

Chapter 8.

Principles and Practices of Irrigation Management for Vegetables

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This section contains basic information on vegetable water use and irrigation management, along with some references on irrigation systems. Proper water management planning must consider all uses of water, from the source of irrigation water to plant water use. Therefore, it is very important to differentiate between crop water requirements and irrigation or production system water requirements. Crop water requirements refer to the actual water needs for evapotranspiration (ET) and plant growth, and primarily depend on crop development and climatic factors which are closely related to climatic demands. Irrigation requirements are primarily determined by crop water requirements, but also depend on the characteristics of the irrigation system, management practices and the soil characteristics in the irrigated area (Figs. 8- 1, 8-2).

BEST MANAGEMENT PRACTICES FOR IRRIGATION

BMPs have historically been focused on nutrient management and fertilizer rates. However, as rainfall or irrigation water is the vector of off-site nutrient movement of nitrate in solution and phosphate in sediments, proper irrigation management directly affects the efficacy of a BMP plan. The irrigation BMPs in the “Agronomic and Vegetable Crops Water Quality/Water Quantity BMP manual for Florida” cover all major aspects of irrigation such as irrigation system design, system maintenance, erosion control, and irrigation scheduling.

USES OF IRRIGATION WATER

Irrigation systems have several uses in addition to water delivery for crop ET. Water is required for a pre-season operational test of the irrigation system to check for leaks and to ensure proper performance of the pump and power plant. Irrigation water is also required for field preparation, crop establishment, crop growth and development, within-season system maintenance, delivery of chemicals, frost protection, and other uses such as dust control.

Field Preparation

Field preparation water is used to provide moisture to the field soil for tillage and bed formation. The water used for field preparation depends on specific field cultural practices, initial soil moisture conditions, the depth to

the natural water table, and the type of irrigation system. Drip-irrigated fields on sandy soils often require an additional irrigation system for field preparation because the drip tubes are not installed until after the beds have been formed. Thus, many drip irrigated vegetable fields may also require an overhead or subirrigation system for field preparation. For example, many strawberry production fields have sprinkler irrigation systems already installed for frost protection. These systems are also used for field preparation and may apply one or more inches of water for this purpose. Subirrigated fields will use the same system for field preparation as well as for crop establishment, plant growth needs and frost protection. Subirrigation water management requirements depend on the soil characteristics within the irrigated field and surrounding areas. Sufficient water must be provided to raise the water table level as high as 18 to 24 inches below the soil surface. Water is required to fill the pores of the soil and also satisfy evaporation and subsurface runoff requirements. As a rough guide, 1.0 to 2.5 inches of water are required for each foot of water table rise. For example, a field with a pre-irrigation water table 30 inches deep may need about 2 inches of water to raise the water table to 18 inches, while a pre-irrigation water table at 48 inches may require 5 inches of water for the same result.

Crop Establishment

Vegetables that are set as transplants, rather than direct seeded, require irrigation for crop establishment in excess of crop ET. Establishment irrigations are used to either keep plant foliage wet by overhead sprinkler irrigation (to avoid desiccation of leaves) or to maintain high soil moisture levels until the root systems increase in size and plants start to actively grow and develop. Establishment irrigation practices vary among crops and irrigation systems. Strawberry plants set as bare-root transplants may require 10 to 14 days of frequent intermittent overhead irrigation for establishment prior to irrigation with drip system. The amount of water required for crop establishment can range widely depending on crop, irrigation system, and climate demand.

Crop Growth and Development

Irrigation requirements necessary to meet the ET needs of a crop depend on the type of crop, field soil characteristics, irrigation system type and capacity, and stage of crop development. Different crops have growth characteristics that result in different relative water use rates. Soils vary

Table 1. Application efficiency for water delivery systems used in Florida

Irrigation system	Application efficiency (Ea)
Overhead	60-80%
Seepage	20-70%
Drip ¹	80-95%

¹ with or without plastic mulch

in texture and hydraulic characteristics such as available water-holding capacity (AWHC) and capillary movement. Because sands generally have very low AWHC values (3% to 6% is common), a 1% change in AWHC affects irrigation practices.

