed approaches. Irrigation scheduling using management zones is the simplest technique that leads to quick decisions. Calculating the amount of available water in the root zone requires more effort but permits more precise recommendations.

The methods presented do not specifically address strategies required for deficit or limited irrigation—where supplies are limited due to water allocations, surface water availability, and/or insufficient water delivery capacity. Using soil water sensors for deficit irrigation requires a season-long strategy. For more information on deficit and limited irrigation, see EC2007, *Corn Irrigation Management Under Water-Limiting Conditions*.

Sensor Charts

Soil Water Sensor Conversion Charts transform sensor readings into management information. Soil types must be determined for the field as discussed below. Select the Soil Water Sensor Conversion Chart that matches the soil texture where sensors are installed. Charts have been prepared that adequately match most soils (see *Table 1*). However, unique charts can be prepared if necessary.

The charts are available in the Appendix at the end of the publication. To use a chart, match the readings from the Watermark sensor to a value in the left column of *Chart 1*. The percent of available water is listed in the second column and the available water above (+) or below (–) field capacity is

Table 1. Charts are available for these soils.

Soil Texture	Available Water Holding Capacity, inches/foot	Soil Texture	Available Water Holding Capacity, inches/foot
Silt Loam	2.25	Silt Clay Loam	1.8
Silt Loam	2.0	Silty Clay and Clay	1.6
Loam	2.0	Sandy Loam	1.4
Fine Sandy Loam	1.8	Loamy Fine Sand	1.1
Clay Loam	1.8	Fine Sand	1.0
Sandy Clay Loam	1.8		

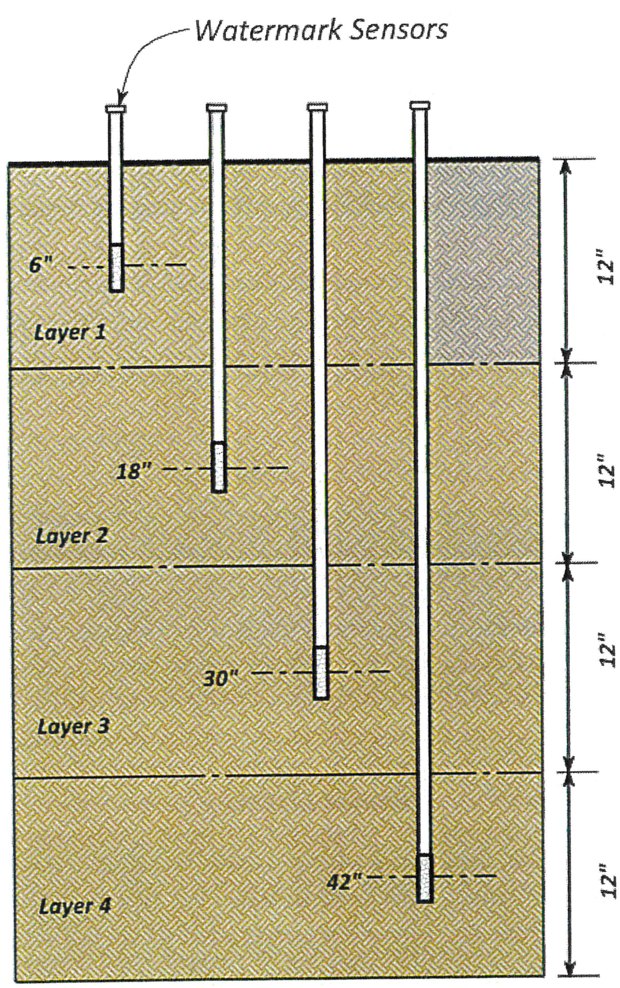

Figure 1. Distribution of sensors to represent the soil profile.

included in the third column. The percent depletion enables a simple method for scheduling while the data for available water involves more detailed analysis for the amount of water available to the crop. Colored bands in the chart represent irrigation management zones that provide a visual evaluation

Chart 1. Soil Water Sensor Conversion Chart for Watermark Sensors.

Watermark Sensor Chart Silt Loam			
Water Holding Capacity, inches/foot = 2.00			
Watermark Reading Centibars	Plant Available Water, %	Soil Water Above(+)/ Below(−) Field Capacity, inches/foot	Management Zone
5	157	1.14	**High Drainage Water Zone** Top soil layer may get this wet from rain or irrigation, but do not irrigate deep layers to this level.
10	139	0.78	
15	125	0.50	
20	114	0.28	
25	106	0.11	
29	100	0.00	**Field Capacity**
30	99	−0.03	**Rain Storage Zone** Keep a one-foot layer of soil dryer than this to store rain.
35	93	−0.15	
40	88	−0.25	
45	83	−0.33	
50	80	−0.41	
55	76	−0.48	
60	73	−0.54	**Desired Water Zone** Keep the deeper soil layers in this range. The goal is to dry out the lower layers throughout the summer and be in the low water zone by crop maturity.
70	68	−0.64	
80	63	−0.73	
90	60	−0.81	
100	56	−0.87	
120	51	−0.98	
140	47	−1.07	
160	43	−1.14	**Low Water Zone** Keep a one-foot layer wetter than this range to avoid stress.
180	40	−1.20	
200	37	−1.26	

of the status of soil water and a quick assessment of soil water adequacy. The following sections describe the application of the scheduling methods.

