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Using Evapotranspiration Reports for Center Pivot Irrigation Scheduling

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Improving production efficiency should be a goal of anyone producing a market item. The irrigation farm manager is no exception. Any new technique or information should be critically investigated and incorporated into the management decision-making process if it benefits the overall program. The use of crop evapotranspiration reports should benefit irrigation farm managers by minimizing excess or deficit irrigation, minimizing leaching of crop chemicals, and providing a favorable soil water environment for crop growth and development.

What is Evapotranspiration

Evapotranspiration is the term coined to describe the consumptive water use of crops — the amount of water used by a growing crop (not the amount applied by an irrigation system). The word is the combination of two words, evaporation and transpiration, and is often referred to as ET. Any water, whether deposited by precipitation, dew, or irrigation, can be consumed by the crop to fulfill the ET requirement. K-State Research and Extension publication MF-2389 *What is ET?* provides additional information on the topic.

The amount of ET is influenced by climatological factors such as temperature, relative humidity, wind, and solar radiation. In addition, crop conditions such as stage of growth and plant health will affect the amount of ET that occurs. Procedures to calculate ET based on weather and crop data have been developed for many Kansas crops and are available for use.

ET information generated by climatological factors gathered at a weather station is generally referred to as reference ET or ETr. ETr values must be customized or modified by factors, called crop coefficients, to properly estimate crop ET or water use of a specific crop for its particular growth stage. This modified ET value is referred to as either actual ET or crop ET or ETc.

ETr values are generated at a number of weather stations across Kansas. Some network of stations are operated and maintained by local Groundwater Management Districts, and ETr data can be accessed by telephone. The Weather Data Library at K-State Research and Extension operates or has access to a number of weather stations throughout Kansas. While the data from some of these stations can be accessed locally, all can be accessed via the Web at *www.oznet.ksu.edu/wdl.*

How to use ET Information

Irrigation scheduling using ET information is like a checkbook accounting procedure. ET is the amount of crop water withdrawal that must be balanced against water deposits of rainfall and irrigation. The water balance must be kept within the limits of crop stress as determined by the field condition, irrigation capacity, and crop type. Through the scheduling procedure, the amount of water application required and the time of application can be determined.

Even irrigation systems with capacities that limit the irrigator's management flexibility can use ET information to benefit water management. The benefit can come from helping to determine when to start and end irrigation. This benefit generally translates into increased economic return, possibly through a lower fuel bill as a result of reduced over-watering, or as increased yield due to fewer periods of crop water stress.

Irrigation scheduling can be accomplished using the following methodology and charts. The ETr information is assumed available via a weather station. The process of irrigation scheduling is then largely a series of simple additions and subtractions that calculate a soil water balance for a given site in a field. While the math is simple, the number of repetitions required for a field throughout a growing season can become tedious. The scheduling process however, lends itself well to computerization. Irrigation scheduling using ET data is the essence of KanSched, an ET based irrigation scheduling software package available through Mobile Irrigation Lab (MIL) project of K-State Research and Extension. Contact your local K-State Research and Extension office, or check out *www.oznet.ksu.edu/mil* for more information. However, if you are more comfortable with paper and pencil accounting, follow the instructions below.

Irrigation Scheduling

To schedule center pivot irrigation using ET information, follow the steps listed below:

1. Determine the total crop water use (ET) since the last update of soil water status.
2. Determine the total effective rainfall and irrigation amount since the last update of soil water status.
3. Update the soil water status.
4. Begin irrigation when the soil water depletion equals or exceeds the net irrigation application amount.

This is the basis for an irrigation scheduling program for a center pivot. Each field has its own characteristics that will affect the scheduling program. To plan the most efficient scheduling procedure, factors such as the soil infiltration rates and the soil water holding capacities must be considered to prevent an excessive application rate or amount. The water holding capacity of the soil also must be known to determine the depletion that can occur before crop stress begins. System capacity must be determined since appropriate scheduling cannot be done unless the potential water application amounts are known. Certain basic irrigation information is required to ensure irrigation application efficiency and proper application amount. The scheduling procedure must be adjusted for the crop root zone, soil water holding capacity, and allowable depletion.

A. Determine the Active Crop Root Zone

The active root zone of the crop is dependent on crop type, its stage of maturity, and soil conditions. Soil conditions, such as hardpans, may restrict root development.

