How to Determine Run Time and Irrigation Cycles for Drip Irrigation: Tomato and Pepper Examples[1]

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Introduction

By 2030, traditional groundwater sources will not be able to meet the increases in demand for freshwater in Florida. Conservation measures and alternative water sources will have to be considered in order to make up for this shortfall. Public water-supply demand is expected to increase by 30%, whereas agricultural water use is only predicted to rise by 9%. This lower increased demand for agriculture is primarily based on the assumption that the water-use efficiency of agricultural systems will continue to improve through the implementation of conservation measures. One such conservation measure is to increase the use of drip irrigation and improve the efficiency at which it is being used.

Drip Irrigation

Drip irrigation is more efficient than both sprinkler and sub-irrigation (seepage irrigation) in terms of water and fuel, as both water use and pumping costs are reduced with drip irrigation. A typical drip irrigation system can achieve a field application efficiency of 90%, while the maximum efficiency of typical sprinkler irrigation can achieve is 75%. Seepage irrigation, which is a common system found in south Florida and the tri-county area of northeast Florida, utilizes an artificially raised water table to a depth of 40–60 cm below the soil surface. Typically, seepage irrigation has an even lower efficiency, which is between 20% and 50%. Even though drip irrigation is more efficient than the other irrigation methods, proper system management is crucial if that increased efficiency is going to result in water savings and a viable crop.

Drip Irrigation Management

One important aspect of drip irrigation management for crop success is irrigation scheduling, which includes determining both how much and when to irrigate. This is especially true in Florida's sandy soils because of their limited water-holding capacity. If proper scheduling is not implemented, water and nutrients can be lost through leaching, which defeats the purpose of using the more efficient drip irrigation system. Because drip irrigation facilitates fertigation, which allows the grower to adjust nutrient application on an as-needed basis and vary it by plant stage throughout the growing season, irrigation scheduling is the single most important factor in keeping most of the nutrients in the root zone. The relatively high cost of liquid fertilizer compared with dry formulations makes leaching of nutrients from improper irrigation scheduling result in not only an economic loss to the grower, but also environmental costs from nutrients entering the groundwater. Additionally, an improper irrigation schedule may cause other problems, such as soil-borne disease outbreaks, reduced soil aeration, and plant stress due to water or salinity.

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Drip Irrigation Scheduling

The goal of irrigation scheduling is to provide the right amount of water when the crop needs it. The grower can use several different methods to help develop a suitable irrigation schedule. Examples of irrigation scheduling include evapotranspiration-based, soil-moisture based, deficit irrigation-based, and calendar-based. If implemented correctly, all of these methods can be used to adequately manage drip irrigation systems.

Evapotranspiration-based Drip Irrigation Scheduling

Reference Evapotranspiration

Reference evapotranspiration (ET_0) is a commonly used concept in irrigation scheduling and refers to the evapotranspiration from a well-watered grass. Reference evapotranspiration can be calculated using commonly available weather parameters. Most modern weather stations can provide ET_0 estimates, including those stations that are part of the Florida Automated Weather Network (FAWN)(To estimate ET_0 using the site specific weather data, visit http://fawn.ifas.ufl.edu/.) The primary weather parameters that influence ET_0 are temperature, humidity, wind speed, and solar radiation. For example, maximum ET_0 would occur on a sunny, dry, windy, and hot day, whereas minimum ET_0 would occur on a cloudy, humid, and cold day with little wind.

Crop Coefficients

All plants do not use the same amount of water under the same climatic conditions. Accordingly, irrigation scientists have developed crop coefficients that provide a relationship between ET_0 and the amount of water that the crop of interest uses. Water-use studies are conducted to find the relationship between the crop's evapotranspiration and ET_0. These studies normally involve lysimeters, which allow the investigators to actually measure the quantity of water that the crop of interest uses on a daily basis. This water use is then related to ET_0 using the following relationship:

$$ET_c = ET_0 \times K_c$$

Where ET_c = crop evapotranspiration

ET_0 = reference evapotranspiration

K_c = crop coefficient

Crop coefficients are available for a wide variety of crops, but they may not be applicable for all situations. For example, due to Florida's unique climatic conditions (subtropical) and soil characteristics (sandy, high water table), crop coefficients developed elsewhere (e.g. arid western United States) may not provide realistic estimates for the same crop grown in Florida. For some of the major vegetable crops in Florida, regional crop coefficients have been developed to allow growers in the state to accurately estimate their crop water needs.