Selection

The first step in using soil water sensors is determining the best locations in the field to monitor and the soil types at those sites. Sensors must be located in representative locations that are accessible, especially if planning to read the data by going to the site and not using telemetry to bring the data to the web. Three or four sensors should be used to represent the top 3 to 4 feet of the soil profile at each location. The Soil Water Sensor Conversion Charts (see *Chart 1*) are designed to use sensors representing a one-foot layer of soil, with sensors installed at the center of the layer at 6, 18, 30,

Table 2. Suggested root depth for irrigation scheduling versus stage of growth (from EC709, *Irrigation Scheduling: Checkbook Method*).

Root Depth (ft)	Corn	Soybeans	Grain Sorghum	Spring Grains	Winter Wheat	Alfalfa	Sugar Beets	Dry beans	Established pasture	Potatoes
1.0	Vegetative	Vegetative	Vegetative					Vegetative		Seeding
1.5								Initial flower pod set		Bloom
2.0	12 leaf	Early bloom			Fall growth		June 1	Beginning pod fill	Cool season	
2.5	16 leaf	Full bloom	Flag leaf	Joint	Spring growth		July 1	Full seed fill		Maturity
3.0	Silking	Pod elongation	Boot	Boot	Joint		July 15		Warm season	
3.5	Blister		Bloom	Flowering	Boot		Aug. 1			
4.0	Beginning dent	Full seed fill	Dough	Dough	Dough	Established stand	Sept. 1			

and 42 inches below the soil surface (*Figure 1*). Only sensors in the currently active root zone of the crop should be used for scheduling calculations. Suggested root depths for irrigation scheduling versus stage of growth appear in *Table 2*.

Soils can be classified by texture. Fine textured soils (silts and clays) hold more available water than coarse textured soils (sands)—see *Table 1*. If the soil type is unknown, check with the local Natural Resources Conservation Service Office (NRCS), examine the county soil survey, or use the online soil survey at http://websoilsurvey.nrcs.usda.gov/app/. If more precision is required, send soil samples to a soils testing laboratory to determine the texture.

Fields that contain several soil types require selection of the primary soils to monitor for scheduling. Areas of the field that contain coarser textured soils—which hold less water per foot of depth—may require more irrigation than areas with fine textured soils. Following thorough rains, some water may drain from the sandier soil, leaving less water for crop use. Irrigators may have to either overwater fine textured areas or lose yield due to water stress in sandier areas. In addition, hillsides may retain less water than level parts of the field because of runoff during heavy rains. Selecting what part of the field to monitor is a management decision that should be based on how much of the field is represented by the specific soil and slope conditions.

Variable rate irrigation (VRI) allows for application of different quantities of water to areas within the field. However, managing VRI systems requires more elaborate scheduling strategies and soil and plant data for each management zone in the field. The procedures presented in this publication are only a portion of the information required for managing VRI systems.

After selecting the general location in the field to monitor, the sensors must be installed in an area that represents average conditions for that location. The soil water content within a small uniform portion of the field may vary noticeably. Sampling soil around the installation site can help ensure that the site is representative. Use a soil probe to check the soil water content at three to five locations in a 50- to 100-foot diameter circle around the installation site to confirm that the location is representative. To check the water content, make a hole using a soil probe to the depth of the deepest sensor. Check the water content at 6-inch intervals using the hand-feel method as the soil is removed (see https://www.nrcs.usda.gov/wps/portal/nrcs/detail/wy/soils/). Then install the deepest sensor in the hole that most closely matched the average water content for the location. Install the other sensors in close proximity to the deepest sensor.

Some producers may choose to install sensors in the driest hole to ensure that all parts of the field will be watered well. With the sensors correctly installed, readings can be obtained to schedule irrigations. Since sensors should be saturated when installed, they should be installed about a week before readings are needed to allow sensors to reach equilibrium with field conditions.

Scheduling Strategies

Scheduling irrigation by measuring soil water has the advantage of knowing precisely the amount and distribution of water in the soil profile. Recording data over time provides trends of soil water conditions and plant water use. The data also can be used with methods that compute the amount of water in the soil profile and utilize that information to determine when to irrigate and the acceptable irrigation depth. Irrigation scheduling requires a strategy to utilize soil water data for management. The following methods describe various approaches and strategies for using soil water data in scheduling.