For this example, using corn grown on good soil, a managed root zone of 3 feet will be used. The root zone of the crop may exceed 3 feet, but the majority of the roots will be in this zone. Therefore, the majority of the water withdrawn will be from this zone as well. Any root development beyond 3 feet can be considered a safety factor. Early in the season, the root zone may be less than 3 feet and should be properly accounted for within the scheduling procedure. Production handbooks for the major Kansas crops are available from local K-State Research and Extension offices. They can help determine root development ranges of various crops.

B. Determine the Amount of Soil Water Storage Capacity in the Root Zone

Soil texture influences the water holding capacity of the soil, the coarser the texture, the lower the holding capacity. Holding capacities of some common Kansas soils are listed in K-State Research and Extension publication L-904, *Soil-Water-Plant Relationships*. County soil surveys from the NRCS provide additional information.

For this example, assume a silt loam soil which has a 2-inch per foot water holding capacity. The total soil water available in a 3-foot root zone would be 2 inches of water per foot, multiplied by 3 feet, equals 6 inches of water.

C. Determine Amount of Allowable Soil Water Depletion Before Starting Irrigation

Crops have differing levels of water depletion tolerance. Too much depletion stresses the crop and depresses yields; too frequent watering wastes water, fuel, fertilizer, and also could depress yield. A general irrigation guideline for most field crops is to maintain at least 50 percent available soil water during the bulk of the growing season. For example, corn research has shown a 50 percent depletion of available soil water to be a good management guideline, although depletion of 60 to 70 percent late in the season is permissible. The allowable depletion for this example is 50 percent, multiplied by 6 inches per 3-foot root zone, equals 3 inches.

It is recommended that soil water monitoring be used as a backup to supplement the ET information and the effective amount of rainfall to ensure that soil water reserves are being maintained, especially for producers new to ET scheduling. General irrigation guidelines for various crops are available in other publications. For additional information on soils and soil water monitoring, ask at a local K-State Research and Extension office about publications from the Irrigation Water Management Series and crop production handbooks, or look at these resources on the K-State Research and Extension Web site listed at the end of this publication.

D. Irrigation System Capacity

Irrigation systems with high capacity are systems that can supply water to a field at, near, or above the growing crop's peak rate of water use. Using corn for an example, the peak rate of water use may exceed 0.35 inches per day during its reproductive stage, especially during periods of severe weather conditions. Many systems in use today have irrigation capacities of much less than the peak crop water use rates. These systems depend on soil water reserves and rainfall to adequately meet the crop needs during peak use periods. For systems on fields with deep silt loam soils, a capacity of around 0.25 inches/day is usually reliable. System capacity can be calculated by the following steps:

1. Determine the pump diversion rate in gpm*
   Example: 750 gpm
2. Determine the acres irrigated
   Example: 132 acres
3. Calculate the irrigation capacity

$$\frac{\text{GPM x HR/DAY**}}{\text{450 x ACRES}} = \text{Irrigation Capacity}$$

$$\frac{\text{750 gpm x 24 hr/day}}{\text{450 gpm/acre-inch/hr x 132 acres}} = 0.30 \text{ in/day}$$

where: 450 gpm = 1 acre-inch/hour is a conversion factor.

* gpm= gallons per minute
** Hours of operation per day

This 132-acre center pivot system can supply 0.30 inches per day to the field at 100 percent irrigation efficiency.

4. Determine the net irrigation capacity:

System application efficiency = 80%*
Gross capacity x application efficiency = Net capacity
0.30 inch/day x 0.80 = 0.24 inch/day

* See Table 1 for general information on system application efficiency.

5. Determine time to apply desired application amounts:

Desired net application = 1.5 inches

$$\frac{1.5 \text{ inches}}{0.24 \text{ in/day}} = 6.25 \text{ days}$$

Scheduling Example 1

Scheduling Example 1, shown in Table 2, assumes a field with a silt loam soil that has an available water holding capacity of 2 inches per foot and a 3-foot root zone. A full soil water profile for the example soil would contain 6 inches. The management guideline is to maintain 50 percent available soil water or 3 inches in the 3-foot root zone. The top of Table 2 lists this information.

