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Excel-Based Computational Template for Irrigation Scheduling Using Dual Crop Coefficients

Abstract
We developed an Excel-based computational template Extension educators can use to assist clientele with scheduling irrigation for efficient use of water. With the template, the user applies the dual crop coefficient method to calculate evaporation and transpiration rates separately, with the result being more accurate soil water tracking as compared to what occurs when a single crop coefficient is used. Crop water needs can be conveniently calculated on the basis of soil characteristics, crop growth stages, and weather information. Application examples demonstrate that the amount and frequency of irrigation should be adjusted according to soil texture. The template and application examples are available to Extension professionals as electronic supplementary material.

Keywords: irrigation scheduling, dual crop coefficients, FAO-56 method, Excel template, Penman-Monteith equation

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Introduction

Evapotranspiration (ET) controls the moisture content of soil, one of the most important freshwater storages in the earth (McColl et al., 2017). Thus, estimating the amount of water evaporated from soil and transpired from vegetation is a necessary process in many engineering and science fields, such as agricultural water management, water resources planning, and hydrologic analysis. A convenient way to calculate an actual ET rate for crop plants (ET_c) is to use a crop coefficient (K_{cb}) method based on a reference ET rate estimate and the types of plants located in an area of interest (Irmak & Haman, 2003; Morgan, Obreza, Scholberg, Parsons, & Wheaton, 2006; Zotarelli, Dukes, Romero, Migliaccio, & Morgan, 2010). There are two approaches to the crop coefficient method. With the single crop coefficient approach, the single coefficient used is the averaged effects of evaporation from soil and transpiration from vegetation for the cropped surface. With the dual crop coefficient approach, evaporation from soil and transpiration from vegetation are considered as two independent coefficients (Allen, Pereira, Raes, & Smith, 1998). The single crop coefficient approach is relatively simple, but the dual crop coefficient approach can more effectively address a soil moisture condition and plant drought stress that can limit evaporation and transpiration, respectively, in an actual ET rate estimation. Despite its expected accuracy, the dual crop coefficient approach has not been widely used in practice due to the complexity of the required calculation procedures. To address this situation, we developed an Excel-based computational template that Extension professionals and irrigation practitioners can use to develop irrigation scheduling based on the dual crop coefficient method. Excel-based computing templates have been developed as tools that aid Extension professionals in their capacity building efforts (Barbosa, 2013; Bowser, Holcomb, & Kerr, 2018; Johnson & Dahlke, 2015; Patterson, 2011; Raper, DeVuyst, & Doye, 2010). The Excel template and two sample application examples are provided as supplementary material for this article (https://joe.org/joe/2019february/Computational_Template_for_Irrigation_Scheduling_Using_Dual_Crop_Coefficients.xlsx) to help Extension educators and irrigation practitioners understand and apply the calculation procedures for the ET-based irrigation scheduling. Additionally, the article describes the calculations and assumptions on which the tool is based.

FAO-56 Dual Crop Coefficient Method

The dual crop coefficient approach was proposed as a part of the FAO-56 method for improving the accuracy of ET_c estimation using the basal crop and soil evaporation coefficients (Allen, 2000; Allen et al., 1998). The basal crop coefficient (K_{cb}) represents the ratio of ET_c for specific vegetation to the reference ET in the cropped areas where soils hold moisture well enough to sustain full plant transpiration. The soil evaporation coefficient (K_e) addresses evaporation from the soil surface. The relationship among the coefficients is

$$K_c = K_{cb} \cdot K_s + K_e,$$

where K_c is an actual crop coefficient, K_{cb} is a basal crop coefficient, K_s is a water stress coefficient, and K_e is a soil evaporation coefficient. The basal crop coefficient (K_{cb}) is expressed as a function of weather variables:

$$K_{cb} = K_{cb(std)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(h/3\right)^{0.3},$$

where $K_{cb(std)}$ is a basal crop coefficient for the standard condition, u_2 is a mean daily wind speed at 2 m height (m/s), RH_{min} is a mean daily minimum relative humidity (%), and h is a mean plant height. The soil evaporation coefficient (K_e) is determined by considering soil moisture condition:

$$K_e = min\left(K_r\left(K_{c,max} - K_{cb}\right), f_{ew} \cdot K_{c,max}\right),$$

where K_r is a dimensionless evaporation reduction coefficient dependent on the cumulative depth of water depleted or evaporated from the topsoil, $K_{c,max}$ is the maximum value of K_c following a rain or irrigation event, and f_{ew} is a fraction of the soil that is both exposed and wetted (the fraction of the soil surface from which most evaporation occurs).