Using Soil Water Trends

Soil water trends can help assess irrigation needs by inspecting the change in soil water status over time to determine if irrigation is keeping up with, or exceeding, crop water use. Data generated with a data logger taking readings two or more times per day are ideal for analyzing soil water trends. However, even manual readings taken weekly can help assess the soil water status. The essence of using trends is to define a range of soil water contents that avoids crop water stress because the soil is too dry and minimizes deep percolation when the soil is too wet. Soil water data are visually inspected to ensure that irrigation maintains soil water within the acceptable range. If soil water begins to decline from the acceptable range, then irrigation should be increased to meet crop water needs. If the soil water trend shows increasing amounts that move toward the upper limit of the zone, then irrigation has been excessive and watering should be reduced.

Methods based on soil water trends require less calculation than techniques using the water content of the soil. Two methods based on analyzing trends are presented.

Management Zones

Irrigation scheduling using Management Zones, the simplest method, is intended to provide quick decisions—much like driving between the lines. It is especially useful when time is not available to analyze data more thoroughly. However, this method does not give detailed information about the amount of water in the soil, how much water the root zone will hold, or how soon irrigation should be applied. This method relies on determining a range of soil water contents that provides adequate water for crop water use and yet minimizes deep percolation losses. The goal is to maintain the soil water within an acceptable range over time. As long as the water content stays within that range, then irrigation is adequate. If the soil dries out of the zone over time, then irrigation is insufficient to keep up with crop needs. If the soil water increases above the target range, then excess irrigation is being applied. The key is determining the range of water contents that is acceptable.

The Soil Water Sensor Chart (*Chart 1*) is divided into management zones that are signified by color bands. The blue management zone is the High Drainage Water Zone and represents soil water levels where water will drain deeper into the profile. Surface soil layers reach this range following rain and/or irrigation intermittently during the season. If deeper soil layers become this wet, deep percolation is likely.

The upper yellow zone, labeled the Rain Storage Zone, represents moderately wet soil conditions. It is suggested that at least one layer of the root zone be maintained drier than this to provide storage for rain.

The green Desired Water Zone is the suggested range for deeper sensors. With normal off-season precipitation, the soil will usually be wetter than this in the spring. Then, the readings should increase—i.e., the soil dries—as plants grow, indicating that water is being used. Readings should move into the Low Water Zone as the crop matures. The water content in the top foot of the soil profile varies considerably during the growing season. It can be dry early between rains, but usually stays fairly wet in the blue High Drainage Water Zone once irrigation has begun, especially with center pivots that apply water once or twice per week to the soil surface.

The bottom soil water zone, shown in yellow and labeled as the Low Water Zone, shows the drier end of the scale. Having one layer this dry is not a problem. However, if possible, it is suggested to maintain more than one layer of the root zone wetter than the Low Water Zone until late in the growing season when the crop begins to mature. The 12- to 24-inch soil zone will often be the layer that reaches this soil water level first during the irrigation season.

Thus, this method only requires sensor data and the appropriate sensor chart that matches the soil type where sensors are installed. Irrigators can simply read the sensor values and compare the readings to the management zones. They can continue past management if the soil remains in the desired zones, irrigate more if the soil water nears the dry end of the zone, and irrigate less if the soil water approaches the upper limit of the respective management zones.

Maintaining a Depleted Layer

The second trend-based method involves depleting water in the 12- to 24-inch layer until the soil reaches the Desired Water Zone (*Chart 1*). Keep in mind that water infiltrates through the soil surface when irrigation is applied with a center pivot or rain occurs. Therefore, the top foot of the soil profile will become wet after rain or irrigation and may stay wet during extended periods of the summer. The second foot of the soil profile only gains water if the top foot is fairly wetter. Deep percolation essentially ceases when the soil water content is lowered into the Desired Water Zone. If rains occur when the upper soil layer is wet, then drainage from the top foot can be stored in the 12- to 24-inch layer; thus, irrigators can be confident that deep percolation is minimized. Maintaining the layer in the Desired Water Zone also provides water to fully meet crop water requirements later in the season. The method simplifies data interpretation because irrigation is managed to maintain the 12- to 24-inch layer in the Desired Water Zone.

An approach to creating the depleted layer is to withhold irrigation in the spring and early summer to allow crops to use the water during the vegetative growth stage. In the spring, the entire soil profile is usually wet. Water is depleted from the 12- to 24-inch layer only after the top layer of soil dries. Fortunately, during the vegetative stage most grain crops can experience moderate water stress without reducing yield. However, during the flowering and early grain fill, the crop needs to be fully watered. The depleted layer should be carefully monitored as the crop enters the reproductive stages to ensure that the irrigation system provides enough water to keep the layer within the Desired Water Zone. If the entire profile refills from rain after reaching the reproductive growth stage, then the depleted layer can be recreated, but it must be done slowly to ensure that the crop is fully watered. It is best to use the method based on determining available water described later to make sure the crop is fully watered during this process.