Water application (irrigation requirement)

Irrigation systems are generally rated with respect to application efficiency (Ea), which is the fraction of the water that has been applied by the irrigation system and that is available to the plant for use (Table 1). Applied water that is not available to the plant may have been lost from the crop root zone through evaporation or wind drifts of spray droplets, leaks in the pipe system, surface runoff, subsurface runoff, or deep percolation within the irrigated area. Irrigation requirements (IR) are determined by dividing the desired amount of water to provide to the plant (ETc), by Ea as a decimal fraction (Eq. [1]). For example, if it is desired to apply 0.5 inches to the crop with a 75% efficient system, then the system should apply 0.5/0.75=0.67 inches. For more information, consult IFAS bulletin 247 ‘Efficiencies of Florida agricultural irrigation systems’ (<http://edis.ifas.ufl.edu/AE110>) and bulletin 265 ‘Field evaluation of microirrigation water application uniformity’ (<http://edis.ifas.ufl.edu/AE094>). Catch cans can be used in the field to determine the actual amount of water applied

Eq. [1] Irrigation requirement = Crop water requirement / Application efficiency
 $IR = ETc/Ea$

Fertigation/Chemigation

Irrigation systems are often used for delivery of chemicals such as fertilizers, soil fumigants, or insecticides. The crop may require nutrients when irrigation is not required, e.g. after heavy rainfall. Fertilizer injection schedules based on soil tests results are provided in each crop production chapter of this production guide. Fertigation should not begin until the system is pressurized. It is recommended to always end a fertigation/chemigation event with a short flushing cycle with clear water to avoid the accumulation of fertilizer or chemical deposits in the irrigation system, and/or rinse crop foliage. The length of the flushing cycle should be 10 minutes longer than the travel time of the fertilizer from the irrigation point to the farthest point of the system.

System Maintenance

Irrigation systems require periodic maintenance throughout the growing season. These activities may require system operation during rainy periods to ensure that the system is ready when needed. In addition, drip irrigation systems may require high levels of maintenance to prevent clogging and system failure. Typically, cleaning agents are injected weekly, but in some instances more frequent injections are needed.

Frost Protection

For some crops, irrigation is used for frost protection during winter growing seasons. For strawberry production, sprinkler irrigation is primarily used with application rates of about 0.25 inches per hour during freeze events. Water freezes at 32°F, while most plant tissue freeze at lower temperatures. Overhead freeze protection is efficient for air temperature as low as 26-28°F, but seldom below. For vegetable fields with subirrigation systems, the heat properties of groundwater can be used for cold protection. Growers may also irrigate to raise the water table throughout the field. Frost protection water requirements vary and depend on the severity and duration of freeze events, the depth to the existing water table level, and field hydraulic characteristics.

Other Uses

Other irrigation uses vary according to the type of crop, system characteristics, and field location. Some examples include: periodic overhead irrigation for dust control; wetting of dry row middles to settle dust and prevent sand from blowing during windy conditions; and, wetting of roadways and drive aisles to provide traction of farm vehicles.

IRRIGATION SCHEDULING

Table 2. Levels of water management and corresponding irrigation scheduling method

Water Mgt. Level	Irrigation scheduling method
0	Guessing (irrigate whenever)
1	Using the ‘feel and see’ method
2	Using systematic irrigation (example: 3/4 in. every 4th day)
3	Using a soil water tension measuring tool to start irrigation
4	Using a soil water tension measuring tool to schedule irrigation and apply amounts based on a budgeting procedure
5 ¹	Adjusting irrigation to plant water use, and using a dynamic water balance based on a budgeting procedure and plant stage of growth, together with using a soil water tension measuring tool

¹ recommended method

Irrigation scheduling is used to apply the proper amount of water to a crop at the proper time. The characteristics of the irrigation system, crop needs, soil properties, and atmospheric conditions must all be considered to properly schedule irrigations. Poor timing or insufficient water application can result in crop stress and reduced yields from inappropriate amounts of available water and/or nutrients. Excessive water applications may reduce yield and quality, are a waste of water, and increase the risk of nutrient leaching.