Column 2 is the amount of effective rainfall that enters the soil profile and is available for crop use. The best estimate of effective rainfall will be based on observation of the intensity and duration of the rainfall event. High intensity rainfall events exceed the soil's infiltration capacity and increase runoff potential. High-intensity rainfall, coupled with long duration, would indicate large runoff volumes. Low intensity rainfalls are desirable since the soil infiltration capacity would be more closely matched. Long-duration rainfall events do have increased runoff potential since soil intake capacity will decrease as water content increases. Small precipitation events of less than 0.2 inches are usually ignored, and large events may require sampling to determine the soil water level to record on the water balance sheet.

Column 3 is the net irrigation applied as previously calculated. Note that in this column the amount is recorded on the first day of the irrigation and the cycle length is indicated by the number of days it takes to complete the circle. The crop water use is determined by columns 4, 5, 6, and 7. However, only Column 7 is used in Table 2 since the crop ET was given. These ET values are actual values determined for corn at a western Kansas field. The amount of ET that occurs daily can be recorded on the water balance sheet as shown in Table 2. The amount of ET may be reported as either ETr or actual ET. If crop ET information is obtained, record it directly into Column 7, marked Crop ET on Table 2, and ignore the columns marked ETr, Stage of Growth, and Crop Coefficient.

ETr refers to reference ET. ETr is the expected ET from a uniform, green, actively growing reference crop. The crop coefficient (Kco) volumes in this publication are calibrated for alfalfa reference ET, and are appropriate to use with the reference ET information provided by the K-State Weather Data Library. Kco values for other reference crops are available and by contacting the authors or through your local K-State Research and Extension office. Alfalfa reference Kco for other crops are also available. Crop ET is usually less than ETr since plant characteristics of other crops and stage of growth reduce the amount. If ETr is used, it must be modified to reflect the crop type and maturity.

Figures 1 and 2 are graphs of crop coefficients for corn and grain sorghum versus their stage of growth. Using these graphs, the ETr can be modified to reflect the field's stage of growth. Record the Kco into the appropriate column. Multiply ETr by the Kco to obtain ET for a crop. The soil water depletion is calculated and recorded in columns 8 and 9 to represent two locations in the field. Location 1 is the start of the irrigation cycle and Location 2 is the end of the irrigation cycle for this example. Other locations, or additional locations in the field, could be used if desired, but the starting and stopping

Table 1. *Probable Range of Irrigation Application Efficiency for Various Sprinkler Packages with No Runoff**

System Type	Application Efficiency Range (%)
High Pressure -- high angle impact	70 to 80
Medium Pressure -- low angle impact	75 to 85
Spray on top truss	75 to 85
Spray on drop	80 to 90
In-canopy spray	75 to 95
Bubble mode or sock LEPA	85 to 95

*See Bulletin L-908, *Considerations for Sprinkler Packages on Center Pivot*, for further information.

Figure 1. *Corn Crop Coefficient vs. Stage of Growth*

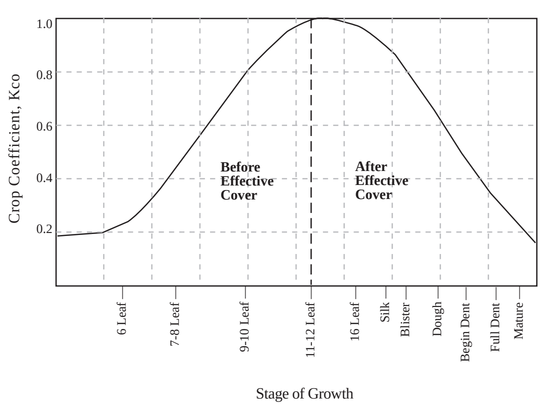
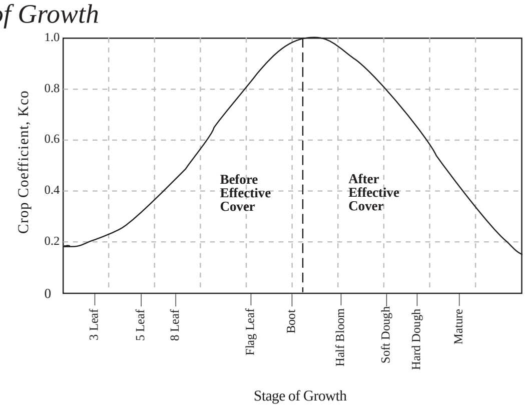


Figure 2. *Grain Sorghum Crop Coefficient vs. Stage of Growth*



points are important. The new soil water depletion is calculated as follows:

Soil water depletion =
Previous day's soil water depletion + ET
– net irrigation – effective rainfall

Soil water depletion cannot be negative. If this occurs, record zero for the depletion level.