Once the depleted zone is established and the crop reaches the reproductive stage, the crop can be fully watered by monitoring the soil water levels using the data from the sensors. If the 12- to 24-inch layer gets drier, keep the irrigation system running. If it starts to get wetter, stop irrigating for a few days. Ideally, after August 1 the depleted layer should slowly expand deeper with the crop using most of the subsoil water by the time it matures. One word of caution: fields with lower capacity irrigation systems—especially in combination with sandy soils—may need to keep the entire soil profile very close to field capacity during the vegetative stages. This provides adequate water to meet crop water demands during the reproductive stages.

Using Soil Water Volume

More involved scheduling methods utilize soil water data to estimate the amount of water (expressed as volume or depth) in the crop root zone. Knowing the amount of water in the root zone assists in applying enough water to produce top yields while minimizing pumping. These scheduling methods require determination of the amount of water stored in the active crop root zone. Readings from the soil water sensors are converted into the volumetric water content of the soil. The water content can then be transformed into the percent depletion of the available water or the amount of soil water above or below field capacity. The volume of soil water also helps determine how long until the crop needs to be irrigated and how much water the soil can hold when irrigating. Starting in early August, soil water data can help determine how much rain and/or irrigation will be needed to satisfy water requirements until crop maturity. For more information on basic irrigation scheduling, see EC709, *Irrigation Scheduling: Checkbook Method.*

The Soil Water Sensor Conversion Charts enable two methods of irrigation scheduling using plant available soil water. Plant available water is defined as the amount of water held by the soil between field capacity and the wilting point. This is the same value as the water holding capacity of the soil shown in *Table 1*. One method provides an estimate of the percent of available water remaining in the root zone. The second method depends on the volume (depth) of available water in the root zone. The percent available water method is simpler while the depth of water method is more precise.

Percent of Available Water Method

Irrigation scheduling using the percent of available water requires fewer calculations than the method based on the depth of available water, but still provides a good indication of the adequacy of the water in the active root zone. It only requires the first two columns from *Chart 1*. The amount of available water that the soil retains decreases as the soil water tension increases, i.e., as readings increase.

The percent of the available water that the soil can hold is shown in the second column. The percent corresponds to the soil water tension reading in centibars (cb). The silt loam soil used in the example in *Chart 1* has a field capacity at a soil water tension of 29 cb. Soil water tension readings smaller than 29 cb (0–28 cb) represent water levels wetter than, or above, field capacity. They are represented by percentages above 100 percent. Sensor readings greater than 29 cb (30–200 cb) represent water levels drier than, or below, field capacity. Watermark sensors only measure to a maximum tension of 200 cb.

The soil water tension at field capacity varies with soil texture. The tension at field capacity for sandy soils, for example, is only about 12 cb. Field capacities for other soils are between the values for sand and silt loam soils.

To determine the percent of available water, find the reading in *Chart 1* for each sensor in the active root zone. Read the corresponding percentage in the second column. Then, average the numbers to compute the average percent of available water in the active root zone. See *Example 1* for application of the method.

The results in *Example 1* show that the top foot of the soil profile is wetter than field capacity, i.e., at 125 percent of the available water holding capacity. When this occurs, water will drain into deeper soil layers if not used by the crop first. If the lower layers are wetter than field capacity (above 100 percent), then water will likely drain from the root zone before crops can utilize the water. If deep percolation is expected, wait a few days and recheck the soil water level to estimate the drainage loss and to recompute the water availability. Ideally, the field should be between 60 and 90 percent of available water during the early and middle portions of the irrigation season. Late in the season, the field can drop to 40 percent of available water prior to irrigation.

Example 1

Determine the percent available water on July 22 when corn is at the silk stage. Four Watermark sensors were installed at 6, 18, 30, and 42 inches to represent the top 4 feet of the soil profile. The Watermark readings were: top foot (0–12 inches) = 15 cb, second foot (12–24 inches) = 100 cb, third foot (24–36 inches) = 70 cb, and fourth foot (36–48 inches) = 29 cb.

From Table 2, corn at the silk stage has an active root zone of about 3 feet; thus, the fourth sensor will not be used until later in the season.

