# Evapotranspiration-Based Irrigation Scheduling for Agriculture[1]

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*This article is part of a series on ET-based irrigation scheduling for agriculture. The rest of the series can be found at* http://edis.ifas.ufl.edu/topic_series_ET-based_irrigation_scheduling_for_agriculture.

## Introduction

Water required for crop growth is supplied by rainfall and/or irrigation. In Florida, rainfall is characterized by high spatial variability and temporal variability, requiring agricultural producers to use irrigation to supplement water during dry periods. Methods are needed to optimize the timing and amount of irrigation water applied to supplement rain water.

One method that can be used to improve irrigation efficiency is evapotranspiration (ET)-based irrigation scheduling. This publication includes the main concepts related to ET-based irrigation scheduling and reviews the use of ET controllers for agricultural applications.

## Irrigation Scheduling

Irrigation scheduling refers to when and how long irrigation occurs (amount of water applied). ET-based irrigation scheduling is scheduling irrigation based on ET so that ET losses are replaced in the root zone to meet plant water requirements. In general, plant water requirements are determined from a balance of water inputs and outputs from the root zone (Equation 1). The main water inputs to the root zone are effective rainfall (rainfall fraction that contributes to crop water requirements, *P*), net irrigation (the amount of water required for optimum crop growth, *I*) and capillary contributions (water contributed from the shallow groundwater table, *C*). Water is mainly lost from the root zone due to crop ET ($ET_c$) and deep percolation (water that flows down beyond the root zone, *D*). All inputs and outputs are in units of depth per time, such as inches per day. The change in root zone soil water storage is represented by *S*.

$$ET_c = P_e + I + C + \Delta S - D$$

Equation 1.

The root zone soil water balance equation can be reduced to Equation 2 for most parts of Florida. The underlying assumptions for simplifying Equation 1 can be found in *Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers* at http://edis.ifas.ufl.edu/ae446. Equation 2 defines the net irrigation water requirement based on $ET_c$ and $P_e$. $ET_c$ is estimated as the product of

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reference ET ($ET_o$) and crop coefficient $K_c$. Sources of $ET_o$ data for various Florida locations can be found in *Evapotranspiration-Based Irrigation for Agriculture: Sources of Evapotranspiration Data for Irrigation Scheduling in Florida* at http://edis.ifas.ufl.edu/ae455. $K_c$ values can be found in *Evapotranspiration-Based Irrigation for Agriculture: Crop Coefficients of Commercial Agricultural Crops in Florida* http://edis.ifas.ufl.edu/ae456.

$$I = ET_c - P_e$$

Equation 2.

## Effective Rainfall ($P_e$)

Precipitation may follow different paths, depending on soil and rainfall characteristics. Soils with greater infiltration rates (gravelly soils and sandy soils) may experience greater rates of deep percolation. Alternatively, soils with lower infiltration rates (clay and silt soils) may experience greater rates of surface runoff. It is necessary to determine the portion of a rainfall event that can contribute to root zone soil water content (or the portion that is not lost to percolation or surface runoff). The portion of rainwater used to meet the crop water requirement is called effective rainfall ($P_e$). In Florida $P_e$ is estimated using an empirical equation developed by the United States Department of Agriculture - Natural Resources and Conservation Service (USDA-NRCS) called TR-21 (Equation 3) (USDA 1970).

$$P_e = f(D)\, x\, [0.70917\, P_m^{\;0.82416} - 0.11556]\, x\, [10^{0.02426\, ET_c}]$$

Equation 3.

$$f(D) = 0.531747 + 0..295164D - 0.057697\, D^2 + 0.003804\, D^3$$

Equation 4.

In Equation 3, $P_e$ is effective rainfall (inches/month), $P_m$ is average monthly rainfall (inches), $ET_c$ is average monthly *ET* (inches/month), and *f(D)* (Equation 4) is soil water storage factor for a given soil in which *D* (inches) represents the soil water deficit or the irrigation depth (management allowable depletion, MAD). MAD is the percentage of the total available soil water (TAW) that plants can withdraw without experiencing water stress or yield loss. In Florida, in the absence of a locally determined MAD value, a MAD value of 50% is typically used. Typical values of $P_e$ are provided in Table 1 for different regions of Florida.

## ET-Based Irrigation Scheduling Technologies

Implementing any form of ET-based irrigation scheduling requires accurately estimating $ET_c$ and *I*. These two quantities are determined using $ET_o$, $K_c$, and $P_e$ data. For purposes of this publication, ET-based irrigation technologies are divided into two categories: 1) smart ET-based irrigation controllers and 2) do-it-yourself ET-based irrigation scheduling.

