IRRIGATION

Irrigation Scheduling: The Water Balance Approach no. 4.707

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Quick Facts...

Irrigation scheduling by the water-balance approach is analogous to running a checkbook balance.

Advertised evapotranspiration rates can be used to run water balance and schedule irrigation.

Ready-to-use computer programs facilitate the use of the water-balance approach in irrigation scheduling.

Soil water-content measurements are needed as a safety check on the predicted water content and irrigation timing.

Colorado State University Cooperative Extension

Putting Knowledge to Work

Irrigation scheduling by the water-balance approach is based on estimating the soil water content. This approach is analogous to a checkbook balance. Daily withdrawals are subtracted from the checkbook balance and deposits are added. Should cash-flow scheduling project the balance to drop below some minimum, a special deposit is needed.

In the field, daily evapotranspiration (ET) amounts are withdrawn from storage in the soil profile. Any rainfall or irrigation are added to storage. Should the water balance computation project soil water to drop below some minimum level, irrigation is indicated. Weather forecasts enable prediction of ET rates and projection of soil water balance to indicate whether irrigation is needed in the near future.

Determinating Irrigation Need

Since irrigation scheduling by the water balance approach is based on keeping a balance of soil water content, the irrigation criterion is the percent of water depleted from the soil water available to plants. Two parameters determine the total soil water available to plants. The first parameter is the soil water-holding capacity, which is the amount of water measured in inches/feet or mm/m held in the soil by capillary forces. Typical values of soil-water-holding capacities of several soil textures are shown in Table 1. The second parameter is the effective root zone of the crop, which is the soil depth of the roots. Table 2 shows suggested rooting depth for selected crops at effective cover, time to reach effective cover, growth stage at effective cover, and recommended allowable depletion in percent of total available water holding capacity.

Effective cover date is the date the crop reaches maximum ET and maximum rooting depth. The rooting depth is assumed to increase linearly as a function of time from a minimum root depth at emergence to a maximum root depth at effective cover. A minimum root depth of 4 inches to 6 inches is a good assumption for annual crops. Maximum root depth is determined by crop and soil texture. For alfalfa and pasture, the minimum rooting depth is the same as the maximum rooting depth once the crop is established.

The management allowable depletion (MAD) is the percent of available soil water that is allowed to be depleted before irrigation is applied. Irrigation is needed when the allowed amount of water is depleted from the root zone. Depletion beyond allowable amount stresses plants and reduces crop yield.

Table 1: Typical available water holding capacities based on soil texture.

Textural classes	Available water in inches/foot* of depth
Coarse sands	0.60-0.80
Fine sands	0.80-1.00
Loamy sands	1.10-1.20
Sandy loams	1.25-1.40
Fine sandy loams	1.50-2.00
Silt loams	2.00-2.50
Silty clay loams	1.80-2.00
Silty clay	1.50-1.70
Clay	1.30-1.50

*To convert to metrics, use the following equivalents: 1 inch = 2.5 centimeters; 1 foot = 30 centimeters.

Estimating Soil Water Content

The water content in the effective root zone is estimated by using the water balance equation:

$$WC_t = WC_{t-1} + IRR + RAIN - AET - DP \quad (1)$$

where:

WC_t= Soil water content today (inches),
WC_{t-1}= Soil water content yesterday (inches),
IRR= Irrigation depth since yesterday (inches),
RAIN= Rain since yesterday (inches),
AET= Actual ET (inches), and
DP= Deep percolation (inches).

Water balance calculations cannot begin until soil water content in the root zone is known. It may be established before or after crop emergence. Methods include gravimetric soil water samples or the hand-feel method (fact sheet 4.700, *Estimating Soil Moisture*). From this, the soil water content of successive days can be estimated using the water balance equation.

Four additional values are needed for the water balance equation. Irrigation and rain are the deposits in water balance and are measured or calculated values. Rain is measured by using rain gauges. Irrigation depth is calculated from the application rate of the irrigation system and the duration of application, or by dividing the total net amount of water applied by the irrigated area. If the depth of irrigation or rain exceeds the depth of water depleted from the root zone, the difference is considered as deep percolation (DP) or water that drained below the root zone and is not available for plants.

The last value, actual evapotranspiration (AET), is not measured easily. This is the daily withdrawal in the equation. It is estimated from weather and crop information.

The procedure used to estimate AET is as follows:

$$AET = ETr * KC * KS \quad (2)$$

The reference ET (ETr) is the rate of water lost by a well-watered reference crop, usually alfalfa. This equation adjusts ETr by the crop coefficient (KC) and the soil dryness coefficient (KS). KC defines the stage of growth of the crop, and KS is a function of actual soil water content.