Column 10 is for comments. The comment column in Table 2 is used to show sample calculations.

Example 1 shows a period of time (July 1 to July 9) where ET averaged 0.21 inches/day, which is less than the net irrigation capacity of 0.24. Yet during a high water use period (July 10 to July 14), Location 2 had depletion exceeding management guidelines because of the application lag between the beginning and ending irrigation points in the circle.

Table 3 is a blank form that could be photocopied for use.

Scheduling Example 2: Use of Split-Application Amounts for the Start-up Irrigation

Many center pivots are equipped with programmable control panels that can be used to help eliminate the large difference in the soil water reserves between the start and end of the circle. This technique would be a staggered application amount for initial irrigation or any irrigation following a rainfall sufficient to completely refill the soil profile. A split application would apply a reduced amount to the first half of a circle and an increased amount for the second half, reducing the total soil water variation within the field. For clarity and illustration, consider the same pivot from the previous example but with a staggered irrigation application on the initial irrigation, shown on Table 4. In this example, a 0.75-inch application was applied on approximately half of the field before switching to the 1.5-inch irrigation. By using the split application the following advantages occurred:

1. Soil water depletion of greater than 50 percent was avoided in the last part of the circle. Sometimes this method will avoid over-irrigation of the beginning of the circle.
2. Water reached the end of the circle sooner and maintained a higher soil water reserve throughout the season.
3. A soil water condition exists across the field that allows irrigation water to maintain the reserves above 50 percent depletion while allowing more effective use of natural precipitation.

Summary

Using ET information should be beneficial to many crop producers by helping them match irrigation application to crop needs. If ET information is available to the irrigator, then scheduling irrigations can be accomplished by following a checkbook method of adding and subtracting changes in the soil water balance. The irrigation scheduling procedures allow managers to determine when to begin an irrigation application and the size or amount of that application. The net results of proper scheduling include efficient and prolonged use of limited water resources and improved crop growth and development, thus improving yield and reducing pumping costs.

Related Publications:

- *Considerations for Sprinkler Packages on Center Pivots*. June 1994. K-State Research and Extension. L-908.
- *Efficiencies and Water Losses of Irrigation Systems*. May 1997. K-State Research and Extension. MF-2243.
- *Irrigation Formulas and Conversions*. November 1999. K-State Research and Extension. MF-2402.
- *Predicting the Final Irrigation for Corn, Grain Sorghum, and Soybeans*. May 1996. Kansas State Cooperative Extension. MF-2174.
- *Scheduling Irrigations by Electrical Resistance Blocks*. November 2001. Kansas State Cooperative Extension. L-901.
- *Soil Water Measurements: An Aid to Irrigation Water Management*. October 1989. Kansas State Cooperative Extension. L-795.
- *Soil, Water and Plant Relationships*. May 1996. Kansas State Cooperative Extension. L-904.
- *Sprinkler Package Effects on Runoff, General Guidelines*. April 1994. Kansas State Cooperative Extension. L-903.
- *Tensiometer Use in Scheduling Irrigation*. July 1997. Kansas State Cooperative Extension. L-796.
- *Using Evapotranspiration Reports for Furrow Irrigation Scheduling*. May 1995. Kansas State Cooperative Extension. L-914.
- *Water Measurements as a Management Tool*. June 1993. Kansas State Cooperative Extension. L-878.

