Colorado State University
Extension

Irrigation Scheduling: The Water Balance Approach

Fact Sheet No. **4.707** Crop Series | **Irrigation**

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The water requirement of a crop must be satisfied to achieve potential yields. The crop water requirement is also called crop evapotranspiration and is usually represented as ET_c. Evapotranspiration is a combination of two processes – evaporation of water from the ground surface or wet surfaces of plants; and transpiration of water through the stomata of leaves. The water requirement can be supplied by stored soil water, precipitation, and irrigation. Irrigation is required when ET_c (crop water demand) exceeds the supply of water from soil water and precipitation. As ET_c varies with plant development stage and weather conditions, both the amount and timing of irrigation are important. The water balance (accounting) method of irrigation scheduling is one method of estimating the required amount and timing of irrigation for crops. This method can be used if initial soil water content in the root zone, ET_c, precipitation, and the available water capacity of the soil are known.

The soil in the root zone has an upper as well as a lower limit of storing water that can be used by crops. The upper limit is called the field capacity (*FC*), which is the amount of water that can be held by the soil against gravity after being saturated and drained; typically attained after 1 day of rain or irrigation for sandy soils and from two to three days for heavier-textured soils that contain more silt and clay. The lower limit is called permanent wilting point (*PWP*), which is the amount of water remaining in the soil when the plant permanently wilts because it can no longer extract water. The available water capacity (*AWC*), or total available water, of the soil is the amount of water between these two limits ($AWC = FC - PWP$) and is the maximum amount of soil water that can be used by the plants. The *AWC* of soil is typically expressed in terms of inches of water per inch of soil depth. General values of *AWC* are provided in Table 1. Available water capacity values for specific soils can be obtained from county soil surveys or online at http://websoilsurvey.nrcs.usda.gov/app/.

Water Balance Accounting

As the crop grows and extracts water from the soil to satisfy its ET_c requirement, the stored soil water is gradually depleted. In general, the net irrigation requirement is the amount of water required to refill the root zone soil water content back up to field capacity. This amount, which is the difference between field capacity and current soil water level, corresponds to the soil water deficit (*D*). The irrigation manager can keep track of *D*, which gives the net amount of irrigation water to apply. On a daily basis, *D* can be estimated using the following accounting equation for the soil root zone:

$$D_c=D_p+ET_c-P-Irr-U+SRO+DP \qquad [1]$$

where D_c is the soil water deficit (net irrigation requirement) in the root zone on the current day, D_p is the soil water deficit on the previous day, ET_c is the crop evapotranspiration rate for the current day, *P* is the gross precipitation for the current day, *Irr* is the net irrigation amount infiltrated into the soil for the current day, *U* is upflux of shallow ground water into the root zone, *SRO* is surface runoff, and *DP* is deep percolation or drainage.

The last three variables in equation 1 (*U, SRO, DP*) are difficult to estimate in the field. In many situations, the water table is significantly deeper than the root zone and *U* is zero. Also, *SRO* and *DP* can be accounted for in a simple way by setting D_c to zero whenever water additions (*P* and *Irr*) to the root zone are greater than $D_p + ET_c$. Using these assumptions, equation 1 can be simplified to:

$$D_c= D_p+ET_c-P-Irr$$

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Quick Facts

- The water balance approach to irrigation scheduling keeps track of the soil water deficit by accounting for all water additions and subtractions from the soil root zone.
- Crop water consumption or evapotranspiration accounts for the biggest subtraction of water from the root zone while precipitation and irrigation provide the major additions.
- Crop evapotranspiration can be obtained from the Colorado Agricultural Meteorological Network (CoAgMet) or by using atmometers.
- The soil in the root zone has an upper as well as a lower limit of storing water that can be used by crops.
- As the crop grows and extracts water from the soil to satisfy its ET_c requirement, the stored soil water is gradually depleted.
- Atmometers are designed to simulate the water use of a well-watered reference crop.

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Table 1. Soil texture and plant available water capacity (AWC)

Soil Texture	Available water capacity		
	Low	High	Average
	– inch of water / inch of soil –		
Coarse sands	0.05	0.07	0.06
Fine sands	0.07	0.08	0.08
Loamy sands	0.07	0.10	0.08
Sandy loams	0.10	0.13	0.12
Fine sandy loams	0.13	0.17	0.15
Sandy clay loams	0.13	0.18	0.16
Loams	0.18	0.21	0.20
Silt loams	0.17	0.21	0.19
Silty clay loams	0.13	0.17	0.15
Clay loam	0.13	0.17	0.15
Silty clay	0.13	0.14	0.13
Clay	0.11	0.13	0.12

(if D_c is negative, then set it to 0.0) [2]

Take note that D_c is set equal to zero if its value becomes negative. This will occur if precipitation and/or irrigation exceed (D_p + ET_c) and means that water added to the root zone already exceeds field capacity within the plant root zone. Any excess water in the root zone is assumed to be lost through *SRO* or *DP*.

