Research Note

A SIMPLE WEB-BASED METHOD FOR SCHEDULING IRRIGATION IN PUERTO RICO[1,2]

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There is antidotal evidence that many farmers in Puerto Rico do not employ scientific methods for scheduling irrigation for their crops. Instead, the pump is turned on for an arbitrary amount of time without knowing whether the amount of water applied is too much or too little. Over application of water can lead to the waste of water, energy, chemicals and money, and also may lead to the contamination of ground and surface waters. Under-application of irrigation can lead to reduced crop yields and a loss of revenue to the grower.

There are various approaches for scheduling irrigation. One approach is to supplement rainfall with enough irrigation so that the cumulative rainfall and irrigation, over a specific period of time (e.g., one day, one week, one season), matches the estimated potential evapotranspiration, which is equivalent to the crop water requirement. Potential evapotranspiration (ET_c) can be estimated by the product of a crop coefficient (K_c) and the reference evapotranspiration (ET_o). Traditionally, potential evapotranspiration is derived from pan evaporation data or meteorological data from weather stations. Another approach involves monitoring the soil moisture and applying irrigation sufficient to maintain the soil moisture content within a predetermined range. In this paper we present an approach based on applying irrigation to the crop to meet the crop water requirements (i.e., potential evapotranspiration), but instead of using pan evaporation or meteorological data, we use a remote sensing technique. The advantage of the method is that reference evapotranspiration can be estimated at a 1 km resolution for the entire island each day. If the relatively simple approach presented in this paper is used it can potentially lead to increased efficiency of water and energy use, and help to reduce crop water stress and losses in crop yields.

Potential crop evapotranspiration is estimated by using the simple relation

$$ET_c = K_c \, ET_o \tag{4}$$

where ET_c and ET_o were previously defined and K_c is the crop coefficient. Reference evapotranspiration is obtained from the operational water and energy balance algorithm for Puerto Rico (GOES-PRWEB). Each day the operational algorithm produces a suite of 24 hydro-climate variables which are available to the public on the internet. Estimates

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of reference evapotranspiration are available for three widely used methods: Penman-Monteith (Allen et al., 1998), Priestly-Taylor (Priestly and Taylor, 1972) and Hargreaves-Samani (Hargreaves and Samani, 1985). Of the three methods, the Penman-Monteith method is generally regarded as superior because it takes into account the major variables which control evapotranspiration (Allen et al., 1998), and the method has been rigorously validated under diverse conditions throughout the world (Jensen et al., 1990). The Penman Monteith method is given by the equation:

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (Rn - G) + \gamma \cdot \left(\frac{900}{T + 273}\right) \cdot u_2(e_s - e_a)}{\Delta + \gamma \cdot (1 + .034 \cdot u_2)} \tag{1}$$

where ET_o is reference evapotranspiration, Δ is slope of the vapor pressure curve (kPa/°C); R_n is net radiation (MJ/m²/day); G is soil heat flux density (MJ/m²/day); γ is the psychrometric constant (kPa/°C); T is mean daily air temperature at 2-m height (°C); u_2 is wind speed at 2-m height (m/s); e_s is the saturated vapor pressure and e_a is the actual vapor pressure (kPa). Equation 5.2 applies specifically to a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m, and an albedo of 0.23.

The crop coefficient changes throughout the crop season as depicted in Figure 1. During the initial crop growth stage, the value of the crop coefficient is $K_{c\ ini}$. During the mid season the crop coefficient is $K_{c\ mid}$, and at the end of the late season the crop coefficient is $K_{c\ end}$. The values of $K_{c\ ini}$, $K_{c\ mid}$, and $K_{c\ end}$ can be obtained from published tables.

We first outline the specific steps to estimate the irrigation requirement for locations within Puerto Rico. A detailed example problem is then given to illustrate use of the method.