Parameters and Assumptions

ET rates are calculated on the basis of the reference ET (ET_0) and the amount of water infiltrated into the soil in the FAO-56 method. The ET_0 is determined by weather, and it is estimated through use of the Penman-Monteith ET equation (Zotarelli et al., 2010). The infiltration rate may be computed using an infiltration model such as Horton's equation or the Natural Resources Conservation Service's curve number method combined with a continuity equation. Assumptions are that irrigation and a rainfall event occur early in a day and that a rainfall event is not followed by an irrigation application. The depth of the surface soil layer that is subject to drying by way of evaporation is set to 0.10 m (0.33 ft) in the template, and a user may want to adjust it to somewhere between 0.10 m and 0.15 m depending on soil textures (0.10 m for coarse soils and 0.15 m for fine soils [Allen et al., 1998]). The amount of the total evaporable water from the soil and the amount of readily evaporable soil water are calculated automatically on the basis of the soil texture (Table 19 of Allen et al., 1998). The parameter values are determined by data the user enters in the "Crop and Soil Characteristics" section in the template. For instance, the amounts of total evaporable water that can be evaporated from the soil and readily evaporable soil water are calculated as functions of field capacity, wilting point, and soil depth, which are determined on the basis of soil texture types specified in the template by the user (Allen et al., 1998).

Application Examples

Sample applications of the Excel-based template for determining irrigation timing are provided in the supplementary material for this article, and screen captures of two examples that can be found in the template are shown in Figure 1. In the first example ("Example_Template_Example_1" worksheet in the template and Figure 1a herein), irrigation is to be applied when the amount of readily available soil water in the root zone is depleted. The calculation shows that there is no need to apply water to the tomato field with sandy loam soil after the irrigation of 40 mm (1.57 in) on the first day or after the rainfall event (or infiltration) of 20 mm (0.79 in) on the fifth day. In the second example ("Example_Template_Example_2" worksheet in the template and Figure 1b herein), the same weather conditions as those of the first example are assumed, but the field will need additional water applications of 13 mm on the fourth day and 14 mm on the ninth day to satisfy the crop water requirement in the sandy soil. A comparison between the two examples shows that the small field capacity makes the sandy soil require more frequent water application than the sandy loam soil.

Figure 1.

Sample Views of the Excel-Based Computational Template

(a) Irrigation Timing Calculation Example for a Sandy Loam Soil

1	Location		
2	Latitude: Type ->	25.67	
3	Longitude: Type ->	-80.40	
4	Region: Select ->	Eastern	
5	Date of Day 1		
6	Date (MM/DD/YYYY): Enter ->	12/01/17	
7	Crop and Soil Characteristics		
8	Items	Values	Unit
9	Crop Type: Select ->	Tomato	None
10	Crop Growth Stage: Select ->	Initial Stage	None
11	Crop Height: Type ->	0.05	m
12	Soil Texture: Select ->	Sandy Loam	None
13	Irrigation Method: Select ->	Furrow, Narrow Bed	None
14	Root Zone Depth on First Day: Type ->	0.30	m
15	Root Zone Depth on Tenth Day: Type ->	0.35	m
16	Soil Depth Subject to Drying by Evaporation: Type ->	0.10	m
17	Other Parameters (Automatically Calculated)		
18	Field Capacity	0.23	Fraction
19	Wilting Point	0.11	Fraction
20	TAW	36	mm
21	RAW	22	mm
22	TEW	17.5	mm
23	REW	8	mm
24	Depletion Factor	0.60	None
25	kcb (Table)	0.15	None

Weather Forecast					
Day	High Temp. (Cel. Deg.)	Low Temp. (Cel. Deg.)	Precip. (mm)	Wind (km/hour)	Humidity (%)
Day 1	25	18	0	21	65
Day 2	23	19	0	17	70
Day 3	27	20	0	21	72
Day 4	29	21	0	23	74
Day 5	27	19	20	14	76
Day 6	28	16	0	17	79
Day 7	25	13	0	19	69
Day 8	23	14	0	22	56
Day 9	22	14	0	23	62
Day 10	24	15	0	22	74

Results		
Day	Irrigation (mm)	Excess or Loss (mm)
Day 1	40	18.4
Day 2	0	0.0
Day 3	0	0.0
Day 4	0	0.0
Day 5	0	0.0
Day 6	0	0.0
Day 7	0	0.0
Day 8	0	0.0
Day 9	0	0.0
Day 10	0	0.0