The amounts of water used in the equations are typically expressed in depths of water per unit area (e.g., inches of water per acre). Equation 2 is a simplified version of the soil water balance with several underlying assumptions. First, any water additions (*P* or *Irr*) are assumed to readily infiltrate into the soil surface and the rates of *P* or *Irr* are assumed to be less than the long term steady state infiltration rate of the soil. Actually, some water is lost to surface runoff if precipitation or irrigation rates exceed the soil infiltration rate. Thus, equation 2 will under-estimate the soil water deficit or the net irrigation requirement if *P* or *Irr* rates are higher than the soil infiltration rate. Knowledge of effective precipitation (*P - SRO - DP*), irrigation, and soil infiltration rates (e.g. inches per hour) are required to obtain more accurate estimates of D_c. Secondly, water added to the root zone from a shallow water table (*U*) is not considered. Groundwater contributions to soil water in the root zone must be subtracted from the right hand side of the equation in case of a shallow water table. Equation 2 will over-estimate D_c if any actual soil water additions from groundwater are neglected.

It is a good practice to occasionally check (e.g., once a week) if D_c from equation 2 is the same as the actual deficit in the field (soil water content readings using soil moisture sensors). Remember that D_c is the difference between field capacity and current soil water content. Therefore, the actual deficit in the field can be determined by subtracting the current soil water content from the field capacity of the root zone. If D_c from equation 2 is very different from the observed deficit, then use the observed deficit as the D_c value for the next day. These corrections are necessary to compensate for uncertainties in the water balance variables. Field measurements of current soil water content can be performed using the gravimetric method (weighing of soil samples before and after drying) or using soil water sensors like gypsum blocks (resistance method).

In irrigation practice, only a percentage of *AWC* is allowed to be depleted because plants start to experience water stress even before soil water is depleted down to *PWP*. Therefore, a management allowed depletion (*MAD*, %) of the *AWC* must be specified. Refer to fact sheet number 4.715 (*Crop Water Use and Growth Stages*) for values of *MAD* for selected crops. Ranges of rooting depth for selected crops are given in Table 2. The rooting depth and *MAD* for a crop will change with developmental stage. The *MAD* can be expressed in terms of depth of water (d_{MAD}; inches of water) using the following equation.

$$d_{MAD}=\frac{MAD}{100}*AWC*D_{rz} \qquad [3]$$

where *MAD* is management allowed depletion (%), *AWC* is available water capacity of the root zone (inch of water per inch of soil), and D_{rz} is depth of root zone (inches; see Table 2).

The value of d_{MAD} can be used as a guide for deciding when to irrigate. Typically, irrigation water should be applied when the soil water deficit (D_c) approaches d_{MAD}, or when $D_c \geq d_{MAD}$. To minimize water stress on the crop, D_c should be kept less than d_{MAD}. If the irrigation system has enough capacity, then the irrigator can wait until *D* approaches d_{MAD} before starting to irrigate. The net irrigation amount equal to D_c can be applied to bring the soil water deficit to zero. Otherwise, if the irrigation system has limited capacity (maximum irrigation amount is less than d_{MAD}), then the irrigator should not wait for D_c to approach d_{MAD}, but should irrigate more frequently to ensure that *D* does not exceed d_{MAD}. However,

Table 2. Irrigation management depths (Drz) in inches for selected crops. (Assumes rooting is not restricted by compaction or shallow soils.) (Bauder and Schneekloth, 2006)

	Irrigation management depths			
Annual crop	**Seedling**	**Vegetative**	**Flowering**	**Mature**
	- Soil depth or D_{rz} (inches) –			
Corn	12	24	30	36 to 48
Potatoes	12	18	24	24 to 48
Small grain	12	18	24	36 to 48
Field beans	12	18	24	24 to 30
Sugarbeets	12	18	24	36 to 48
Vegetables	6 to 12	18	18	18 to 24

Perennial crop	Seedling	Establishment	Mature
Alfalfa	6 to 12	24 to 36	48 to 72
Turf and lawns	6	12	12
Grass and pasture	6	12	24

keep in mind that more frequent irrigations increase evaporation of water from the soil surface, which is considered a loss. In addition, when rainfall is in the forecast, the irrigator might want to leave the root zone below field capacity to allow for storage of forecasted precipitation.