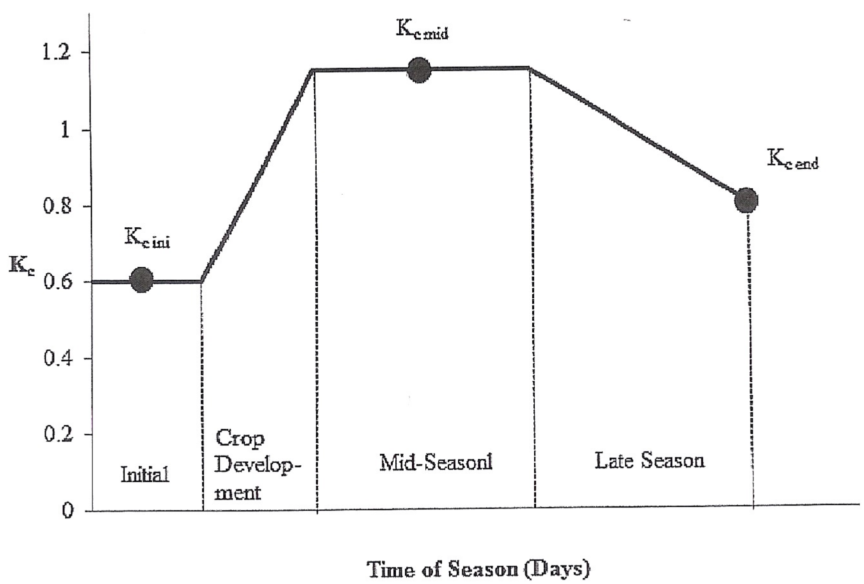

FIGURE 1. Crop coefficient curve.

Steps to estimate irrigation requirement

Step 1. Create an evapotranspiration crop coefficient curve for your crop. The following link to the Food and Agriculture Organization (FAO) Document No. 56 (Allen et al., 1998) provides tables of crop stage growth (Table 11) and K_c values (Table 12) for a large number of crops: http://www.fao.org/docrep/X0490E/x0490e00.htm . Your K_c curve should look like Figure 1 when you are finished. Note that crop coefficient curves can also be created by using computer programs such as PRET (Harmsen and González, 2005) or CropWat (FAO, 2012).

Step 2. Go to the following website address to obtain the appropriate ET_o map(s) for your location:http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/reference_ET/. Note that if you are irrigating every day, then you need only to obtain the ET_o for yesterday's date. If, however, you are irrigating once per week, for example, then you will need to obtain the ET_o values from the maps for the previous week. In this latter example, you will need to sum up the daily values of ET_o to obtain a value of the weekly ET_o.

Step 3. From your K_c curve obtained in Step 1, determine a representative value of K_c for the current growth stage of the crop.

Step 4. Estimate the crop water requirement (crop evapotranspiration) $ET_c = K_c \times ET_o$.

Step 5. Estimate the required amount of irrigation in depth units: Irrigation = ET_c − Rainfall. If the estimated Irrigation is negative, then you do not need to irrigate.

It is recommended that rainfall be measured on the farm with a rain gauge; however, if measured rainfall is not available, the approximate value of the rainfall (derived from NEXRAD radar) can be obtained at the following website: http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/rainfall/. It will also be necessary to measure the irrigation volume. A digital or mechanical flow meter which measures the cumulative volume in gallons is recommended.

The irrigation scheduling approach described above is based on various simplifying assumptions (e.g., surface runoff and deep percolation are ignored). The FAO (Allen et al., 1998) has suggested corrections to $K_{c\ ini}$ for time interval between wetting events, evaporative power of the atmosphere and magnitude of the wetting events, and corrections to $K_{c\ mid}$ and $K_{c\ end}$ for air humidity, crop height and wind speed; however, these corrections have been ignored in order to preserve simplicity in the approach presented above. Despite the

TABLE 1. *Information used in example problem.*

Location	Juana Díaz, Puerto Rico
Site latitude	18.02 degrees N
Site longitude	66.52 degrees W
Site elevation above sea level	21 m
Crop	Tomato
Planting date	1-Jan-12
Rainfall information	A rain gauge is not available on or near the farm
Type of irrigation	Drip
Irrigation system efficiency	85%
Field size	10 acres
Pump capacity	300 gallons per minute

