AE457

UF UNIVERSITY of FLORIDA
IFAS Extension

Evapotranspiration-Based Irrigation Scheduling for Agriculture[1]

Isaya Kisekka, Kati W. Migliaccio, Michael D. Dukes, Bruce Schaffer, and Jonathan H. Crane[2]

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. General information on various approaches to irrigation scheduling in Florida can be found in *Basic Irrigation Scheduling in Florida* http://edis.ifas.ufl.edu/AE111.

This publication focuses on evapotranspiration (ET)-based irrigation scheduling for agriculture. It includes the main concepts related to ET-based irrigation scheduling and reviews the use of "smart" irrigation scheduling controllers for agricultural applications.

Irrigation Scheduling

Irrigation scheduling is the process through which water lost by the plant through ET is replaced to maintain the desired soil water content in the root zone. 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 include: 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). Water is mainly lost from the root zone through 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.

---

[1] This document is AE457, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date January 2010. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.

[2] Isaya Kisekka, graduate student, , Department of Agricultural and Biological Engineering, Tropical Research and Education Center (REC)--Homestead FL; Kati W. Migliaccio, assistant professor, Department of Agricultural and Biological Engineering, Tropical REC--Homestead FL; Michael D. Dukes, associate professor, Department of Agricultural and Biological Engineering; Bruce Schaffer, professor, Department of Agricultural and Biological Engineering, Tropical REC--Homestead FL; Jonathan H. Crane, professor, Department of Agricultural and Biological Engineering, Tropical REC--Homestead FL; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

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

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* 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 reference ET (ET_o) and crop coefficient K_c. Sources of ET_o data for various Florida locations can be found in *Sources of Evapotranspiration Data for Irrigation Scheduling in Florida* http://edis.ifas.ufl.edu/AE455. K_c values can be found in *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 that is used in meeting 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.

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. Based on the irrigation scheduling technology selected, K_c, ET_o and P_e may be automatically estimated by the irrigation scheduling controller using locally defined information on soil, plant, climate and management practices or manually determined as outlined in the earlier sections of this article. For purposes of this publication, ET-based irrigation scheduling technologies are divided into two categories: 1) "smart" ET-based irrigation scheduling controllers and 2) do-it-yourself ET-based irrigation scheduling.

"Smart" ET-based irrigation scheduling 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 sub-groups based on the way the controllers receive weather data used to generate an irrigation schedule. These groups are: i) signal ET-based irrigation controllers (weather data is transmitted to the controller from remote weather stations using wireless technology, and is usually on a daily time step), ii) historical ET-based irrigation controllers (that use long term climatic data to schedule irrigation) and iii) on-site ET-based irrigation controllers (that use on-site temperature and radiation sensors to collect a limited amount of weather data to estimate daily ET_o). Smart ET-based irrigation scheduling controllers can be add-ons to typical irrigation timers or complete irrigation control systems and may also have the capability of adding an onsite rain sensor. If programmed properly, ET-based irrigation scheduling 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-based irrigation scheduling 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 (that depends on the water holding capacity of the soil). Preliminary research on carambola irrigation with ET-based irrigation scheduling controllers has demonstrated their potential to save water and maintain optimum crop production if properly installed and programmed. There is no standard guide on programming ET controllers. Agricultural producers are encouraged to seek professional assistance through extension agents or specialists during installation to ensure proper setup. General information on programming ET-based irrigation scheduling controllers can be found in *Smart Irrigation Controllers: Programming Guidelines for Evapotranspiration-Based Irrigation Controllers* http://edis.ifas.ufl.edu/AE445.

General information on implementing ET-based irrigation scheduling control systems in agriculture can be found in *Implementing Evapotranspiration-based Irrigation Scheduling in Agriculture* http://edis.ifas.ufl.edu/AE 458. Examples of commercially available smart ET-based irrigation scheduling controllers are listed in Table 2. Agricultural producers should consider the following when selecting the type of smart ET-based irrigation scheduling 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.

- In the case of **historical ET based irrigation scheduling controllers**, ensure that the controller has onsite temperature and radiation sensors to improve historical averages.