Calculation Procedures

1. Find the locational information of your farm and type the information (latitude and longitude) in the "Location" section in yellow; you can find the latitude and long
2. Type the date of Day 1 in the yellow text box of the 'Date of Day 1" section following the recommended format (MM/DD/YYYY).
3. Select the type of a crop from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
4. Select the growth stage of a crop from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
5. Type the height of a crop in the yellow textbox in the "Crop and Soil Characteristics" section.
6. Select the texture of a soil from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
7. Select the method of irrigation from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
8. Type the depth of a root zone on the first day of irrigation in the yellow textbox in the "Crop and Soil Characteristics" section.
9. Type the depth of a root zone on the last (or tenth) day of irrigation in the yellow textbox in the "Crop and Soil Characteristics" section.
10. Type the depth of soil layer that is subject to drying by evaporation (the default value is 0.10 m)
11. Find 10-day weather forecast and type the values in the table in the "Weather Forecast" section; you can find the forecast at https://weather.com/weather/today/
12. Then, you can find the recommended amount of water to be applied in the next 10 days in the "Results"\ section.
13. Once all calculations are done, you can try different amount of water and/or different application date. Then, you can check if there is loss of water applied due to

(b) Irrigation Timing Calculation Example for a Sandy Soil

1	Location		
2	Latitude: Type ->	25.67	
3	Longitude: Type ->	-80.40	
4	Region: Select ->	Eastern	
5	Date of Day 1		
6	Date (MM/DD/YYYY): Enter ->	12/01/17	
7	Crop and Soil Characteristics		
8	Items	Values	Unit
9	Crop Type: Select ->	Tomato	None
10	Crop Growth Stage: Select ->	Initial Stage	None
11	Crop Height: Type ->	0.05	m
12	Soil Texture: Select ->	Sand	None
13	Irrigation Method: Select ->	Furrow, Narrow Bed	None
14	Root Zone Depth on First Day: Type ->	0.30	m
15	Root Zone Depth on Tenth Day: Type ->	0.35	m
16	Soil Depth Subject to Drying by Evaporation: Type ->	0.10	m
17	Other Parameters (Automatically Calculated)		
18	Field Capacity	0.12	Fraction
19	Wilting Point	0.05	Fraction
20	TAW	21	mm
21	RAW	13	mm
22	TEW	9.5	mm
23	REW	4.5	mm
24	Depletion Factor	0.60	None
25	kcb (Table)	0.15	None

Weather Forecast					
Day	High Temp. (Cel. Deg.)	Low Temp. (Cel. Deg.)	Precip. (mm)	Wind (km/hour)	Humidity (%)
Day 1	25	18	0	21	65
Day 2	23	19	0	17	70
Day 3	27	20	0	21	72
Day 4	29	21	0	23	74
Day 5	27	19	20	14	76
Day 6	28	16	0	17	79
Day 7	25	13	0	19	69
Day 8	23	14	0	22	56
Day 9	22	14	0	23	62
Day 10	24	15	0	22	74

Results		
Day	Irrigation (mm)	Excess or Loss (mm)
Day 1	40	27.4
Day 2	0	0.0
Day 3	0	0.0
Day 4	13	0.0
Day 5	0	3.3
Day 6	0	0.0
Day 7	0	0.0
Day 8	0	0.0
Day 9	14	0.0
Day 10	0	0.0

Calculation Procedures

1. Find the locational information of your farm and type the information (latitude and longitude) in the "Location" section in yellow; you can find the latitude and longi
2. Type the date of Day 1 in the yellow text box of the 'Date of Day 1" section following the recommended format (MM/DD/YYYY).
3. Select the type of a crop from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
4. Select the growth stage of a crop from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
5. Type the height of a crop in the yellow textbox in the "Crop and Soil Characteristics" section.
6. Select the texture of a soil from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
7. Select the method of irrigation from the drop-down list in yellow in the "Crop and Soil Characteristics" section.
8. Type the depth of a root zone on the first day of irrigation in the yellow textbox in the "Crop and Soil Characteristics" section.
9. Type the depth of a root zone on the last (or tenth) day of irrigation in the yellow textbox in the "Crop and Soil Characteristics" section.
10. Type the depth of soil layer that is subject to drying by evaporation (the default value is 0.10 m)
11. Find 10-day weather forecast and type the values in the table in the "Weather Forecast" section; you can find the forecast at https://weather.com/weather/today/
12. Then, you can find the recommended amount of water to be applied in the next 10 days in the "Results"\ section.
13. Once all calculations are done, you can try different amount of water and/or different application date. Then, you can check if there is loss of water applied due to p

Summary

This article introduces an Excel-based irrigation scheduling template and includes a description of the relevant background theory as well as application examples. Extension educators can use the template as a handy tool for helping irrigation practitioners and growers save water while maintaining crop productivity. Copies of the template are freely available in the supplementary material for the article. Additionally, the Excel template can serve as the basis for smartphone or tablet applications Extension educators and irrigation practitioners can use in developing site-specific crop irrigation schedules.

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