TABLE 2. *Web addresses used to obtain information for solving the example problem.*

Length of Growth Stages (Table 11) and Crop Coefficients (Table 12)	http://www.fao.org/docrep/X0490E/x0490e00.htm
Daily Reference ET Results for Puerto Rico[1]	http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/reference_ET/
Daily NEXRAD Rainfall for Puerto Rico	http://academic.uprm.edu/hdc/GOES-PRWEB_RESULTS/rainfall/

[1]The web subdirectory contains Penman-Monteith, Hargreaves-Samani and Priestly-Taylor ET_o data.

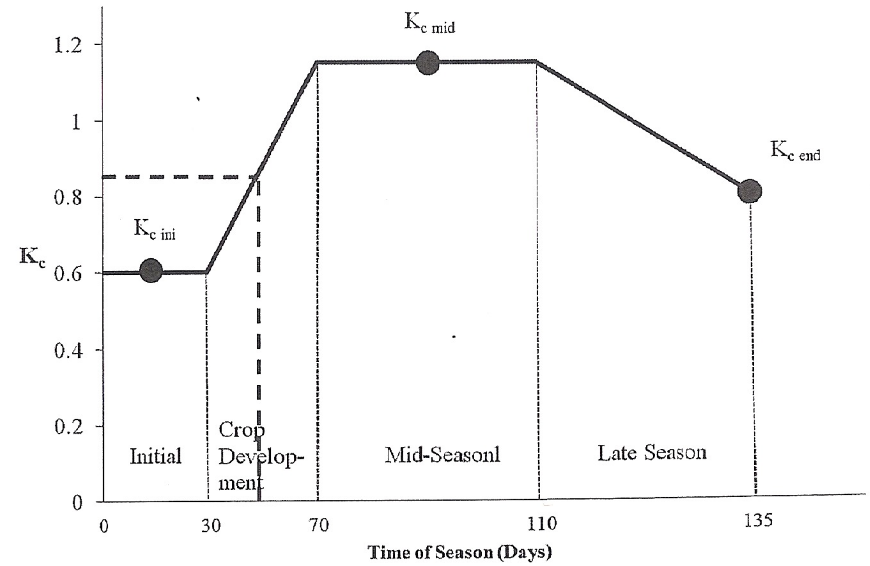

FIGURE 2. Crop coefficient curve for the example problem. The heavy dashed line applies to the example problem with day of season 46-50 (horizontal axis) corresponding to an approximate crop coefficient of 0.85 (vertical axis).

simplifying assumptions, the approach should significantly improve water management on a farm if currently there is no irrigation scheduling method being used.

Detailed example problem

A detailed example problem is presented here to illustrate the use of the proposed methodology. In this problem we will determine the irrigation requirement for the five day period, 15-19 February 2012, for a tomato crop being grown in Juana Díaz, Puerto Rico. Table 1 summarizes the information used in the example problem. Table 2 provides the important web addresses necessary for obtaining data for use in the example problem.

With the information in Table 1 it is now possible to construct the crop coefficient curve by consulting the FAO Document No. 56, Table 11 (Lengths of crop development

TABLE 3. *Crop growth stage lengths and crop coefficient data for the example problem.*

Initial Crop Growth Stage	30 days
Crop Development Growth Stage	40 days
Mid-Season Growth Stage	40 days
Late-Season Growth Stage	25 days
Total Length of Season	135 days
$K_{c\ ini}$	0.6
$K_{c\ mid}$	1.15
$K_{c\ end}$	0.8