- For **onsite ET-based irrigation scheduling controllers**, ensure that the ET_o estimation equation used in the controller irrigation scheduling algorithm is radiation-based. Earlier research in Florida by Jacobs and Satti (2001) demonstrated the superiority of radiation based methods over temperature based methods.

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, FAWN), obtaining K_c for the crop of interest, and determining P_e. In order 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 (http://edis.ifas.ufl.edu/AE110). More information on a step-by-step guide for implementing do-it-yourself ET-based irrigation scheduling can be found in *Implementing Evapotranspiration-Based Irrigation Scheduling for Agriculture* 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), 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 if the best ET-based technology is selected and properly implemented. Whenever available, locally generated input data to the ET-based irrigation schedule should be used. However, if no local data are available for the input variables, typical average values provided in this article and related literature can be used. Finally, timely maintenance of irrigation systems should always be practiced to fully realize the benefits (e.g., reduced nutrient leaching and water and energy savings) of ET-based irrigation scheduling.

References

Dukes, M. D., M. L. Shedd, and S.L. Davis. 2009. Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers AE 446. Gainesville: University of Florida Institute of Food and Agricultural Sciences, University of Florida. [07-28-09]. Available from: http://edis.ifas.ufl.edu/AE446.

Jacobs, J.M and S.R. Satti. 2001. Evaluation of reference evapotranspiration methodologies and AFSIRS crop water use simulation model, Final Report, St. Johns River Water Management District, Palatka, FL, April 2001. Available at: http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2001-SP8.pdf. Accessed 13 August 2009.

Kisekka, I., K.W. Migliaccio, M.D. Dukes, B. Schaffer, J.H. Crane, and K. Morgan. 2009. Sources of Evapotranspiration Data for Irrigation Scheduling in Florida. Homestead: University of Florida Institute of Food and Agricultural Sciences, University of Florida. [10-16-09]. Available from: http://edis.ifas.ufl.edu/AE455.

Kisekka, I., K.W. Migliaccio, M.D. Dukes, J.H. Crane, and B. Schaffer. 2009. Crop coefficients of commercial agricultural crops grown in Florida. Homestead: University of Florida Institute of Food and Agricultural Sciences, University of Florida. [10-16-09]. Available from: http://edis.ifas.ufl.edu/AE456.

Kisekka, I., K.W. Migliaccio, M.D. Dukes, J.H. Crane, and B. Schaffer. 2009. Implementing evapotranspiration-based irrigation scheduling in agriculture. Homestead: University of Florida Institute of Food and Agricultural Sciences, University of Florida. [10-16-09]. Available from: http://edis.ifas.ufl.edu/AE458.

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. 2002. Efficiencies of Florida Agricultural Irrigation Systems BULL 247 Gainesville: University of Florida Institute of Food and Agricultural Sciences, University of Florida. [07-28-09]. Available from: http://edis.ifas.ufl.edu/AE110.

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, University of Florida. [07-28-09]. Available from: http://edis.ifas.ufl.edu/AE110.

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, University of Florida. [07-25-09]. Available from: http://edis.ifas.ufl.edu/AE111.

USDA. 1970. Irrigation water requirements. Technical Release no 21. USDA Soil Conservation Service, Washington, DC.

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 requirement, which could result in over irrigation.

[1] The P_e value calculated for north Florida is based on 10 years (1999 to 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 to 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 to June.

[3] The P_e value calculated for south Florida is based on 10 years (1999 to 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% were 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/irrigation/res/smturfcont/intelli/
Rainbird ET Manger	Yes	Remote weather station	http://www.rainbird.com/landscape/products/controllers/etmanager.htm
Weathermatic Smartline	No	Onsite sensors	http://www.weathermatic.com/
Hunter ET system	No	Onsite sensors	http://www.hunterindustries.com/products/Controllers/etintro.html
ET Water Smart	Yes	Remote weather station	http://www.etwater.com/public/index.html
Irritrol Systems	Yes	Remote weather station	http://www.irritrol.com/
Aqua Conserve	No	Onsite sensors/Historical	https://www.aquaconserve.com/

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 (%)	[1]Average efficiency (%)
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 http://edis.ifas.ufl.edu/AE110 . 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.