Drip Irrigation Scheduling Examples

Proper scheduling needs to be implemented to take full advantage of the increased drip irrigation efficiency. Two examples are presented below for tomatoes and peppers (Figure 1), which are two important vegetable crops in Florida, to demonstrate the use of reference evapotranspiration and crop coefficients in developing a drip irrigation

Figure 1. Tomato (left) and bell pepper (right) grown with plastic mulch and drip irrigation.
Credits: Sanjay Shukla

schedule. Both examples are for crops grown with plastic mulch.

There are three soil properties that growers need to know to design crop-specific irrigation scheduling. These are field capacity, wilting point, and plant-available water. Field capacity is defined as the soil moisture level when drainage due to gravity stops. Wilting point is the soil moisture level below which water in the soil can no longer be taken by the plant. Plant-available water is considered to be the soil moisture between field capacity and wilting point and is where soil moisture should be maintained to have a healthy crop. These values vary depending upon soil type, so county soil surveys should be consulted to get site-specific information. These soil surveys are available online at http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. If a county soil survey is not available, the local USDA/NRCS or UF/IFAS location can be contacted to obtain this information.

Peppers

Situation: Double-row bell pepper crop was planted on raised plastic mulch beds on February 19, and it is now 50 days after transplant. Crop is irrigated with double drip tape each with a flow rate of 27 GPH/100 ft., on six-foot centers in south Florida.

Question: What is the total daily irrigation run time to meet crop water need?

Step 1. Determine the crop coefficient. Use the following graph to determine the crop coefficient for bell pepper at 50 days after transplant.

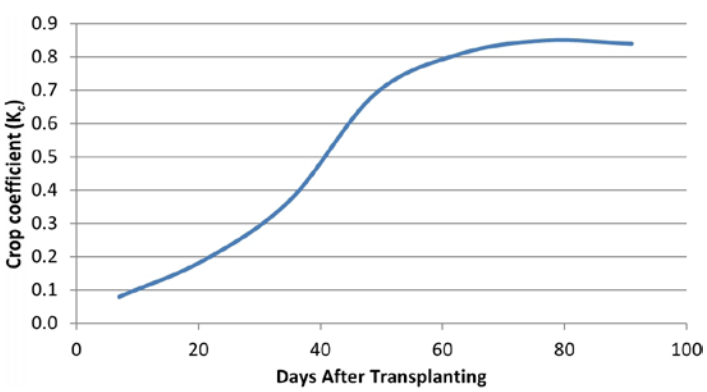

Figure 2. Crop coefficient (K_c) for bell pepper grown with drip irrigation and plastic mulch in Florida. Note that the crop coefficient above includes mainly plant water use and not evaporation losses from the row-middles (derived from Shukla et al., 2012). K_c values for other plasticulture crops can be found at http://edis.ifas.ufl.edu/cv107.
Credits: Shukla et al., 2012

$K_c = 0.7$

Step 2. Determine the daily ET_0 for a farm. This can be obtained from a weather station, a nearby FAWN weather station, online at https://edis.ifas.ufl.edu/ae481, or from other sources. Alternatively, use the following graph for south Florida to determine the ET_0 for April. The crop was planted on February 19, so 50 days after transplant would correspond to April.

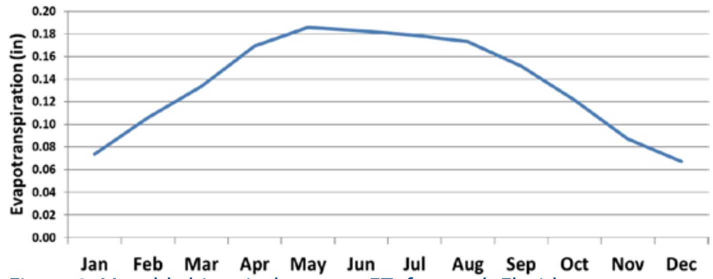

Figure 3. Monthly historical average ET_0 for south Florida
Credits: Florida Water Resources Atlas 1997

ET_0 = 0.17 in./day

To convert in./day to gal./ac./day, use a conversion factor of 27,154 gal. = 1 ac.-in.

ET_0 = 0.17 in./day (x) 27,154 gal./ac.-in = 4,620 gal./ac./day

Step 3. Determine the crop water need (i.e., pepper crop evapotranspiration (ET_c)).