## Smart ET-Based Irrigation Controllers

These controllers consist of irrigation scheduling devices that use weather data (e.g., solar radiation, air temperature, wind speed, and relative humidity), site-specific characteristics (e.g., slope and soil type), crop characteristics (e.g., $K_c$ and root depth) and irrigation system characteristics (e.g., system type, precipitation rate, and irrigation efficiency) to schedule irrigation. Smart ET-based irrigation controllers are divided into three subgroups based on the way the controllers receive weather data used to generate an irrigation schedule. These groups are: i) signal-based ET controllers (use data from remote weather stations via wireless technology that is updated daily), ii) historical ET controllers (use long-term climatic data to schedule irrigation), and iii) on-site ET controllers (use on-site temperature data and historical data to estimate daily $ET_o$).

Smart ET controllers can be add-ons to typical irrigation timers or complete irrigation control systems and may also have the capability of adding a rain sensor. On-site ET controllers often have a rain gauge to estimate effective rainfall. The on-site calculation of rainfall is beneficial in Florida because of the spatial variability of rainfall in this state. If programmed properly, ET controllers are a convenient and practical tool for irrigation scheduling because they require minimum labor and maintenance compared with other irrigation scheduling technologies (e.g., tensiometers that require frequent maintenance).

Currently, commercially available ET controllers are specifically designed for landscape irrigation, so precautions should be taken when they are used for agriculture applications. One important precaution for agriculture applications is that specific data about the crop, such as $K_c$, must be known. In addition, the soil type must be clearly defined since some ET controllers operate based on the concept of allowable soil water depletion (which depends on the water-holding capacity of the soil). A study conducted in a carambola orchard in Homestead, Florida, comparing ET controllers to a timer set schedule showed that ET controllers produced an average water savings of 72% without affecting tree growth as measured using physiological response factors (Kisekka et al. 2010).

There is no standard guide on programming ET controllers because of the variability among crops, soils, and weather in Florida. Agricultural producers are encouraged to seek professional assistance through Extension agents or specialists during installation to ensure proper setup. General information on programming ET controllers can be found in *Smart Irrigation Controllers: Programming Guidelines for Evapotranspiration-Based Irrigation Controllers* at http://edis.ifas.ufl.edu/ae445.

General information on implementing ET-based irrigation scheduling in agriculture can be found in *Evapotranspiration-Based Irrigation for Agriculture: Implementing Evapotranspiration-Based Irrigation Scheduling in Agriculture* at http://edis.ifas.ufl.edu/ae458. Examples of commercially available ET controllers are listed in Table 2. Agricultural producers should consider the following when selecting the type of ET controller for their farms:

- For **signal-based controllers**, ensure that the site where the controller is installed receives a strong signal from the weather data service provider. Cross-check the $ET_o$ data sent to the controller with $ET_o$ data from the nearest public weather station at initiation.
- For **on-site ET controllers**, ensure that there is a location for installing the weather sensors.

## Do-It-Yourself ET-Based Irrigation Scheduling

The do-it-yourself approach is based on accessing daily or monthly $ET_o$ data from the nearest weather station or from a public weather network database (e.g., Florida Automated Weather Network or FAWN), obtaining $K_c$ for the crop of interest, and determining $P_e$. To account for irrigation system inefficiency (e.g., due to non-uniform water application), the gross irrigation water requirement *(GI)* needs to be determined (Equation 5). The *GI* is the amount of water that must be pumped to the field and includes the crop water requirement and additional water to account for irrigation water that will be lost due to irrigation system inefficiencies. Typical efficiencies *(E)* of various irrigation systems used in Florida are listed in Table 3. More information on a step-by-step guide for implementing do-it-yourself ET-based irrigation scheduling can be found in *Evapotranspiration-Based Irrigation for Agriculture: Implementing Evapotranspiration-Based Irrigation Scheduling for Agriculture* at http://edis.ifas.ufl.edu/ae458. Irrigation runtime *(IR) (hours)* per irrigation cycle/event is calculated using (Equation 6) in which *PR* is the irrigation system precipitation rate (volume of water applied over a given area in a given time), while the irrigation frequency *(IF) (days)* (i.e., number of days between irrigation events) is calculated using Equation 7.

$$GI = \frac{I}{E} = \frac{ET_c - P_e}{E} = \frac{ET_o K_c - P_e}{E}$$

Equation 5.

$$IR = \frac{MAD * TAW}{PR}$$

Equation 6.

$$IF = \frac{MAD * TAW}{GI}$$

Equation 7.