The ETr can be estimated using different ET models that relate ETr to weather conditions. To estimate ETr using ET models, daily weather information is needed. This information may include temperatures, solar radiation, humidity and wind run, depending on the particular ET model used. In several locations, daily ET rates are computed and published by Cooperative Extension agents or Natural Resources Conservation Service (NRCS) personnel as ETr values or AET values for specific crops. If AET values are published, the crop coefficients were already considered for the particular crop.

The number of days from planting to assumed effective cover is given in Table 2 in increments of five days. For a number not a multiple of five, round up the number of days and use the higher number for the crop coefficient. Crop coefficients for several crops were calculated as a function of days from planting and are given in Table 3.

As soil dries, it is more difficult for plants to withdraw water. This phenomenon is described by the soil coefficient, KS, which is a function of soil moisture depletion. Table 4 gives values of KS as a function of depletion from field capacity expressed as a percentage. For example, 10 percent depletion means that the soil profile is 90 percent full, and the soil coefficient is 0.97.

This procedure requires tedious calculations if done by hand. To facilitate its use, several computer programs are available. One program, SCHED, was developed by the ARS irrigation group at Fort Collins and is available from the agricultural and chemical engineering department at Colorado State University.

Many of the programs allow the user to choose the method of ET calculation. The data required are weather, soil and crop information. By using the computerized method, the irrigation decision can be made quickly. The only labor and time involved is that needed to collect the data and input it into the computer. If a computer and weather station are not available, use published ET rates from the closest location to the field and calculate water balance by hand.

A word of caution: Irrigation scheduling by the water balance approach is based on estimates and is not always accurate. When this procedure is first used, monitor the soil water content in the field and compare it to the calculated content once a week or every other week. If a discrepancy is found, correct the calculated water balance. Once the program is tuned to the particular field conditions and the predicted values agree with measured soil water values, less frequent measurements of soil water content serve as a safety check on the predicted values.

Example

Corn was planted May 10 on a silty clay-loam soil with a water-holding capacity of 2 inches per foot of soil depth. The effective root zone is 2.5 feet and the corn has tasseled (after effective cover). The total available water is 2 x 2.5 = 5 inches for the corn root zone. The MAD (Table 2) is 50 percent. The irrigation strategy is to fill the soil profile to field capacity at each irrigation.

An example of a typical balance sheet (Table 5) starts on July 10 with an irrigation of 2.5 inches, which brings the soil to field capacity. In this example, the ETr calculation (column 2) is not shown but is assumed to be available. Column 3 is the crop coefficient found from Table 3.

The number of days from May 10 to July 11 is 62. Because we round up, the value for the crop coefficient (Table 3) for the next three days will be the one for 65 days from planting, which is KC = 0.92. On July 15 (70 days from planting) KC = 0.93. The soil coefficient (column 4) is found from Table 4.

Table 4: Soil coefficient (KS) as a function of depletion level.

Depletion %	KS
0	1.0
5	0.98
10	0.97
15	0.96
20	0.95
25	0.94
30	0.92
35	0.90
40	0.89
45	0.87
50	0.85
60	0.80
70	0.74

To find the percent of soil water depletion, divide the depletion of the previous day (column 9) by the total available water. For example, to find KS for July 12, divide the previous day's depletion (0.29 inches) by the total available water (5 inches), which gives 5.8 percent. The corresponding KS value is 0.98.

For July 11, KS = 1 since the soil water depletion is 0. Column 5 is the actual ET (AET), which is the actual water consumption for this day and is found by applying Equation 2 or multiplying columns 2, 3 and 4.

The next two columns (6 and 7) are irrigation and rain that can be measured and taken into account. Column 8 is the MAD in inches, or the amount of water that is allowed to be depleted before irrigation is called for. For this example, the allowable depletion is 2.5 inches because we allow 50 percent of 5 inches of total available water.

The last column (9) is the present depletion that should be compared with column 8 to indicate a need for irrigation. In this example, irrigation was applied on July 20, which was the first day after the depletion level was higher than 2.5 inches (50 percent level of allowable depletion).