$ET_c = K_c$ (x) ET_0 = 0.7 (x) 0.17 = 0.12 in./day

Again, to convert in./day to gal./ac./day, use the conversion factor.

ET_c = 0.12 in./day (x) 27,154 gal./ac.-in. = 3,231 gal./ac./day

Step 4. Determine the drip flow rate.

a. Drip tape flow rate is 27 GPH/100 ft. Two tapes are used, so the total flow rate is 54 GPH/100 ft. (2 tapes (x) 27 GPH/100 ft.).

b. On six-foot centers, there are 7,260 linear ft./ac. (1 ac. = 43,560 sq. ft., 43,560 sq. ft./6 ft. row spacing = 7,260 linear bed ft./ac.)

c. Divide 7,260 by 100 to get **72.6** 100 ft. sections/ac.

d. The total water delivered through the drip tape (Q) is calculated by multiplying the total flow rate (54 GPH/100 ft.) by the number of 100 ft. sections.

Q = 72.6 100-ft. sections (x) 54 GPH/100 ft. = 3,920 gallons/hr./ac.

Step 5. Determine the irrigation run time.

Run time = ET_c / Q = 3,231 gallons/ac./day ÷ 3,920 gallons/hr./ac. = 0.82 hr./day

Convert to minutes: 0.82 hr. (x) 60 min. = 49 min./day assuming 100% efficiency

Step 6. Adjust for the field application efficiency. Depending on the drip system maintenance and irrigation water quality, numbers ranging from 80% to 95% may be used. For this example, use 90% efficiency.

Run time = 49 min./day ÷ 90% efficiency = 55 min./day

Additional adjustments would need to be made depending on current soil moisture status of the soil.

Tomatoes

Situation: Tomato crop was planted on January 20, and it is now 60 days after transplant. Crop is irrigated with single drip tape with a flow rate of 13 GPH/100 ft.

Question A: What is the total daily run time to meet crop water need?

Step 1. Determine the crop coefficient. Use the following graph to determine the crop coefficient for tomato at 60 days after transplant.

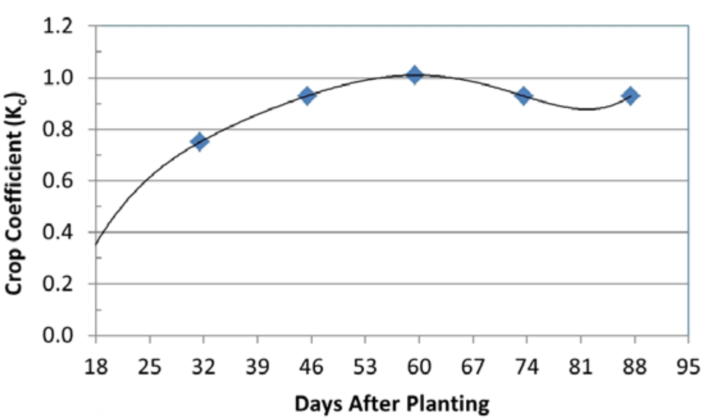

Figure 4. Crop coefficient (K_c) for tomato grown with drip irrigation and plastic mulch in Florida.
Credits: Clark et al., 1993. K_c values for other plasticulture crops can be found at http://edis.ifas.ufl.edu/cv107.

K_c = 1.0

Step 2. Determine the daily ET_0 for a farm. This can be obtained from a weather station, a nearby FAWN weather station, online at https://edis.ifas.ufl.edu/ae481, or from other sources. Alternatively, use the graph in Figure 3 to determine the ET_0 for March. The crop was planted on January 20, so 60 days after transplant would correspond to March.

ET_0 = 0.13 in./day

To convert in./day to gal./ac./day, use a conversion factor of 27,154 gal. = 1 ac.-in.

ET_0 = 0.13 in./day (x) 27,154 gal./ac.-in. = 3,530 gal./ac./day

Step 3. Determine the crop water need (i.e., tomato crop evapotranspiration (ETc)).

ET_c = K_c (x) ET_0 = 1.0 (x) 0.13 = 0.13 in./day

Again, to convert in./day to gal./ac./day, use the conversion factor.