Estimating Crop ET

Crop evapotranspiration (ET_c), in inches per day, is estimated as:

$$ET_c = ET_r \times K_c \times K_s \qquad [4]$$

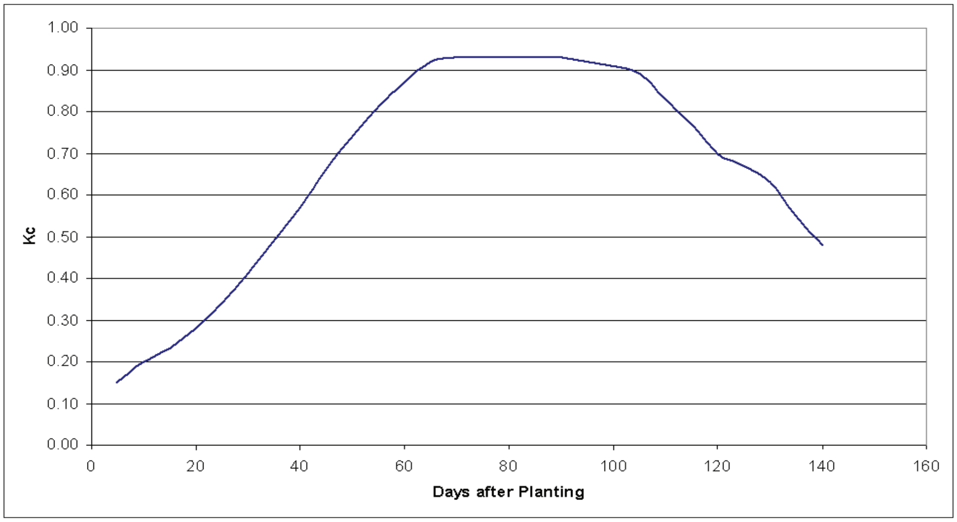
where ET_r is the evapotranspiration rate (inches/day) from a reference crop (e.g., alfalfa), K_c is a crop coefficient that varies by crop development stage (ranges from 0 to 1), and K_s is a water stress coefficient (ranges from 0 to 1). At any given point in the growing season, the K_c for a crop is simply the ratio of its ET over the reference crop ET. The K_c can be thought of as the fraction of the reference crop ET that is used by the actual crop. Values of K_c typically range from 0.2 for young seedlings to 1.0 for crops at peak vegetative stage with canopies fully covering the ground. In some instances, peak K_c might reach 1.05-1.10, for crops showing similar biomass characteristics as alfalfa, when the soil and canopies are wet (after irrigation/rain). A typical crop coefficient curve (K_c values that change with crop development) is shown in Figure 1. Crop coefficient values for commonly grown crops are given in Table 3. If D_c remains less than d_{MAD}, K_s may be assumed to be 1. A K_s of 1 means that the crop is not experiencing water stress. The Colorado Agricultural Meteorological Network (CoAgMet) provides daily values of ET_c for common crops assuming that K_s = 1 (no water stress). CoAgMet calculates K_c internally, based on planting date and weather data. Refer to fact sheet 4.723, *The Colorado Agricultural Meteorological Network (CoAgMet) and Crop ET Reports*, to obtain daily ET_c values at many locations around the state.

In cases when water availability is limited (e.g., lack of precipitation or irrigation; $D_c > d_{MAD}$), then K_s will be less than 1, and crop ET_c will not occur at the potential (non-water-limited) rate. The water stress coefficient is calculated by (Allen et al., 1998):

$$K_s = \frac{TAW\text{-}D}{(1\text{-}MAD)*TAW} \quad (K_s = 1 \text{ if } D < d_{MAD}) \qquad [5]$$

where *TAW* is total available water in the soil root zone (inches), *D* is the soil water deficit (inches), and *MAD* is management

Figure 1. Example crop coefficient curve that shows K_c values that change with crop development.



allowed depletion (decimal fraction). The value of *TAW* can be calculated from:

$$TAW=AWC*D_{rz} \qquad [6]$$

where *AWC* is available water capacity of the root zone (inch of water / inch of soil) and D_{rz} is the total depth of the root zone (inches). In equation 5, *MAD* is specifically defined as the fraction of *AWC* that a crop can extract from the root zone without suffering water stress. Note that K_s should be set equal to one when *D* is less than d_{MAD}. The ET_c obtained from CoAgMet should be multiplied by K_s calculated from equation 5 to get an "actual" (water-stressed) ET_c value that can be used in equation 2.

Equations 2 through 6 can easily be entered as formulas into a spreadsheet, with columns for daily values of *P*, *Irr*, D_{rz}, *TAW*, K_s, ET_c, and D_c. Values of *P*, *Irr*, D_{rz}, and potential (non-water-stressed) ET_c can be input in the spreadsheet on a daily basis, and D_c calculated automatically. Daily values of potential ET_c and *P* can be obtained from CoAgMet (www.coagmet.com), if your field is near enough to an existing CoAgMet weather station.