A wide range of irrigation scheduling methods is used in Florida, with corresponding levels of water management (Table 2). The recommend method to schedule irrigation (drip or overhead) for vegetable crops is to use together, (1) the crop water requirement method that takes into account plant stage of growth (water management level 5 in Table 2), (2) a measurement of soil water status, and (3) guidelines for splitting irrigation. For seepage irrigation, the water table should be maintained near 18 inches at planting and 24 inches near harvest. Water tables should be maintained at the proper level to ensure optimum moisture in the bed without leading to oversaturation of the root zone and potential losses of nutrients. Water tables can be monitored with a section of PVC pipe sunk in the

soil with a calibrated float inside the PVC pipe. The calibrated float can be used to determine the exact level of the water table.

Soil water status and soil water tension

Soil water tension (SWT) represents the magnitude of the suction (negative pressure) the plant roots have to create to free soil water from the attraction of the soil, and move it into the root cells. The dryer the soil, the higher the suction needed, hence, the higher SWT. SWT is commonly expressed in centibars (cb) or kiloPascals (kPa; 1cb = 1kPa; 7kPa = 1psi). For most vegetable crops grown on the sandy soils of Florida, SWT in the rooting zone should be maintained between 6 (field capacity) and 15 cb. Because of the low AWHC of Florida soils, most full-grown vegetable crops will need to be irrigated daily. During early growth, irrigation may be needed only two to three times weekly. SWT can be measured in the field with moisture sensors or tensiometers. For more information on SWT measuring devices, consult IFAS circular 487 'Tensiometers for soil moisture measurement and irrigation scheduling' available at <http://edis.ifas.ufl.edu/AE146> and bulletin 319 'Tensiometer service, testing and calibration' available at <http://edis.ifas.ufl.edu/AE086>.

Table 3. Historical Penman method reference ET (ET_o) for four Florida locations expressed in (A) inches per day and (B) gallons per acre per day.

Month	Tallahassee	Tampa	West Palm Beach	Miami
(A) inches per day				
JAN	0.06	0.09	0.10	0.10
FEB	0.09	0.12	0.13	0.13
MAR	0.12	0.14	0.16	0.16
APR	0.16	0.19	0.19	0.19
MAY	0.18	0.20	0.19	0.19
JUN	0.18	0.20	0.18	0.18
JUL	0.17	0.18	0.18	0.18
AUG	0.16	0.17	0.18	0.17
SEP	0.14	0.16	0.16	0.15
OCT	0.11	0.14	0.14	0.14
NOV	0.08	0.11	0.12	0.11
DEC	0.06	0.08	0.10	0.10
(B) gallons per acre per day¹				
JAN	1630	2440	2720	2720
FEB	2440	3260	3530	3530
MAR	3260	3800	4340	4340
APR	4340	5160	5160	5160
MAY	4890	5430	5160	5160
JUN	4890	5430	4890	4890
JUL	4620	4890	4890	4890
AUG	4340	4620	4890	4620
SEP	3800	4340	4340	4070
OCT	2990	3800	3800	3800
NOV	2170	2990	3260	2990
DEC	1630	2170	2720	2720

¹ assuming water application over the entire area, i.e., sprinkler or seepage irrigation with 100% efficiency

Crop water requirement (ET)

Crop water requirements depend on crop type, stage of growth, and evaporative demand. Evaporative demand is termed evapotranspiration (ET) and may be estimated using historical or current weather data. Generally, reference evapotranspiration (ET_o) is determined for use as a base level. By definition, ET_o represents the water use from a uniform green cover surface, actively growing, and well watered (such as a turf or grass covered area).

Historical daily averages of Penman-method ET_o values are available for four Florida locations expressed in units of acre-inches and gallons per acre (Table 3). While these values are provided as guidelines for management purposes, actual values may vary above and below these values, requiring individual site adjustments. Actual daily values may be as much as 25% higher on days that are hotter and drier than normal or as much as 25% lower on days that are cooler or more overcast than normal. As a result, SWT or soil moisture should be monitored daily in the field.