ET_c = 0.13 in./day (x) 27,154 gal./ac.-in. = 3,530 gal./ac./day

Step 4. Determine the drip flow rate.

a. Drip tape flow rate is 13 GPH/100 ft.

b. On six-foot centers, there are 7,260 linear ft./ac. (1 ac. = 43,560 sq. ft., 43,560 sq. ft./6 ft. row spacing = 7,260 linear bed ft./ac.)

c. Divide 7,260 by 100 to get **72.6** 100 ft. sections/ac.

d. The total water delivered through the drip tape (Q) is calculated by multiplying total flow rate (13 GPH/100 ft.) by number of 100 ft. sections.

Q = 72.6 100 ft-sections (x) 13 GPH/100 ft. = 944 gallons/hr./ac.

Step 5. Determine the irrigation run time.

Run time = ET_c / Q = 3,530 gallons/ac./day ÷ 944 gallons/hr./ac. = 3.74 hr./day

Convert to minutes: 3.74 hr. (x) 60 min. = 224 min./day assuming 100% efficiency

Step 6. Adjust for the field application efficiency. Depending on the drip system maintenance and irrigation water quality, numbers ranging from 80% to 95% may be used. For this examples, use 85% efficiency.

Run time = 224 min./day ÷ 0.85 = 264 min./day (0.85 represents fraction form of 85%)

Additional adjustments would need to be made depending on current soil moisture status of the soil. This will be addressed in Question B of this example.

Question B: What is the optimal run time for each irrigation cycle, considering initial soil moisture and the total number of irrigation cycles needed per day to meet crop water need? Initial soil moisture for each cycle is at 50% plant available water (PAW). Assume the soil has a field capacity of 12% and a wilting point of 4%. For a specific soil at the farm, field capacity and wilting point can be obtained from county-specific soil survey.

Step 1. Determine 50% PAW.

Plant available water = Field capacity – wilting point = 12% – 4% = 8%

50% of PAW = 50% (x) 8% = 4%

Field soil moisture level at 50% of PAW = Field Capacity – 50% of PAW = 12% – 4% = 8%

Step 2. Determine the flow rate of each individual emitter.

Number of emitters per 100 ft. = 100 ft. ÷ 1 ft. (12 in.) emitter spacing = 100 emitters

Emitter flow rate = 13 GPH(per 100 ft.) ÷ 100 emitters = 0.13 GPH/emitter

Step 3. Determine the volume of assumed irrigated area per emitter. To simplify the example, the wetted bulb under each area can be approximated as an 8-inch diameter (4-inch radius) by 8-inch tall cylinder. The actual wetted area will be more of an ovoid, but for this example a cylinder will be used.

Volume of 8 inch by 8 inch cylinder = $\pi r^2 h$ = 3.14 (x) 4^2 (x) 8 = 402 in^3

Step 4. Determine the volume of irrigation water needed to bring soil from 50% PAW to field capacity.

Volume of irrigation water = Volume of cylinder x 50% PAW =

402 in^3 (x) 4% = 402 (x) 0.04 = 16.08 in^3

Convert volume from inches to gallons where 231 in^3 = 1 gal.

16.08 in^3 ÷ 231 in^3/gal. = 0.07 gal.

Step 5. Determine the run time needed to raise the soil from 50% of PAW to field capacity (i.e., raise the soil moisture level from 8% to 12%).

Run time = volume needed ÷ emitter flow rate = 0.07 gal. ÷ 0.13 GPH = 0.535 hr.

0.602 hr. (x) 60 min./hr. = 36 min

Step 6. Determine the number of cycles needed per day to meet crop water need.

Number of cycles = total run time ÷ cycle run time

264 min. ÷ 32.1 min. = 8.22 cycles per day

Since the number of crop cycles is not an even number, this should be rounded up to 9 cycles per day to ensure that the crop water need is met. Note it is assumed that the root zone depth is 8 in. Root zone depths can vary depending on location; growers have reported up to 14 in. or more root zone depths. To determine the irrigation cycles and run time for a root zone depth other than 8 in., the cylinder volume height can be changed. For example, a root zone depth of 12 in. for the above tomato example will require six cycles with 48 minutes of run time. In the above example, if 9 cycles is not feasible due to the site-specific irrigation system configuration, then adjustments can be made to the irrigation cycle run time. However, it should be kept in mind that if the irrigation cycle run time is increased, then water and nutrients may be leached beyond the root zone, resulting in economic losses and negative environmental impacts.

References

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