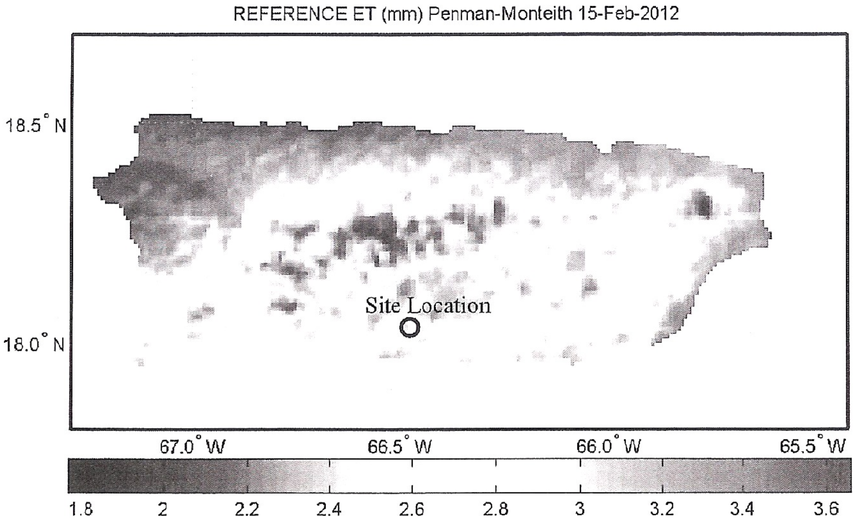

FIGURE 3. Estimated reference evapotranspiration (ET_o) for 15 February 2012, the approximate ET_o at the site location is 2.95 mm. (For full-color figures visit http://art.eea.uprm.edu/2013-08-06-001.pdf)

stages for various planting periods and climatic regions) and Table 12 (Single time-averaged crop coefficients). FAO Document No. 56 is available online at the web address given in Table 2. Table 3 summarizes the crop stage and crop coefficient information.

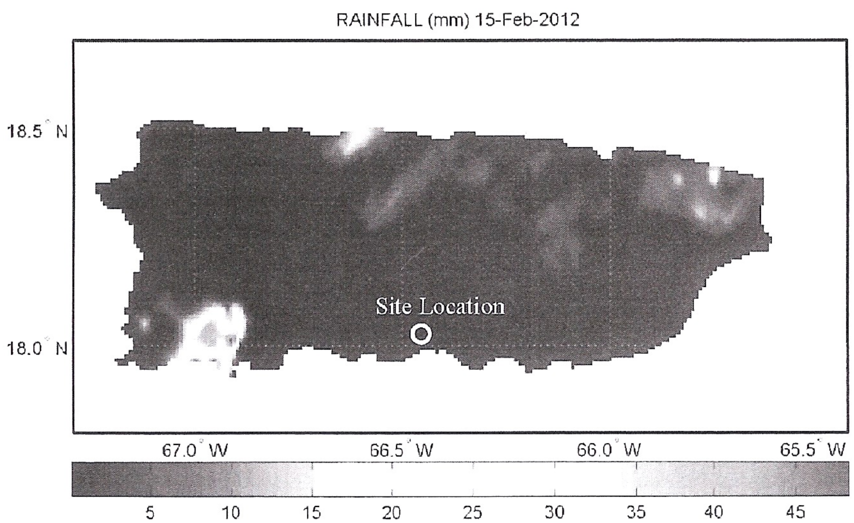

FIGURE 4. Estimated NEXRAD rainfall for 15 February 2012.