K-State Irrigation Web sites:

www.oznet.ksu.edu/irrigate
www.oznet.ksu.edu/mil
www.oznet.ksu.edu/sdi

Table 2. *Soil Water Balance Worksheet*

Field Example #1

Crop Corn

Root Depth Zone 3 feet

Root Zone Available Water Holding Capacity 6 inches

Soil Type Silt Loam

% Allowable Depletion 50 %

Available Water Holding Capacity 2.0 inches/foot

Allowable Depletion 3.0 inches

Date	Effective Rainfall Inches	Net Irrigation Inches	ETr Inches	Stage of Growth	Kco Crop Coefficient	Crop ET Inches	Soil Water Depletion Location 1	Soil Water Depletion Location 2	Comments
7/1			0.22	16 Leaf	1.0+	0.22*	1.50	1.50	+Example of using ETr and Kco*
7/2						0.21	1.71	1.71	*Average ET 7/1 to 7/19=0.21 in./day
7/3		1.5" 1				0.21	0.42	1.92	Location 1 is start of circle
7/4		2				0.25	0.67	2.17	Location 2 is end of circle
7/5		3				0.12	0.79	2.29	Location 1 on 7/3= 1.71+.21-1.50-.00=.42
7/6		4				0.13	0.92	2.42	Location 2 on 7/3= 1.71+.21-.00-.00=1.92
7/7		5				0.22	1.14	2.64	
7/8		6				0.25	1.39	2.89	
7/9		1.5" 1				0.22	1.61 0.11	1.61	Begin 2nd irrigation- Note: 1.61 depletion
7/10		2				0.26	0.37	1.87	greater than application amount of 1.50.
7/11		3				0.34	0.71	2.21	
7/12		4				0.37	1.08	2.58	
7/13		5				0.43	1.51	3.01	Management Guideline exceeded at location 2.
7/14		6				0.35	1.86	3.36	
7/15		1.5" 1				0.16	2.02 0.52	2.02	Begin 3rd irrigation.
7/16	1.25	2				0.30	0 -0.43	1.07	Location 1 .52+.3--0-1.25=-.43 Set depletion to 0.
7/17		3				0.15	0.15	1.22	
7/18		4				0.17	0.32	1.54	
7/19		5				0.23	0.55	1.77	

Table 3. *Soil Water Balance Worksheet*

Field ____________________ Crop ____________________

Root Depth Zone ____________________ feet

Root Zone Available Water Holding Capacity __________ inches

Soil Type ____________________

% Allowable Depletion ____________________ %

Available Water Holding Capacity ______________ inches/foot

Allowable Depletion ____________________ inches

							Soil Water Depletion		
Date	Effective Rainfall Inches	Net Irrigation Inches	ETr Inches	Stage of Growth	Kco Crop Coefficient	Crop ET Inches	Location 1	Location 2	Comments

Table 4. *Soil Water Balance Worksheet*

Field ____Example #2____ Crop ____Corn____

Root Depth Zone ____3____ feet Root Zone Available Water Holding Capacity ____6____ inches

Soil Type ____Silt Loam____ % Allowable Depletion ____50____ %

Available Water Holding Capacity ____2.0____ inches/foot Allowable Depletion ____3.0____ inches

							Soil Water Depletion		
Date	Effective Rainfall Inches	Net Irrigation Inches	ETr Inches	Stage of Growth	Kco Crop Coefficient	Crop ET Inches	Location 1	Location 2	Comments
7/1						0.22	1.50*	1.50	*With split applications irrigation could
7/2						0.21	1.71	1.71	begin with less soil water depletion.
7/3		0.75 1				0.21	1.17	1.92	7/3 - Start 1st irrigation
7/4		2				0.25	1.42	2.17	Half circle @ 0.75 takes about 1.5 days.
7/5		3				0.12	1.54	2.29	Switch to 1.5 inches to finish circle.
7/6		4				0.13	1.67	2.42	
7/7		1.5 5				0.22	1.89	1.14	
7/8		1.5 1				0.25	0.64	1.39	7/8 - Start 2nd irrigation- Full circle has
7/9		2				0.22	0.86	1.61	1.5 inches applied.
7/10		3				0.26	1.12	1.87	
7/11		4				0.34	1.46	2.21	
7/12		5				0.37	1.83	2.58	
7/13		6				0.43	2.26	3.01	Management Guideline of 3.0 inches
7/14		1.5 1				0.35	1.11	1.86	of depletion reached.
7/15		2				0.16	1.27	2.02	
7/16	1.25	3				0.30	0.32	1.09	No loss of rainfall as in previous example.
7/17		4				0.15	0.47	1.24	
7/18		5				0.17	0.64	1.41	
7/19		6				0.23	0.87	1.64	End irrigation would occur 7/20.

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