Find the sensor readings in the left column of Chart 1; then follow across to the second column to read the percent of available water. After finding the percentage for each sensor, calculate the average for the active root zone by dividing the total of the readings by the number of readings (249/3 = 83 percent of available water):

Soil Depth Interval	Column 1 Sensor Reading	Column 2 Available Water, %
Top foot	15	125
Second foot	100	+56
Third foot	70	+68
Total	—	249

Example 2

Determine how much water from rain and irrigation the field in Example 1 could hold today. Irrigators can decide when to start watering if they know the amount of storage available in the soil today.

The sensor readings are in the left column of Chart 1; then follow across to the third column to read the plant available water above/below field capacity. After finding the value for each sensor, calculate the plant available water above/below field capacity for the active root zone. **Some of the numbers may be positive or negative. Remember that the result of adding a negative number is the same as subtracting a positive number.**

Soil Layer	Column 1 Sensor Readings	Column 2 Percent from Chart 1	Column 3 Available Water in Inches from Chart 1
Top foot	15	125	(+0.50)
Second foot	100	+ 56	+(−0.87)
Third foot	70	+ 68	+(−0.64)
Total		249	−1.01

Volume of Available Water Method

Irrigation scheduling using the volume of available water can provide more accurate estimates of the amount of plant available water remaining in the root zone as well as data to determine how much water the root zone can hold. The method also provides data to calculate how long until the next irrigation should be applied.

The amount of water in the soil, expressed as inches of water per foot of soil, relative to the amount held at field capacity is shown in the third column in *Chart 1*. The numbers in the 5 to 25 cb range are positive, indicating the quantity of soil water above field capacity that will drain deeper into the soil. The numbers in the 30 to 200 cb range are negative, showing the quantity of water that would need to be added per foot of soil to bring the soil water up to field capacity.

An example of the basic procedure is illustrated in *Example 2*. The results show that the root zone is 1.01 inches below field capacity, and the top foot of the soil profile is 0.50 inches above field capacity. Thus, water will drain into deeper soil layers if not used by the crop first. In this case, deeper layers can hold the water. This example emphasizes the importance of knowing how much water is in each layer.

Example 3 illustrates a shortcut method. It requires fewer calculations to determine the plant available water above or below field capacity, but the results can be slightly different because of rounding errors.

The last step is estimating how long until the crop will need irrigation to prevent water stress. Keep in mind that the irrigation will need to be completed on the entire field before crop stress starts. In other words, if it is determined that irrigation will be needed in seven days and it takes four days to complete the irrigation on the entire field, the system should be started in three days. While this is useful information, it is often not calculated until late in the irrigation season to help determine when to stop irrigating for the year. However, the number is needed all season when scheduling furrow irrigated fields or low capacity center pivots that require several days to complete an application.

Example 4 illustrates use of the data to estimate the amount of water available in the root zone when scheduling, using a percent of available water threshold.

Use of the data to estimate the approximate time until irrigation is required is illustrated in *Example 5*. For this situation, irrigation should be completed within seven days to avoid crop water stress. If hotter and windier conditions than normal are forecast, increase the estimated daily water use to 0.35–0.40 inches/day. If cooler conditions are forecast, consider lowering the water use rate. Using this information,

Example 3

Using the average percent of available water calculated in Example 1, find the value in the second column that is closest to the average percentage (83%). Then, follow across to the third column to read the amount of water above or below field capacity. The value is –0.33 inches/foot in the chart. The number represents the average amount of water in each one-foot soil layer. Next, multiply by the depth of the active root zone (in feet) to determine how much water the root zone can hold.

Column 2	Column 3, Depletion in inches from Chart 1
@ 83%	(–0.33)
Multiply Column 3 by 3 for a three-foot root zone	
–0.99 inches of water below field capacity	

The chart indicates that 0.99 inches of water could be held by the root zone before reaching field capacity. Negative values indicate the amount of rain and irrigation that the root zone can hold. If the number is positive, the soil water level is already above field capacity. Irrigation should be delayed until the crop has used enough water to allow the soil to hold the planned irrigation.

Next, determine the estimated average weekly crop water use in *Table 3* for corn at the silk stage and add the average weekly water use to the current amount of water that could be stored. This will determine the maximum amount of rain and irrigation that could be applied over the next week (7 days x 0.30 inches/day = 2.1 inches of crop water use per week + 0.99 inches for the current storage = 3.09 inches that could be applied).

Table 3. Approximate water use rates by stage of growth for various crops (from EC709, *Irrigation Scheduling: Checkbook Method*).

