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 https://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 and temporal variability, requiring agricultural producers to use irrigation to supplement rainfall during dry periods (Meijing Zhang 2017; Zhang et al. 2018). However, methods are needed to optimize the timing and amount of irrigation water applied to supplement rainwater. One method that can be used to improve irrigation efficiency is evapotranspiration (ET)-based irrigation scheduling. This method allows irrigation managers to increase the efficiency of water application based on the plant water requirements and soil processes. In this publication we introduce the main concepts related to ET-based irrigation scheduling and review the use of ET controllers for agricultural applications.

Irrigation Scheduling

Irrigation scheduling refers to when (timing) and how long (volume) irrigation occurs. ET-based irrigation scheduling is based on ET, that combine the effects of soil evaporation and plant transpiration rates; and water lost from the root zone due to ET is replenished to meet plant water requirements.

In general, plant water requirements are determined by balancing 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_e), net irrigation (the amount of water required for optimum crop growth, I) and capillary contributions (water contributed from the shallow groundwater table, C). A change in soil water storage in the root zone at a given time (represented by ΔS) is due to water use by the crop ET (ET_c) and water loss due to deep percolation (water that flows down below the root zone, D). All inputs and outputs are in units of depth per time (e.g., inches per day). The change in root zone soil water storage is represented by ΔS.

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 https://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 reference ET (ET_o) and a crop coefficient (K_c). ET_o data sources for various Florida locations can be found in *Evapotranspiration-Based Irrigation for Agriculture: Sources of Evapotranspiration Data for Irrigation Scheduling in Florida* at https://edis.ifas.ufl.edu/ae455. ET_o data for several locations in Florida can be obtained from the Florida Automated Weather Network (http://fawn.ifas.ufl.edu/). K_c values can be found in *Evapotranspiration-Based Irrigation for Agriculture: Crop Coefficients of Commercial Agricultural Crops in Florida* at https://edis.ifas.ufl.edu/ae456.

$$ET_c = P_e + I + C + \Delta S - D$$
Equation 1.

$$I = ET_c - P_e$$
Equation 2.

Effective Rainfall (Pe)

Water input by rainfall may follow different paths, depending on soil and rainfall characteristics. Deep percolation rates may be greater in soils with greater infiltration rates (gravelly and sandy soils) while surface runoff may be greater in soils with lower infiltration rates (clay and silt soils). 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 and surface runoff). The portion of rainwater that contributes towards 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.

In Equation 3, P_e is effective rainfall (inches/month), P_m is average monthly rainfall (inches/month), ET is average monthly crop ET (inches/month), and SE in 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.

$$f(D) = 0.531747 + 0..295164D - 0.057697 \, D^2 + 0.003804 \, D^3$$
Equation 4.

Weather or ET-Based Irrigation Scheduling Technologies

Implementing any form of weather or 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 Weather or ET-Based Irrigation Controllers

These controllers consist of irrigation scheduling devices that use weather data (e.g., precipitation rate, 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 and irrigation efficiency) to schedule irrigation (Dukes et al. 2018). Smart weather or ET-based irrigation controllers are divided into three subgroups based on the way the controllers receive weather data used to generate an irrigation schedule (Dukes 2018). These groups are: 1) signal-based ET controllers (use data from remote weather stations via wireless technology that is updated daily), 2) historical ET controllers (use long-term climatic data to schedule irrigation), and 3) on-site ET controllers (use on-site weather measurements and/or 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 or rain measurement device. On-site ET controllers often have a rain gauge to estimate effective rainfall. The on-site measurement of rainfall is beneficial in Florida because of the spatial variability of rainfall. If programmed properly, ET controllers are convenient and practical tools 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 https://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 https://edis.ifas.ufl.edu/ae458. 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 available public weather station at initiation.

- For **on-site ET controllers**, ensure that there is a location for installing the weather sensors and all sensors are installed correctly.

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 2. 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 https://edis.ifas.ufl.edu/publication/AE457. Irrigation runtime (IR) (hours) per irrigation cycle/event is calculated using (Equation 6) in which PR is the irrigation system application rate (volume of water applied over a given area in a given time), TAW is the total available water, and MAD is the management allowed depletion. 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 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.

References

Dukes, M.D., 2018. *Smart Irrigation Controllers: What Makes an Irrigation Controller Smart?* Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/AE442 (accessed 3.13.19).

Dukes, M.D., Shedd, M.L., Davis, S.L., 2018. Smart Irrigation Controllers: Programming Guidelines for Evapotranspiration-Based Irrigation Controllers. smart irrigation controllers 6.

Dukes, M. D., M. L. Shedd, and S.L. Davis. 2009. *Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers*. AE446. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/ae446

Kisekka, I., K. W. Migliaccio, M. D. Dukes, B. Schaffer, and J. H. Crane. 2010. "Evapotranspiration-Based Irrigation Scheduling and Physiological Response in a Carambola (Averrhoa Carambola L.) Orchard." *Applied Engineering in Agriculture* 26(3): 373–380.

Kisekka, I., K. W. Migliaccio, M. D. Dukes, B. Schaffer, J. H. Crane, and K. Morgan. 2009. *Evapotranspiration-Based Irrigation for Agriculture: Sources of Evapotranspiration Data for Irrigation Scheduling in Florida*. AE455. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/ae455

Kisekka, I., K. W. Migliaccio, M. D. Dukes, J. H. Crane, and B. Schaffer. 2009. *Evapotranspiration-Based Irrigation for Agriculture: Crop Coefficients of Commercial Agricultural Crops Grown in Florida*. AE456. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/ae456

Kisekka, I., K. W. Migliaccio, M. D. Dukes, J. H. Crane, and B. Schaffer. 2009. *Evapotranspiration-Based Irrigation for Agriculture: Implementing Evapotranspiration-Based Irrigation Scheduling in Agriculture*. AE458. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/ae458

Meijing Zhang, Y.G.H., 2017. *Florida Rainfall Data Sources and Types*. Gainesville: University of Florida Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/AE517 (accessed 3.6.19).

Smajstrla, A. G., B. J. Boman, G. A. Clark, D. Z. Haman, D. S. Harrison, F. T. Izuno, D. J. Pitts and F. S. Zazueta. 1991. *Efficiencies of Florida Agricultural Irrigation Systems*. BULL 247. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

Smajstrla, A. G., B. J. Boman, G. A. Clark, D. Z. Haman, F. T. Izuno, and F. S. Zazueta. 1988. *Basic Irrigation Scheduling*. BUL 249. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

USDA. 1970. *Irrigation Water Requirements*. Technical Release No 21. Washington, DC: USDA Soil Conservation Service.

Zhang, M., Leon, C. de, Migliaccio, K., 2018. Evaluation and comparison of interpolated gauge rainfall data and gridded rainfall data in Florida, USA. Hydrol. Sci. J. 63, 561–582. https://doi.org/10.1080/02626667.2018.1444767

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

Month	North Florida[1]	Central Florida[2]	South Florida[3]
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 a 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 a 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. 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	Efficiency Range (%)	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.