Using Atmometers

An alternative to obtaining ET_c values from CoAgMet is to obtain onsite measurements using a field instrument called an atmometer. This device can estimate reference crop ET at locations that don't have a CoAgMet weather station, have unusual micro-climate characteristics, or when a user doesn't have access to CoAgMet data. An atmometer can give reasonable estimates of alfalfa reference ET (ET_r) but may underestimate ET_r during periods of rain or high wind (Chen and Robinson, 2009). An atmometer basically consists of a wet, porous ceramic cup mounted on top of a cylindrical water reservoir (Figure 2). The ceramic cup is covered with a green fabric that simulates the canopy of a crop. The reservoir is filled with distilled water that evaporates out of the ceramic cup and is pulled through a suction tube that extends to the bottom of the reservoir. Underneath the fabric, the ceramic cup is covered by a special membrane that keeps rain water from seeping into the ceramic cup. A rigid wire extending from the top keeps birds from perching on top of the gauge. A site tube on the front of the instrument allows the user to observe and record the water level, similar to a rain gauge. The ET rate for a given time period is the difference in water level between two time periods.

Atmometers are designed to simulate the water use of a well-watered reference crop, which is either alfalfa (represented as ET_r) or clipped grass (represented as ET_o) that is fully covering the ground. In Colorado, alfalfa reference (ET_r) is commonly used. Actual ET from a specific crop can be estimated using equation 4, following a similar procedure described in the previous section. The atmometer provides an estimate of ET_r, which must be multiplied by the appropriate K_c and K_s (if there is water stress) values to obtain ET_c. Crop coefficients for commonly grown crops are provided in Table 3. For most non-water-stressed forage and grain crops at full canopy, water loss from an

Table 3. Representative crop coefficients (Kc) of commonly grown crops for use with alfalfa reference ET (ETr).

Days from planting or green-up	Corn	Dry Beans	Potatoes	Winter Wheat	Transplant onions	Spring Small Grains(barley, oats, etc)	Sugar Beets	Alfalfa	Pasture
5	0.25	0.23	0.22	0.30	0.38	0.20	0.19	0.25	0.33
10	0.25	0.30	0.21	0.33	0.38	0.25	0.20	0.43	0.33
15	0.26	0.33	0.26	0.44	0.39	0.32	0.20	0.61	0.45
20	0.27	0.44	0.33	0.52	0.40	0.40	0.21	0.82	0.56
25	0.27	0.57	0.40	0.65	0.42	0.50	0.22	1.00	0.68
30	0.29	0.71	0.50	0.74	0.43	0.60	0.27	1.00	0.79
35	0.35	0.89	0.59	0.82	0.45	0.69	0.30	1.00	0.79
40	0.41	1.00	0.70	0.89	0.46	0.78	0.33	1.00	0.79
45	0.49	1.00	0.73	0.95	0.47	0.88	0.36	1.00	0.79
50	0.58	1.00	0.81	1.00	0.48	0.96	0.38	1.00	0.79
55	0.67	1.00	0.87	1.00	0.50	1.00	0.43	1.00	0.79
60	0.73	1.00	0.94	1.00	0.52	1.00	0.50	0.33*	0.79
65	0.78	1.00	0.95	1.00	0.56	1.00	0.55	0.45	
70	0.86	1.00	0.95	1.00	0.59	1.00	0.60	0.77	
75	0.91	0.92	0.95	1.00	0.61	1.00	0.66	1.00	
80	0.94	0.85	0.95	1.00	0.65	0.93	0.77	1.00	
85	1.00	0.79	0.95	0.92	0.67	0.85	0.84	1.00	
90	1.00	0.73	0.95	0.85	0.74	0.77	0.92	1.00	
95	1.00	0.66	0.95	0.72	0.78	0.61	1.00	1.00	
100	1.00	0.59	0.95	0.58	0.81	0.45	1.00	1.00	
105	0.98	0.52	0.95	0.48	0.81	0.29	1.00	*after cutting	
110	0.96	0.45	0.95	0.35	0.81	0.23	1.00		
115	0.91	0.38	0.95	0.22	0.81	0.20	1.00		
120	0.85		0.95	0.22	0.81	0.20	1.00		
125	0.78		0.95	0.22	0.81	0.20	1.00		
130	0.69		0.95	0.22	0.81	0.20	1.00		
135	0.64		0.95	0.22	0.81	0.20	1.00		
140	0.58		0.95	0.22	0.80	0.20	0.96		

Source: Coefficients for all crops except pasture were from www.CoAgMet.com. CoAgMet Kc curves were based on values developed by Wright (1981, 1982) at Kimberly, Idaho and were adapted for Colorado conditions by the U.S. Bureau of Reclamation. Coefficients for pasture were based on the Food and Agriculture Organization (FAO) paper 56 Kc values (Allen et al., 1998).

atmometer will be practically equal to actual crop ET.