Water Use Rate inch/day	Water Use Rate inch/week	Corn	Grain Sorghum	Soybeans	Alfalfa*	Dry Beans	Sugar Beets	Winter Wheat
0.18	1.26						June 15	Spring growth
0.20	1.40							
0.22	1.54			Full bloom			July 1	
0.24	1.68	12 leaf				Rapid veg. growth		Joint
0.26	1.82		Flag leaf	Begin pod				
0.28	1.96	Early tassel	Boot		June 15			
0.30	2.10	Silking	Half bloom	Full pod	July 1	Flowering and pod dev.	July 15	Boot
0.28	1.96				August 1			
0.26	1.82	Blister	Soft dough				August 1	
	1.68	Milk		Seed fill	August 15			
0.22	1.54				Sept 1			Dough
0.20	1.40	Begin dent						
0.18	1.26	Full dent	Hard dough			Pod fill and maturation		

* Alfalfa water use rates should be multiplied by 0.50 during the first 10 days following cutting and by 0.75 for the 10th to 20th day following cutting.

the recommendation for a center pivot that is set to apply 1 inch of water would be to have the irrigation system off for the next day or two to allow the crop to use some of the soil water and make room for a rain. However, the next irrigation should be completed within six days unless rain is received. Allowing the field to dry to 50 percent of plant available water is not recommended because if anything goes wrong and water cannot be applied, the crop may suffer yield loss.

Late Season Irrigation Needs

Predicting the amount of water needed from rain and irrigation to sustain the crop through maturity becomes

Example 4

Determine how much water the crop could use before the root zone in Example 2 dries to 50% of available water holding capacity. After the dough stage for corn and grain sorghum, and the R5 stage for soybeans and dry beans, the recommendation is to allow the soil to dry to 40% of available water.

Using the average percent of available water calculated in Example 1 (83%), find the closest value in the second column. Then read the amount of water above or below field capacity in the third column. Next, subtract the amount of soil water in the third column represented by about 50% of the available water. **Some of the numbers may be positive or negative. Remember that subtracting two negative numbers results in a positive number.**

Column 2	Column 3, depletion in inches
Water Used @ 83%	(–0.33)
Water Used @ 50%	–(–0.98)
Available Water	0.65 inches per foot of soil in the root zone

Multiply by the depth of the active root zone to get the inches of water that could be used by the crop before the soil would dry to 50% of available water: 0.65 in × 3 ft root depth = 1.95 in. Thus, the crop could use 1.95 inches of water before the soil reaches 50% of available water.

Example 5

Determine how many days remain before the next irrigation to prevent the available water from going below 50%.

Look up the average daily water use in Table 3 for corn at the silk stage (0.3 inches per day) and divide the remaining available water determined in Example 3 (1.95 inches) by the estimated daily crop water use.

Remaining available water	1.95 inches water
Estimated daily water use	÷ 0.3 inches/day
Days until irrigation is required	6.5 days

important starting in early August. The goal is to leave the field as dry as possible without lowering yield. This process relies on

- estimating the amount of crop water use from the current date through maturity,
- measuring the amount of available water in the root zone at the current time, and
- considering the likely amount of rainfall from the current time until crop maturity.

Table 4. Normal water requirements for corn, grain sorghum, soybeans, and dry beans between various stages of growth and maturity in Nebraska (from G1871, *Predicting the Last Irrigation of the Season)*.

Crop		Stage of Growth	Approximate days to maturity	Water use to maturity (inches)
Corn				
	R2	Blister	45	10.5
	R4	Dough	34	7.5
	R4.7	Beginning dent	24	5.0
	R5	1/4 milk line	19	3.75
		1/2 milk line—Full dent	13	2.25
		3/4 milk line	7	1.0
	R6	Physiological maturity	0	0.0
Grain Sorghum				
	Stage 6	Half bloom	34	9.0
	Stage 7	Soft dough	23	5.0
	Stage 8	Hard dough	12	2.0
	Stage 9	Physiological maturity	0	0.0
Soybeans				
	R4	End of pod elongation	37	9.0
	R5	Beginning seed enlargement	29	6.5
	R6	End of seed enlargement	18	3.5
	R6.5	Leaves begin to yellow	10	1.9
	R7	Beginning maturity	0	0.0
Dry Beans				
	R5	Early seed fill	35	7.0
	R6	Mid-seed fill	25	4.2
	R7	Beginning maturity	15	2.0
	R8	Harvest maturity	0	0

The approximate amount of time and crop water use from specific growth stages until maturity are included in *Table 4*—approximate days to maturity in column 2 and water use to maturity in column 3. The amount of available water is determined from soil water data as described in the previous section. The approximate date of maturity is estimated by