Table 4. Description of stages of growth (plant appearance and estimated number of weeks) for most vegetable crops in Florida¹

Crop	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Expected growing season (weeks)
Bean	Small plants 2-3	Growing plants 3-4	Pod enlargement 2-3	Pod maturation 2-3		9-10
Cabbage, Cauliflower, Chinese cabbage	Small plants 2-3	Growing plants 5-6	Head development 3-4			10-12
Cantaloupe (muskmelon)	6-in vine 1-2	12-in vine 3-4	First flower 3-4	Main fruit production 2-3	Late fruit production 2-3	11-12
Carrot	Small plants 1-2	Growing plants 3-4	Root development 5-7	Final growth 1-2		10-13
Cucumber	6-in vine 1-2	12-in vine 2-3	Fruit production 6-7	Late season 1-2		10-12
Eggplant	Small plants 2-3	Growing plants 2-3	Fruit production 6-7	Late season 2-3		12-13
Potato	Small plants (after hilling) 2-4	Large plants (vegetative growth) 4-6	First flower (tube initiation and bulking) 3-5	Maturation (top dies) 2-4		12-14
Okra	Small plants 2-3	Growing plants 2-3	Pod production 7-8	Late season 1-2		12-13
Onion	Small plants 2-4	Growing plants 4-5	Bulb development 6-8	Maturation (top falls) 1-2		13-16
Pepper	Small plants 2-3	Growing plants 2-3	Pod production 6-7	Last bloom 1-2	Last harvest 1	13-15
Pumpkin (bush)	Small plants 2-3	First flower 2-3	Fruit enlargement 5-6	Harvest 1-2		9-11
Pumpkin (vining)	6-in vines 2-3	12-in vines 2-3	Small fruit 3-4	Large fruit 2-3	Harvest 1-2	13-15
Radish	Small plants 1-2	Rapid growth 2-4				3-5
Strawberry	Young plants October	Growing plants November	Early harvest December- January	Main harvest period February- March	Late harvest April	23-30
Summer Squash (crookneck, straightneck, zucchini)	Small plants 1-2	Growing plants 2-3	Fruit production 3-4	Late fruit production 1		7-9
Sweet corn	Small plants 3-4	Large plants 5-8	Ear development 2-3			10-15
Sweetpotato	Early vine growth 2-3	Expanding vines 5-6	Storage root enlargement 6-10	1	Late season	13-17
Tomato	Small plants 2-3	1st bloom 2-3	2nd - 3rd bloom 6-7	Harvest 1-2	Last harvest 1-2	12-14
Watermelon	6-in vines 2-3	12-in vines 2-3	Small fruit 3-4	Large fruit 2-3	Harvest 1-2	13-15

¹ Same growth stages used for irrigation and fertilizer schedules, for south Florida each stage may be 30% longer because of winter planting during short days.

Crop water use (E_{Tc}) is related to E_{To} by a crop coefficient (K_c) which is the ratio of E_{Tc} to the reference value E_{To} (Eq. [2]). Because different methods exist for estimating E_{To} , it is very important to use K_c coefficients which were derived using the same E_{To} estimation method as will be used to determine the crop water requirements. Also, K_c values for the appropriate stage of growth (Table 4; Fig. 8-3) and production system (Tables 5 and 6) must be used.

With drip irrigation where the wetting area is limited and plastic mulch is often used, K_c values are lower to reflect changes in row spacing and mulch use. Plastic mulches substantially reduce the evaporation of water from the soil surface. Associated with the reduction of evaporation is a general increase in transpiration. Even though the transpiration rates under mulch may increase by an average of 10-30% over the season as compared to no-mulched system, overall water use values decrease by an average of 10-

Table 5. Crop coefficient estimates for use with the E_{To} values in Table 3 and growth stages in Table 4 for unmulched crops. (Actual values will vary with time of planting, soil conditions, cultural conditions, length of growing season and other site-specific factors)