Atmometers are typically mounted on a wooden post near irrigated fields. A good location for placement is a border ridge in an alfalfa field. However, you may also locate the instrument alongside a dirt road if surrounded by low growing irrigated crops. Dust accumulation from the dirt road may require more frequent cleaning of the green fabric. The site should represent average field conditions. Do not install near farm buildings, trees, or tall crops that may block the wind. Additionally, avoid placement near dry, fallow fields. The top of the ceramic cup should be 39 inches above the ground. The manufacturer of a modified atmometer sold in Colorado (ETgage®; www.etgage.com) provides detailed instructions on how to install and maintain their instrument.

Yuma, Colorado

The example below is for a hypothetical dry bean field in Yuma, Colorado having Kuma silt loam soil with an available water capacity (*AWC*) of 0.20 inches of water per inch of soil for the top 30 inches. The *AWC* for this soil was taken from the online Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/app/. The Web Soil Survey is an online soils database maintained by USDA-Natural Resources Conservation Service. Instructions on how to use the tool are given on the home page.

The dry beans were planted on May 31, 2008 and the initial soil water was assumed to be at field capacity (profile was full). This meant that the soil water deficit (*D*) was zero at the start of the growing season. This assumption was reasonable because actual precipitation from January 15 to May 30, 2008 was 2.56 inches, which was greater than *AWC* for the top foot of soil (root zone during stand establishment phase).

Water requirements of dry beans change throughout the season because rooting depth (access to available soil water) and the rate of ET_c change as the crop develops and weather varies. Table 4 shows the assumed management rooting depths and corresponding values of root zone *AWC* and *MAD* for different growth phases of dry beans (Bauder and Schneekloth, 2006).

Before using equation 2, an irrigator must pre-determine the depth of

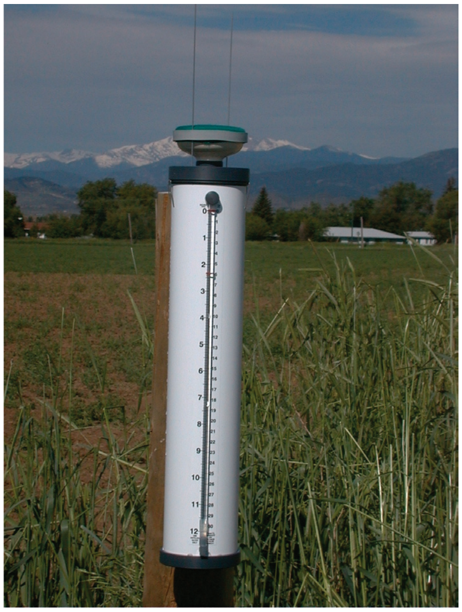


Figure 2. An atmometer installed in a field. Reference crop ET is estimated from changes in the water level, which is visible through the graduated site tube in front of the distilled water reservoir.

management allowed depletion (d_{MAD}) that corresponds to the *MAD* for dry beans at a particular growth stage. The values of d_{MAD} were calculated using equation 3. The total available water (*TAW*) in Table 4 was obtained using equation 6. For example, d_{MAD} of the root zone during stand establishment is: (60 / 100) ×12 inches soil × 0.20 inches of water/inch soil = 1.4 inches of water. This means that during the stand establishment phase (June 1 to June 30), when the soil water deficit (D_c) becomes equal to or greater than 1.4 inches, then irrigation water must be applied. Similar calculations were done for the other growth phases in Table 4.

This example assumes that irrigation water is available throughout the growing season so that water stress can be avoided.

Table 4. Assumed rooting depths and MAD at different developmental phases of dry beans.

Dates	Phase	D_{rz}, in	*TAW*, in	MAD, %	d_{MAD}, in
6/1 - 6/30	stand establishment	12	2.4	60	1.4
7/1 - 7/21	rapid vegetative	20	4.0	60	2.4
7/22 - 8/15	flowering; pod dev't.	30	6.0	50	3.0
8/16 - 9/10	pod fill and maturation	30	6.0	70	4.2

Therefore, equation 5 for K_s was not used and K_s was assumed equal to 1. Daily evapotranspiration values for dry beans and daily precipitation in 2008 were obtained from a CoAgMet weather station at Yuma, Colorado (http://ccc.atmos.colostate.edu/cgi-bin/extended_etr_form.pl). Instructions on how to use the tool are given at the top of the webpage. For this example, the following options were selected on the webpage:

Select a Start Date: 2008 May 31;
Select days (# to do): 120;
Station: yum02 - Yuma;
Select Crops and Planting Date: Drybeans, m = 05, d = 31;
Reference ET Model: Penman-Kimberly.
The "Submit" button was clicked once the above selections were made.