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Table 2: Rooting depths, effective cover and allowable depletion for selected crops (Duke et al. 1987)*

Crop	Root depth at effective cover (ft)	Growth stage at effective cover	Days from planting to effective cover	Days from effective cover to harvest	Range for allowable depletion %
Alfalfa	4-6	12 in. (30 cm) growth	50-60	35-40	30-50
Beans	2-3	bloom	50-55	40-45	50-70
Corn	2.5-4	10 days after tasseling	70-75	65-70	40-60
Grain sorghum	3-4	heading	45	60-75	40-60
Onions	1.5-2	max. leaf height	90-100	45	25-50
Pasture	3-4	30 days after spring growth begins	30	--	40-60
Potatoes	2-3	week after bloom	75-80	90	25-50
Small grain	3-4	heading	75-80	55-60	50-70
Sugar beets	3-4	full canopy between rows	80-85	90-95	30-60

**Scheduling Irrigations: A guide for improved irrigation water management through proper timing and amount of water application*. Fort Collins, Colorado. 1987.

Table 3: Crop coefficients of different crops as a function of days from planting.

Days from Planting	Corn	Dry Beans	Potatoes	Sorghum	Soybeans	Small Grains	Sugar Beets	Alfalfa	Pasture
5	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.25	0.25
10	0.20	0.24	0.20	0.25	0.22	0.16	0.20	0.45	0.75
15	0.23	0.30	0.23	0.34	0.28	0.18	0.21	0.55	0.90
20	0.28	0.38	0.26	0.46	0.36	0.22	0.22	0.65	0.90
25	0.34	0.49	0.31	0.59	0.45	0.28	0.24	0.74	0.90
30	0.41	0.60	0.37	0.73	0.56	0.37	0.27	0.84	0.90
35	0.49	0.72	0.43	0.86	0.68	0.46	0.31	0.94	0.90
40	0.57	0.84	0.50	0.93	0.79	0.56	0.35	1.00	0.90
45	0.66	0.92	0.58	0.93	0.90	0.67	0.40	1.00	0.90
500.74	0.92	0.65	0.93	0.92	0.77	0.47	1.00	0.90	
55	0.81	0.92	0.72	0.93	0.92	0.86	0.54	1.00	0.90
60	0.87	0.92	0.78	0.93	0.92	0.94	0.62	0.63	0.90
65	0.92	0.92	0.84	0.93	0.92	1.00	0.71	0.75	
70	0.93	0.92	0.88	0.93	0.92	1.00	0.81	0.88	
75	0.93	0.92	0.90	0.93	0.92	1.00	0.91	1.00	
80	0.93	0.91	0.90	0.93	0.92	1.00	1.03	1.00	
85	0.93	0.85	0.90	0.93	0.92	1.00	1.00	1.00	
90	0.93	0.79	0.90	0.93	0.92	1.00	1.01	1.00	
95	0.92	0.73	0.90	0.93	0.92	0.94	1.01	1.00	
100	0.91	0.66	0.90	0.93	0.89	0.85	1.01	1.00	
105	0.89	0.59	0.90	0.93	0.86	0.74	1.00	1.00	
110	0.83	0.52	0.90	0.93	0.83	0.62	0.99	1.00	
115	0.77	0.45	0.90	0.93	0.81	0.49	0.98		
120	0.70	0.38	0.90	0.90	0.78	0.34	0.96		
125	0.67	0.31	0.90	0.88	0.77	0.19	0.94		
130	0.63	0.25	0.90	0.87	0.76	0.15	0.91		
135	0.55	0.20	0.90	0.87	0.75	0.15	0.89		
140	0.48	0.15	0.90	0.87	0.75	0.15	0.86		

Table 5: Balance sheet example for corn.

(1) Date	(2) ETr (in)	(3) Crop Coefficient (KC)	(4) Soil Coefficient (KS)	(5) AET (in)	(6) Irrigation (in)	(7) Rain (in)	(8) AD (in)	(9) Depletion (in)
07/10					2.5	--	2.50	0
07/11	0.32	0.92	1.00	0.29	--	--	2.50	0.29
07/12	0.36	0.92	0.98	0.32	--	--	2.50	0.61
07/13	0.35	0.92	0.97	0.31	--	--	2.50	0.92
07/14	0.38	0.92	0.95	0.33	--	--	2.50	1.25
07/15	0.32	0.93	0.94	0.28	--	--	2.50	1.53
07/16	0.36	0.93	0.92	0.30	--	--	2.50	1.83
07/17	0.29	0.93	0.90	0.24	--	--	2.50	2.07
07/18	0.39	0.93	0.89	0.32	--	--	2.50	2.39
07/19	0.35	0.93	0.85	0.27	--	--	2.50	2.66
07/20	0.32	0.93	0.85	0.25	2.5	--	2.50	0.41
07/21	0.38	0.93	0.97	0.34	--	--	2.50	0.75