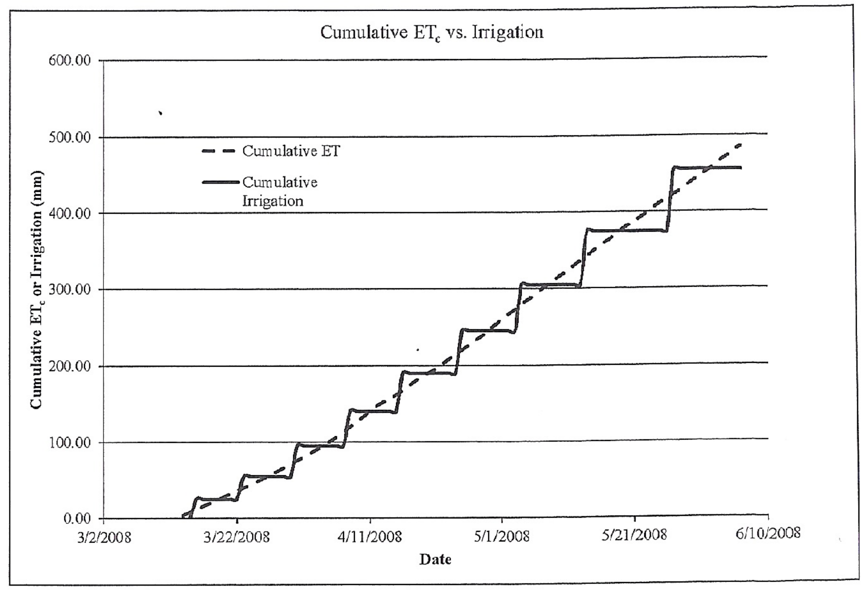

FIGURE 5. Example of the cumulative irrigation and ET_c plotted with time for a crop season. (Note that this graph is not related to the example problem.)

The crop coefficient curve constructed from the data in Table 2 is shown in Figure 2. The approximate average crop coefficient for February 15-19 (day of season 46-50) is approximately 0.85.

The next step is to determine the reference evapotranspiration for the five day period. Figure 3 shows the estimated reference evapotranspiration for Puerto Rico 15 February 2012 obtained from the web address provided in Table 2. Note that the preferred reference evapotranspiration method is used (i.e., Penman-Monteith method). The estimated ET_o for the site location on 15 February 2012 is 2.95 mm. Using a similar procedure, the ET_o for Feb. 16, 17, 18 and 19 is 2.8 mm, 3.1 mm, 3.5 mm and 3.7 mm, respectively. Summing up the ET_o values comes to a total crop water requirement (for the five days) of 16.1 mm.

A rain gauge is not available on or near the farm; therefore, it is necessary to obtain rainfall information from the NEXRAD radar. Figure 4 shows the NEXRAD rainfall for Puerto Rico for 15 February 2012. At the site location no rainfall was estimated from the NEXRAD radar. Checking the other maps for the other days reveals that no significant rainfall occurred at the site. Therefore, all of the crop water requirement will have to be satisfied with irrigation.

The crop water requirement for the time period can now be estimated as follows:

$ET_c = K_c\, ET_o = (0.85)(16.1\text{ mm}) = 13.7\text{ mm}$ (slightly greater than one-half of an inch). The final step is to determine the number of hours that the pump should be run to apply the 13.7 mm of water. A form of the well-known irrigation equation (Fangmeier et al., 2005) can be used.

$$T = 17.817 \times [D \times A]/[Q \times eff] \quad (5)$$

where T is time in hours, D is depth of irrigation water in mm, A is effective field area in acres[4], Q is flow rate in gallons[5] per minute and eff is irrigation system efficiency. Using D = 13.7 mm, A = 10 acres, Q = 300 gallons per minute and eff = 0.85, yields

$$T = 17.817 \times [13.7 \times 10] / [300 \times 0.85] = 9.57 \text{ hours}$$

To evaluate the irrigation management with the approach described in this paper, construction of a graph similar to the one shown in Figure 5 is recommended. The graph shows the cumulative depth of irrigation and ET_c plotted with time. The goal of irrigation scheduling is to try to match the applied irrigation with the ET_c. By the end of the season, the cumulative irrigation (plus rainfall) should more or less equal the cumulative ET_c. If these two curves stay close together, this is an indication that good irrigation management is being achieved. Note that the graph shown in Figure 5 is not related to the example problem given above.

With ever-increasing pressure on water resources, it is essential that irrigators apply methods to increase efficiency. Improved efficiency will reduce the waste of water, fuel and chemicals, and will help growers to maximize crop yields and profits. In this research note a method was described to estimate crop water requirements at any location in Puerto Rico using a web-based irrigation scheduling procedure. A step-by-step procedure was presented and a detailed example problem was given.

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[4]One acre = 0.405 hectares
[5]One gallon = 3.78 L

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