From the planting date of May 31, 2008 to the maturity date of September 10, 2008, the dry bean crop consumed a total of 22.78 inches of water by evapotranspiration, but only received a total of 14.31 inches of precipitation (Figure 3). It is interesting to note that until July 2, 2008, cumulative precipitation exceeded the cumulative ET_c requirement of dry beans. However, precipitation could not keep up with the cumulative ET_c requirement after this date.

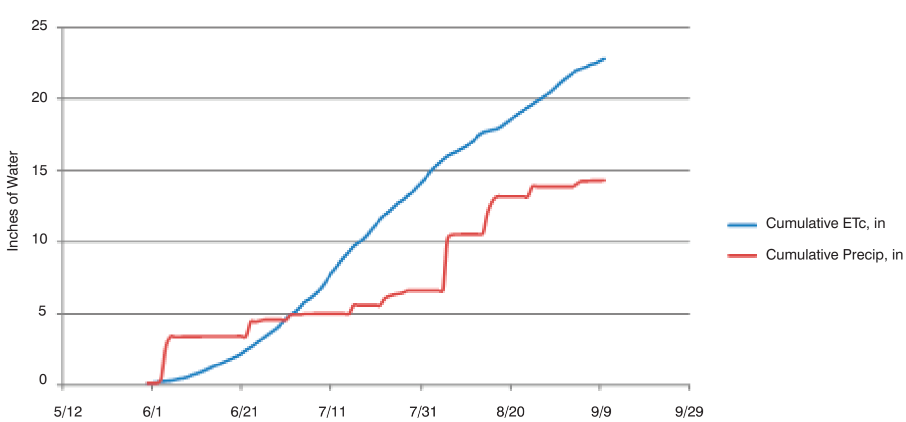
The daily ET_c and *P* values for 2008 were copied from the CoAgMet crop ET access page and pasted into separate columns of a spreadsheet. Equation 2 was then input as a formula for a new column to keep track of daily soil water deficits. A fourth spreadsheet column was also added for input of any irrigation amounts. Figure 4 shows a screen shot of the spreadsheet used for this example. For different growth phases of the dry bean crop, irrigation amounts equal to the current soil water deficit were entered on days when the soil water deficit (D_c) equaled or exceeded the d_{MAD} (inches of soil water) given in the right-most column of Table 4.