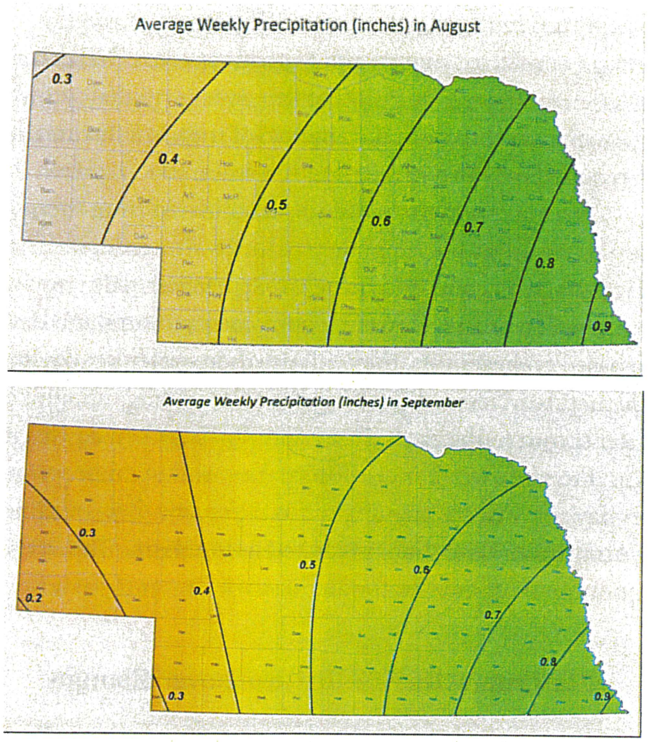

Figure 2. Average Weekly Precipitation for August and September in Nebraska.

Example 6

Determine how much water from rain and irrigation will be needed to reach crop maturity assuming the field is located in central Buffalo County, Nebraska. Today's date is August 10 and the corn crop is at the R4 (Dough) stage. The remaining available water would be 2.25 inches if the soil is allowed to dry to 40 percent of available water holding capacity.

From Table 4, corn at the R4 stage should take approximately 34 days to mature and will use about 7.5 inches of additional water to reach maturity.

Add 34 days to today's date to get the approximate day of maturity.

Date, today	8/10
Days to maturity	34 days
Predicted maturity date	9/13

Subtract the water required to reach maturity from the remaining available water

Currently available water	2.24 inches
Water required to mature crop	−7.50 inches
Remaining water at maturity	−5.26 inches

The calculation shows that 5.25 inches of water will be needed from rain and/or irrigation to sustain the crop through maturity while not limiting yield.

adding the time to maturity to the current date. The amount of rain or irrigation needed through maturity is computed by subtracting the water use to maturity from the remaining available water as calculated in *Example 3*. Remember to use 40 percent of available water after the dough stage for corn and grain sorghum and the R5 stage for soybeans and dry beans. If this value is positive, the soil has adequate water to mature the crop. If the number is negative, the value is the amount of water needed from rain and irrigation to reach maturity. This process is illustrated in *Example 6*. For more information on end of season irrigation scheduling, see G1871, *Predicting the Last Irrigation of the Season.*

Predicting how much rain a field will receive is difficult, but if one does not plan for the possibility of rain, it is easy

Example 7

Determine the average rainfall per week for the remaining weeks of crop growth and add it into the prediction of how much water may be needed from irrigation. The process should be updated and recalculated each week until the crop is mature.

From *Figure 2* determine the average rainfall for a week in August and in September for central Buffalo County, Nebraska.

The chart shows that 0.60 inches of rain are received in an average week in August and 0.55 inches in September. The crop will still grow for three weeks in August and two weeks in September. **Some of the numbers may be positive or negative. Remember that the result of adding a negative number is the same as subtracting a positive number.**

Remaining available water at maturity	(−5.26) inches
Average August rain for three weeks	+(+1.80) inches
Average September rain for two weeks	+(+1.10) inches
Needed water less average rain	−2.36 inches

The chart predicts that if average rainfall is received over the next five weeks, only 2.35 inches of irrigation would be needed to mature the crop.

Using this information for a center pivot that is set to apply 1 inch of water per irrigation, the system should be shut off for the next few days to use some of the remaining water. The next inch of water should be applied within the next seven days. Then, the next irrigation should be recalculated using updated soil water readings. The best way to use the remaining water is to delay the start of the last few irrigations and react to any rain that might occur during the period. Slowly using the water in the lower portion of the root zone starting in early to mid-August is much better than keeping the profile full until the very end and expecting the crop to use the water all at once.

Example 8

Determine how much water from rain and irrigation the field in Example 1 could hold, assuming a soil profile consisting of 20 inches of silt loam over sandy subsoil. One method is to install sensors at 6 inches (representing the depth from 0–12 inches), at 16 inches (representing 12–20 inches), and at 30 inches (representing 20–36 inches). The soil water tension and the percent of available water can be used for each soil type directly from the respective chart.

To determine the amount of water storage available in the root zone, the thickness of the soil layers for the second and third sensors should be adjusted. The second sensor only represents 8 inches (i.e., 8/12th of a foot) and the third sensor represents a depth of 16 inches (i.e., 16/12th of a foot). The soil water above or below field capacity for the sensor should be multiplied by the fraction of the foot that it represents.