Crop	Growth Stage	Crop Coefficient
All field-grown vegetables	1	0.20 ¹ to 0.40 ²
	2	Stage 1 ³ value to Stage 3 value (See Figure 8-3)
Legumes: snapbean, lima bean and southernpea	3	0.95 ⁴
	4	0.85 ⁴
Beet	3	1.00
	4	0.90
Cole crops: broccoli, brussels sprouts cabbage, cauliflower collards, kale mustard turnip	3	1.00
	4	0.85
	3	0.95 ⁴
	4	0.90 ⁴
	3	1.00 ⁴
	4	0.90 ⁴
Carrot	3	1.05
	4	0.75
Celery	3	1.05
	4	0.95
Cucurbits: cucumber, cantaloupe, pumpkin squash, watermelon	3	0.90
	4	0.70
Lettuce: endive, escarole	3	0.95
	4	0.90
Okra	3	1.00 ⁴
	4	0.90 ⁴
Onion (dry)	3	0.95
	4	0.75
Onion (green)	3	0.95
Parsley	3	1.00 ⁴
Potato	3	1.10
	4	0.70
Radish	3	0.80
	4	0.75
Spinach	3	0.95
	4	0.90
Sweet corn	3	1.10
	4	1.00
Sweetpotato	3	1.10 ⁴
	4	0.70 ⁴
¹ low plant population; wide row spacing ² high plant population; close row spacing ³ 0.20 or K_c value from Stage 1 ⁴ values estimated from similar crops		

30% due to the reduction in soil evaporation. ETo may be estimated from atmometers (also called modified Bellani plates) by using an adjustment factor. During days of no rain fall, ETo may be estimated from evaporation from an ET gauge (Ea) as $E_{To} = E_a/0.89$. On rainy days (>0.2 in) $E_{To} = E_a/0.84$.

Eq. [2] Crop water requirement = Crop coefficient x Reference evapotranspiration

$$E_{Tc} = K_c \times E_{To}$$

SOIL WATER HOLDING CAPACITY AND THE NEED TO SPLIT IRRIGATIONS

In Florida sandy soils, the amount of water that can be stored in the root zone and be available to the plants is limited. Usually, it is assumed that approximately 0.75 inches of water can be stored in every foot of the root zone. Only half of that should be used before next irrigation to avoid plant stress and yield reduction (this will help maintain SWT below 15cb). Any additional water will be lost by deep percolation below the root zone.

Table 7 gives approximate amount of water that can be applied at each event in Florida sandy soil for different production systems. When the calculated volume of water to be applied in one day exceeds the values in Table 7, then it is necessary to split applications. The number of split irrigations can be determined by dividing the irrigation requirement (eq. [1]) by the numbers in Table 7, and rounding up the result to the nearest whole number. Splitting irrigation reduces both risks of water loss through deep percolation and nutrient leaching. Sandy soil with the available water holding capacity of 0.75 in/ ft was assumed in these calculations. If your soil contains more clay or organic matter the amount of water applied during one irrigation event and stored in the root zone can be increased. It is recommended to check the depth of wetting after irrigation to assure that the water is not lost from the roots by digging out a perpendicular profile to the drip line and observing the wetted pattern.

Example

As an example, consider drip irrigated tomatoes on 6- ft center beds, grown under plastic mulch production system in the Tampa Bay area (sandy soils). For plants in growth Stage 4 the crop coefficient is 0.90 (Table 6). If this period of growth occurred in April, the corresponding ETo value

Table 6. Crop coefficient estimates (Kc) for use with ETo values in Table 3 and growth stages in Table 4 for selected crops grown in a plasticulture system.¹

Crop	Growth Stage	Crop Coefficient (Kc)
Cantaloupe	1	0.35
	2	0.6
	3	0.85
	4	0.85
	5	0.85
Cucumber	1	0.25
	2	0.5
	3	0.75
	4	0.75
Summer squash	1	0.3
	2	0.55
	3	0.8
	4	0.8
Strawberry (4-ft bed centers)	1	0.4
	2	0.5
	3	0.6
Tomato (6-ft bed centers)	1	0.3
	2	0.4
	3	0.9
	4	0.9
	5	0.75
Watermelon (8-ft bed center)	1	0.3
	2	0.5
	3	0.7
	4	0.75
	5	0.8

¹ Adapted from Table 25, FAO Paper 56

is 5160 gal/ac/day (Table 3). Daily crop water use would be estimated as:

$$ET_{crop} = (0.90) \times (5,160 \text{ gal/ac/day}) = 4,644 \text{ gal/ac/day}$$