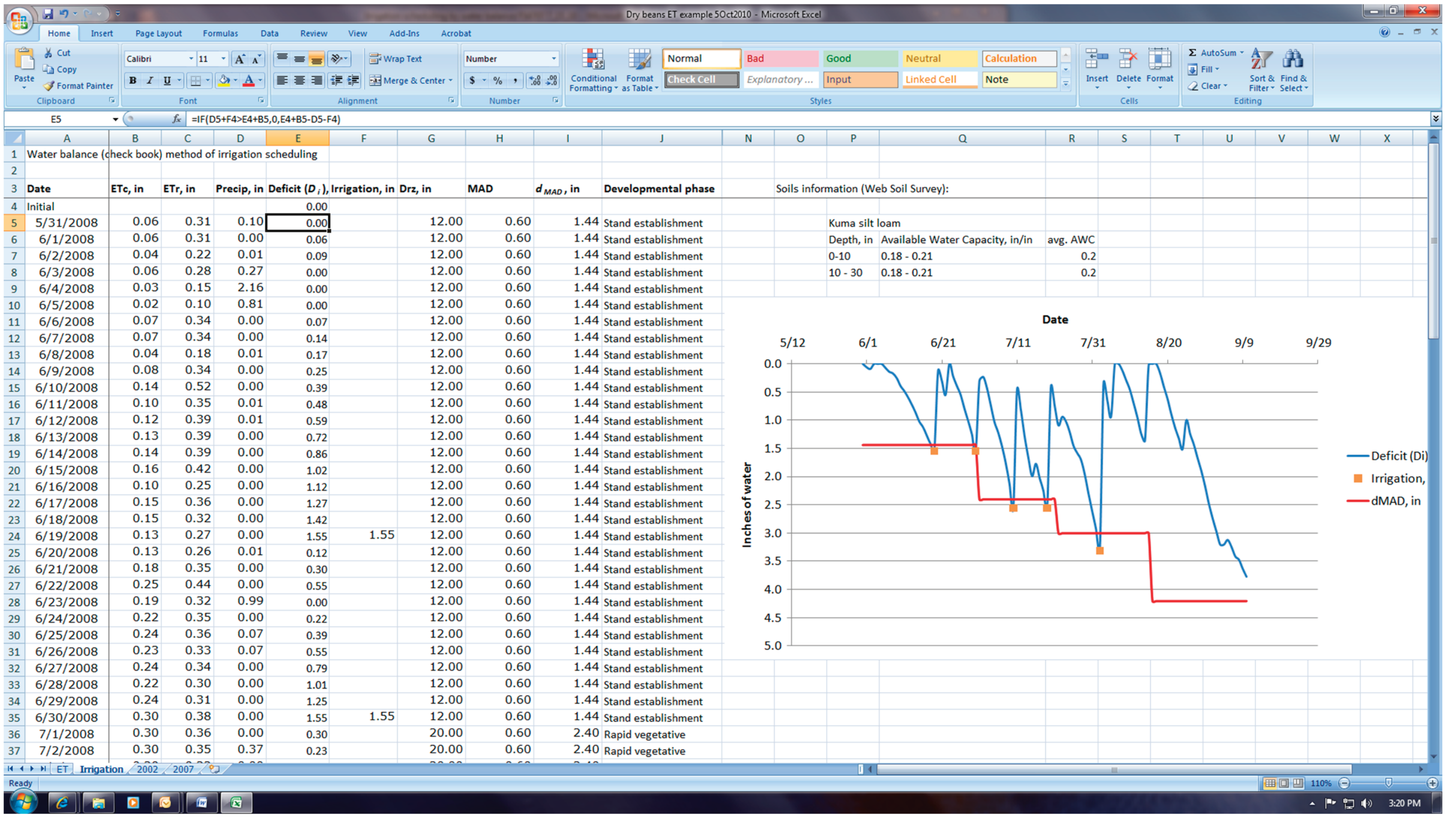
Figure 5 shows the progression of soil water deficits, irrigation dates, and irrigation amounts through the growing season. The red line indicates the d_{MAD} (inches of soil water) values that were used as thresholds for specifying irrigation timings and amounts. Irrigations were scheduled (orange squares) when the soil water deficit curve (blue line) went below the d_{MAD} (red line) in each growth phase. For example, 2.56 inches of irrigation were required on July 10, 2008. This was when the current soil water deficit (D_c = 2.56 in) exceeded the management allowed depletion of 2.4 inches during the vegetative phase.

Based on equation 2, five irrigations were required to satisfy the ET_c requirements of dry beans from May 31 to September 10, 2008. Note how the soil water deficit was reduced when irrigations occurred (Figure 5). In addition, the soil water deficit was also reduced at times when rainfall occurred. The total net irrigation requirement for this period was 11.53 inches. The last irrigation required was 3.31 inches on August 2. After this, there were several significant rainfall events that eliminated or reduced the soil water deficit, keeping it below the dMAD during pod development and maturation.

The irrigation amounts shown in Figure 5 may have to be applied in several installments or irrigation sets, depending on the type of irrigation system. Realistically, these amounts (1.6 to 3.3 inches) may be more suitable for surface systems such as furrow irrigation.

Figure 3. Cumulative dry bean evapotranspiration (ET_c) and precipitation (*P*) at Yuma in 2008.