Find the sensor readings in the left column on the chart representing the soil type where the sensor is located. Next, read the amount of soil water above or below field capacity in the third column. Then, find the numbers for each sensor and multiply them by the fraction of a foot that the sensor represents. Finish by adding the values for each soil depth to determine the maximum amount of water from rain and irrigation the field could hold before exceeding field capacity. **Some of the numbers may be positive or negative. Remember that the result of adding a negative number is the same as subtracting a positive number.**

Soil Layer	Sensor Readings Column 1	Number from Chart Column 3
Top foot	15	(+0.50)*(12/12) = (+0.50)
Second foot	100	+(−0.87)*(8/12) = (−0.58)
Third foot	70	+(−0.64)*(16/12) = (−0.85)
Total		−0.93 in

The chart indicates that 0.93 inches of water could be held in the root zone before exceeding field capacity.

to apply too much irrigation water. The long-term weekly average rainfall for August and September across Nebraska is included in *Figure 2*. Inclusion of the average rainfall provides an improved estimate of the amount of irrigation that might be required for the remainder of the season (see *Example 7*).

Corn and sorghum are somewhat different from beans in crop water use as they approach maturity. For example, if hot, dry, and windy conditions occur in September, daily crop water use will increase. However, since corn and sorghum develop based on heat units, they will use more water per day, but will mature in fewer days using about the average amount of water shown in the chart. Beans develop based on day length. With the same weather conditions, they will use more water per day and will still mature at about the same date, resulting in using more water than predicted in the charts. Thus, it is important to monitor soil water in soybeans until maturity.

Working with Soil Texture Layer Changes

The examples provided assume a uniform soil profile with the same soil texture throughout the profile. If your soil profile has significantly different textures with depth, some adjustments are recommended. First, sensors should not be installed at a depth near the change in soil texture. The recommendation is that sensors not be placed closer than 4 inches to the depth of texture change. The charts assume that each sensor represents a 12-inch layer of soil. Thus, if the spacing is different, adjustment is needed for the depth of the soil represented by the sensors, and a copy of the Soil Water Sensor Conversion Charts for both soil textures will be needed. The procedure for nonuniform soil profiles is illustrated in *Example 8.*

Summary

The irrigation scheduling procedures described in this publication are designed to help Nebraska irrigators growing deeper-rooted crops such as corn or soybeans to quickly and accurately plan their irrigation timing and application amounts utilizing the Soil Water Sensor Conversion Charts.

Irrigation scheduling using the Management Zones is the simplest and is intended to lead to very quick decisions, much like just driving between the lines. Calculating the inches of available water requires a little more work, but results in more precise recommendations. Each technique has its own advantages and disadvantages. They can be used as stand-alone methods or in combination with one or more of the other methods. Many irrigators use all four techniques sometime during the year, depending on how accurate theyneed to be during a particular crop growth stage and the amount of time available to make the decision.

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Appendix

Soil Water Sensor Conversion Chart Summary

	Available Water Holding Capacity	Parameters for van Genuchten Function				Wilting Point	Field Capacity		50% Depletion	
Soil Texture	Inches/feet	Θs	Qs	a	n	Volumetric Water Content (@ 1500 cbars)	Volumetric Water Content	Tension, cbars	Volumetric Water Content	Tension, cbars
Silt Loam (Hastings)	2.25	0.490	0.020	0.0182	1.2472	13.7%	32.4%	28	23.1%	137
Silt Loam (Hord)	2.0	0.410	0.050	0.0110	1.3328	11.5%	28.2%	29	19.9%	124
Loam (Holdrege)	2.0	0.440	0.000	0.0224	1.2184	12.3%	29.0%	27	20.6%	139
Fine Sandy Loam (Bridgeport)	1.8	0.440	0.075	0.0176	1.7410	8.1%	23.1%	16	15.6%	42
Clay Loam (Pawnee)	1.8	0.397	0.000	0.0145	1.1636	16.4%	31.4%	24	23.9%	147
Sandy Clay Loam	1.8	0.390	0.091	0.0114	1.4406	12.2%	27.2%	23	19.7%	89
Silty Clay Loam	1.8	0.480	0.171	0.0083	1.3844	21.9%	36.9%	32	29.4%	127
Silty Clay & Clay	1.6	0.490	0.120	0.0283	1.1525	26.7%	40.0%	19	33.3%	127
Sandy Loam	1.4	0.420	0.047	0.0899	1.3389	7.9%	19.6%	16	13.7%	71
Loamy Fine Sand (Dundy)	1.1	0.400	0.055	0.0431	1.7657	5.8%	14.9%	12	10.3%	30
Fine Sand	1.0	0.400	0.030	0.0344	1.9767	3.1%	11.4%	13	7.2%	26