If the drip irrigation system can apply water to the root zone of the crop with an application efficiency of 85%, the irrigation requirement would be

$$\text{Irrigation Requirement} = (4,644 \text{ gal/ac/day}) / (0.85) = 5,459 \text{ gal/ac/day}$$

If the maximum water application in one irrigation event for this type of soil is 1,700 gal/ac/irrigation, then the irrigation will have to be split:

$$\begin{aligned} \text{Number of events} &= (5,459 \text{ gal/acre/day}) / (1,700 \text{ gal/acre/day/irrigation event}) \\ &= 3.2, \text{ rounded up to 4 irrigation events} \end{aligned}$$

Therefore in this example, four irrigations of 1,365 gal/ac each will be needed to replace ET_c, not exceed the soil water holding capacity. This amount of water would be a good estimate for scheduling purposes under average growth and average April climatic conditions. However, field moisture plant status should be also monitored to determine if irrigation levels need to be increased or reduced. While deficit irrigation will reduce fruit size and plant growth, excessive irrigation may leach nutrients from the active root system. This may also reduce plant growth.

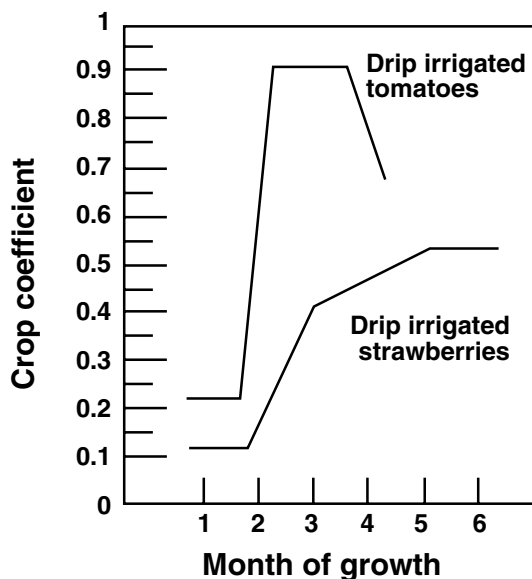


Fig 8-3. Crop coefficient for tomato and strawberry grown with plasticulture.

Table 7. Maximum water application (in gallons per acre and in gallons/100ftb) in one irrigation event for various production systems on sandy soil (available water holding capacity 0.75 in/ ft and 50% soil water depletion). Split irrigations may be required during peak water requirement.

Wetting width (ft)	Gal/100ft to wet depth of 1 ft		Gal/100ft to wet depth of 1.5 ft		Gal/100ft to wet depth of 2 ft		Vegetable crop	Bed spacing (ft)	Bed length (100 lbf/a)	Gal/acre to wet depth of 1 ft		Gal/acre to wet depth of 1.5 ft		Gal/acre to wet depth of 2 ft	
	24	36	36	54	48	72				2,600	3,800	2,600	3,800	2,600	3,800
1.0	24	36	36	54	48	72	Lettuce, Strawberry	4	109	2,600	3,800	2,600	3,800	2,600	3,800
1.5							Cantaloupe	5	87	2,100	3,100	2,100	3,100	2,100	3,100
							Broccoli, Okra, Cabbage, Pepper, Cauliflower, Summer squash, Pumpkin (bush) Eggplant, Tomato	6	73	1,700	2,600	1,700	2,600	1,700	2,600
							Watermelon, Pumpkin (vining)	8	55	1,300	1,900	1,300	1,900	1,300	1,900
							Lettuce, Strawberry	4	109	3,800	5,800	3,800	5,800	3,800	5,800
							Muskmelon	5	87	3,100	4,700	3,100	4,700	3,100	4,700
							Broccoli, Okra, Cabbage, Pepper, Cauliflower, Summer squash, Pumpkin (bush) Eggplant, Tomato	6	73	2,600	3,900	2,600	3,900	2,600	3,900
							Watermelon, Pumpkin (vining)	8	55	1,900	3,000	1,900	3,000	1,900	3,000