## Conclusion

ET-based irrigation scheduling can lead to optimum irrigation water use based on a simple water balance concept. Different types of ET controllers are available and their selection depends on site characteristics and desired irrigation needs. The primary difference among the controllers is how they obtain weather data for determining $ET_o$ and the equations used to estimate $ET_c$. ET controllers are simple to install but require some programming to operate correctly.

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Table 1. Typical values of $P_e$ (inches/month) for different regions in Florida based on USDA NRCS TR-21 method.

| Month | North Florida[1] | Central Florida[2] | South Florida[2] |
|---|---|---|---|
| January | 1.0 | 0.8 | 0.9 |
| February | 1.6 | 0.8 | 1.1 |
| March | 1.6 | 0.9 | 1.4 |
| April | 0.8 | 0.8 | 1.1 |
| May | 0.9 | 0.9 | 2.5 |
| June | 3.3 | 2.8 | 3.9 |
| July | 2.8 | 2.2 | 3.6 |
| August | 2.4 | 2.8 | 3.1 |
| September | 2.4 | 2.6 | 2.8 |
| October | 1.1 | 1.1 | 1.8 |
| November | 0.9 | 0.4 | 0.7 |
| December | 1.6 | 1.0 | 0.8 |

**Note**: These are only rough estimates and should only be used if local data to evaluate TR-21 method are not available. However, the authors believe that these estimates are better than assuming that all the rainfall received is effective, which could lead to under irrigation, or not considering rainfall in calculating net irrigation requirements, which could result in over irrigation.

[1]The $P_e$ value calculated for North Florida is based on 10 years (1999–2008) of weather data from a FAWN weather station located at Alachua. Sandy soils with water-holding capacity of 0.06 ft/ft, root depth of 12 inches, and management allowable depletion (MAD) of 50% are assumed.

[2]The $P_e$ value calculated for Central Florida is based on 10 years (1999–2008) of weather data from a FAWN weather station located at Lake Alfred. Candler sand soils with water-holding capacity of 0.06 ft/ft, root depth of 18 inches, and management allowable depletion of 50% are assumed. For citrus irrigation the growers should change MAD to 25% between February and June.

[3]The $P_e$ value calculated for South Florida is based on 10 years (1999–2008) of weather data from a FAWN weather station located at Homestead. Krome gravely loam soils with water-holding capacity 0.1 ft/ft, root depth of 12 inches, and management allowable depletion of 50% are assumed.

Table 2. Examples of commercially available brands of smart ET-based irrigation scheduling controllers.

| ET-based irrigation scheduling controllers | Subscriptions* | Mode of operation | Web address |
|---|---|---|---|
| Toro Intelli-sense | Yes | Remote weather station | http://www.toro.com/en-us/homeowner/professional-irrigation/controllers/pages/default.aspx |
| Rainbird ET Manger | Yes | Remote weather station | http://www.rainbird.com/landscape/products/controllers/etmanager.htm |
| Weathermatic Smartline | No | On-site sensors | http://www.weathermatic.com/products/smart-controls/smartline |
| Hunter ET system | No | On-site sensors | http://www.hunterindustries.com/products/Controllers/etintro.html |
| ET Water Smart | Yes | Remote weather station | http://www.etwater.com/ |
| Irritrol Systems | Yes | Remote weather station | http://www.irritrol.com/ |
| * Monthly subscription to the weather data service provider and ranges from $45 to $50. | | | |

Table 3. Typical irrigation system efficiency for systems commonly used in Florida (values are based on seasonal averages of well-designed systems managed by replacing water lost from the root zone through ET).

| Irrigation system type | Range of efficiency (%) | Average efficiency (%)[1] |
|---|---|---|
| Micro sprinklers (Spray head) | 75–85 | 80 |
| Micro sprinkler (bubbler) | 75–85 | 80 |
| Drip system | 70–90 | 85 |
| Solid set sprinkler systems | 70–80 | 75 |
| Center pivot and lateral move systems | 70–85 | 75 |
| Portable guns | 60–70 | 65 |
| [1]Average irrigation system efficiencies reported in the table were taken from Smajstrla et al. 1991. These values vary based on the way the system is designed, managed and operated. Growers are encouraged to measure the application efficiency of their systems under their local conditions and management practices. | | |