Water balance (check book) method of irrigation scheduling

Date	ETc, in	ETr, in	Precip, in	Deficit (D_i),	Irrigation, in	Drz, in	MAD	d_{MAD}, in	Developmental phase
Initial				0.00					
5/31/2008	0.06	0.31	0.10	0.00		12.00	0.60	1.44	Stand establishment
6/1/2008	0.06	0.31	0.00	0.06		12.00	0.60	1.44	Stand establishment
6/2/2008	0.04	0.22	0.01	0.09		12.00	0.60	1.44	Stand establishment
6/3/2008	0.06	0.28	0.27	0.00		12.00	0.60	1.44	Stand establishment
6/4/2008	0.03	0.15	2.16	0.00		12.00	0.60	1.44	Stand establishment
6/5/2008	0.02	0.10	0.81	0.00		12.00	0.60	1.44	Stand establishment
6/6/2008	0.07	0.34	0.00	0.07		12.00	0.60	1.44	Stand establishment
6/7/2008	0.07	0.34	0.00	0.14		12.00	0.60	1.44	Stand establishment
6/8/2008	0.04	0.18	0.01	0.17		12.00	0.60	1.44	Stand establishment
6/9/2008	0.08	0.34	0.00	0.25		12.00	0.60	1.44	Stand establishment
6/10/2008	0.14	0.52	0.00	0.39		12.00	0.60	1.44	Stand establishment
6/11/2008	0.10	0.35	0.01	0.48		12.00	0.60	1.44	Stand establishment
6/12/2008	0.12	0.39	0.01	0.59		12.00	0.60	1.44	Stand establishment
6/13/2008	0.13	0.39	0.00	0.72		12.00	0.60	1.44	Stand establishment
6/14/2008	0.14	0.39	0.00	0.86		12.00	0.60	1.44	Stand establishment
6/15/2008	0.16	0.42	0.00	1.02		12.00	0.60	1.44	Stand establishment
6/16/2008	0.10	0.25	0.00	1.12		12.00	0.60	1.44	Stand establishment
6/17/2008	0.15	0.36	0.00	1.27		12.00	0.60	1.44	Stand establishment
6/18/2008	0.15	0.32	0.00	1.42		12.00	0.60	1.44	Stand establishment
6/19/2008	0.13	0.27	0.00	1.55	1.55	12.00	0.60	1.44	Stand establishment
6/20/2008	0.13	0.26	0.01	0.12		12.00	0.60	1.44	Stand establishment
6/21/2008	0.18	0.35	0.00	0.30		12.00	0.60	1.44	Stand establishment
6/22/2008	0.25	0.44	0.00	0.55		12.00	0.60	1.44	Stand establishment
6/23/2008	0.19	0.32	0.99	0.00		12.00	0.60	1.44	Stand establishment
6/24/2008	0.22	0.35	0.00	0.22		12.00	0.60	1.44	Stand establishment
6/25/2008	0.24	0.36	0.07	0.39		12.00	0.60	1.44	Stand establishment
6/26/2008	0.23	0.33	0.07	0.55		12.00	0.60	1.44	Stand establishment
6/27/2008	0.24	0.34	0.00	0.79		12.00	0.60	1.44	Stand establishment
6/28/2008	0.22	0.30	0.00	1.01		12.00	0.60	1.44	Stand establishment
6/29/2008	0.24	0.31	0.00	1.25		12.00	0.60	1.44	Stand establishment
6/30/2008	0.30	0.38	0.00	1.55	1.55	12.00	0.60	1.44	Stand establishment
7/1/2008	0.30	0.36	0.00	0.30		20.00	0.60	2.40	Rapid vegetative
7/2/2008	0.30	0.35	0.37	0.23		20.00	0.60	2.40	Rapid vegetative

Figure 4. Spreadsheet for calculating soil water deficits (D_c) and irrigation amounts for dry beans at Yuma, Colorado in 2008. The cell information box (“*fx* =”) just above the spreadsheet columns is showing the Excel formula used to calculate D_c.

Sprinkler systems such as center-pivots may not have the capacity to apply large amounts of water in one pass. Therefore, more frequent but smaller amounts of irrigation are necessary for such systems and irrigations are scheduled before the soil water deficit reaches d_{MAD}. Regardless of the type of irrigation system, the water balance approach of irrigation scheduling (Equations 1 or 2) can be used to keep track of the soil water deficit and schedule irrigations before or when management allowed depletion is reached. The approach shown in the above example can be used at other locations having nearby CoAgMet weather stations.

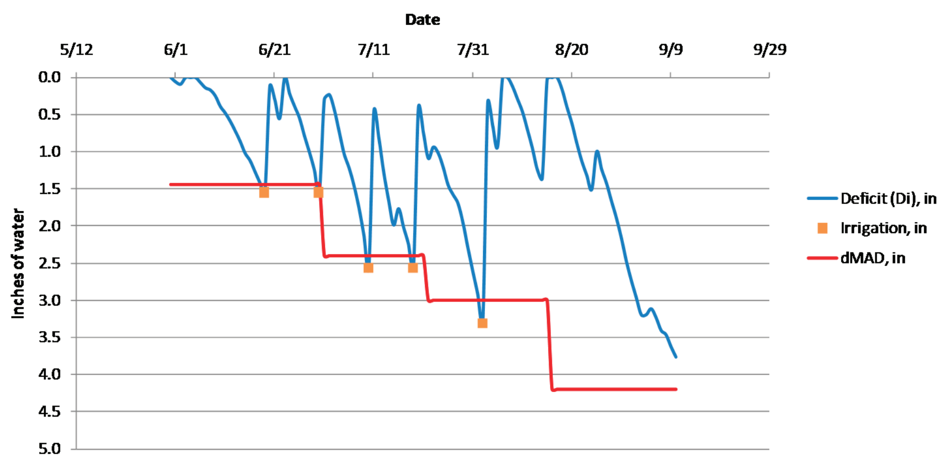


Figure 5. Soil water deficit and irrigation amounts for dry beans at Yuma in 2008.

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