Drip System Design for Established Landscape Trees and Shrubs

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Abstract

A procedure for designing drip systems for established trees and shrubs based on the ANSI/ASABE S623 OCT2015 Standard has been developed based on soil characteristics, emitter wetting patterns, and plant water needs. It is supported by an Excel spreadsheet and/or a set of design charts to ensure proper wetted pattern development and proper amount of water applied.

Good irrigation involves two fundamental concepts: putting water where it needs to be, and applying the right amount of water. At times keeping the water where you put it is also a factor. Drip irrigation amounts to a series or set of discrete points of application. Each point of application initially puts water on faster than the soil can accept it, so it spreads until the wetted area is equal to the application flow rate divided by the infiltration rate as given in equation 1.

$$r = 8.57 \times \sqrt{\frac{q_e}{IR}} \qquad \text{Equation 1}$$

where

- r = radius of wetted soil {in.}
- q_e = flow rate of the emitter {gph}
- IR = infiltration rate of the soil {in./h}

This is the minimum that the area can be. Because the area of the wetted pattern is not immediately the size needed for the emitter flow and the soil, it will actually be larger. This suggests that the wetted pattern continues to grow for some time during and after the irrigation cycle. The amount of water needed is governed by the plant and ET_o and set by the flow rate and time of irrigation. The infiltration rate is governed by the soil. Hence several factors are in involved in the design of a drip system. Furthermore, usually one of the goals of a drip system on established trees to wet a portion of the soil surface. Rather, it is preferred to wet 70-75% of the surface as determined by the canopy drip line of the tree. This requires considering run time when designing where to place emitters.

Putting the water where it needs to be

Wetted Pattern (2-D: surface and 3-D: including depth)

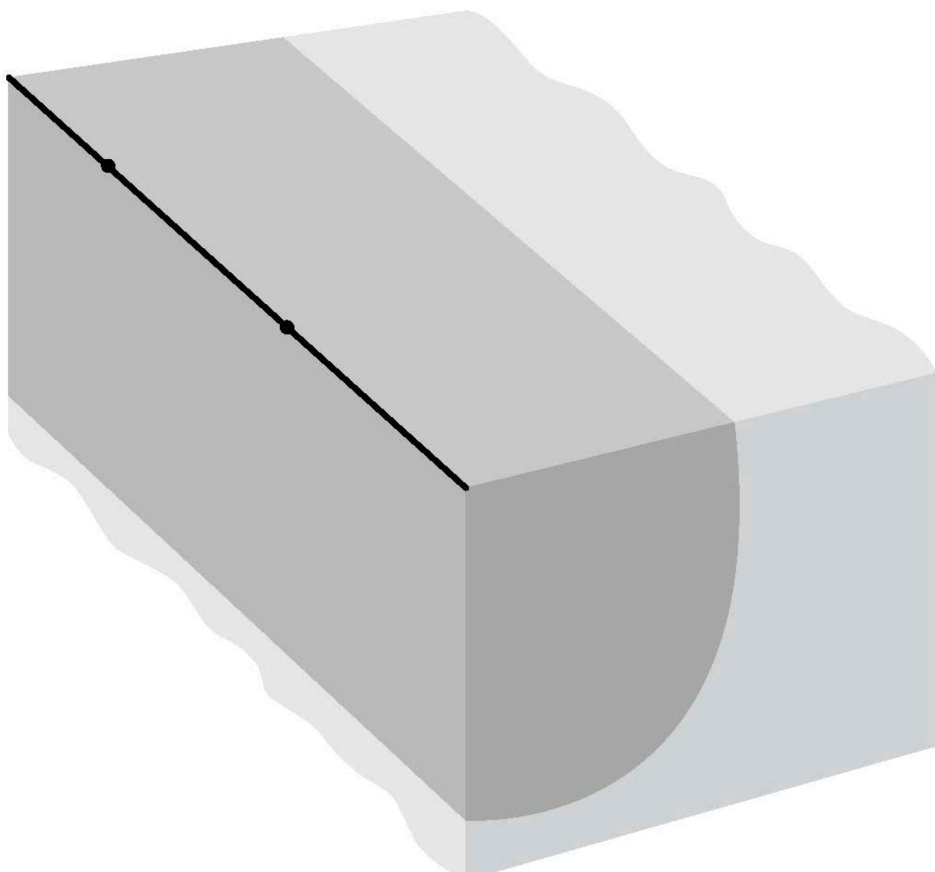
Our approach has been to develop a model based on soil characteristics and emitter flow rate to determine the size of the wetted pattern as a function of time. Figure 1 shows the wetted pattern of a system run for a few minutes (left) and for a few hours (right).

Figure 1 showing wetted patterns after a few minutes (left) and a few hours (right).

The wetted pattern begins as a circle around the emission point and in time the circles overlap. If the emitter spacing is less than the row spacing as shown the figures, they will join to form first a scalloped edge and then a rectangle. If the row spacing is not too wide, the rows will eventually overlap. If the goal is to have the wetted area less than 100%, then the emitter spacing, row spacing, emitter flow rates, and run times must be chosen to achieve the desired results. As the wetted pattern spreads on the surface, the water is also moving downward in a hemispherical fashion. Eventually, as the wetted volume overlaps, the pattern becomes cylindrical. If the system is run long enough that the surface wetted pattern stabilizes, the cross-sectional depth profile is a 3-D rectangle with a hemispherical bottom as shown in Figure 2.

This model of water movement in the soil is dependent on the soil being very uniform in type, organic matter, and compaction. Often in landscape situations the surface area may have been tilled to improve soil structure, but deeper down the soil can be quite compacted. This compaction will affect water movement.

Figure 2. 3-D wetted pattern with stabilized surface wetted area.



As the system is run, the wetted depth increases, so another challenge of managing the system is to avoid deep percolation.   This is further complicated in that the grey zone is saturated, and the water will continued downward well after the irrigation event is stopped until the wetted area reaches field capacity. So…a management system must consider the eventual wetted depth.   The amount of water the soil can accept depends not only on the soil characteristics but also on the wetness when the irrigation event was begun. This antecedent wetness is dependent on the management allowable depletion (MAD) employed.

Input Values to Model

Summarizing the discussion thus far, the following are important considerations in a drip wetted pattern model.

1. Soil characteristics
2. Row spacing
3. Desired width of the surface wetted pattern (sets percent of surface area wetted)
4. Root depth
5. ET_o
6. MAD
7. Emitter flow rate
8. Emitter spacing

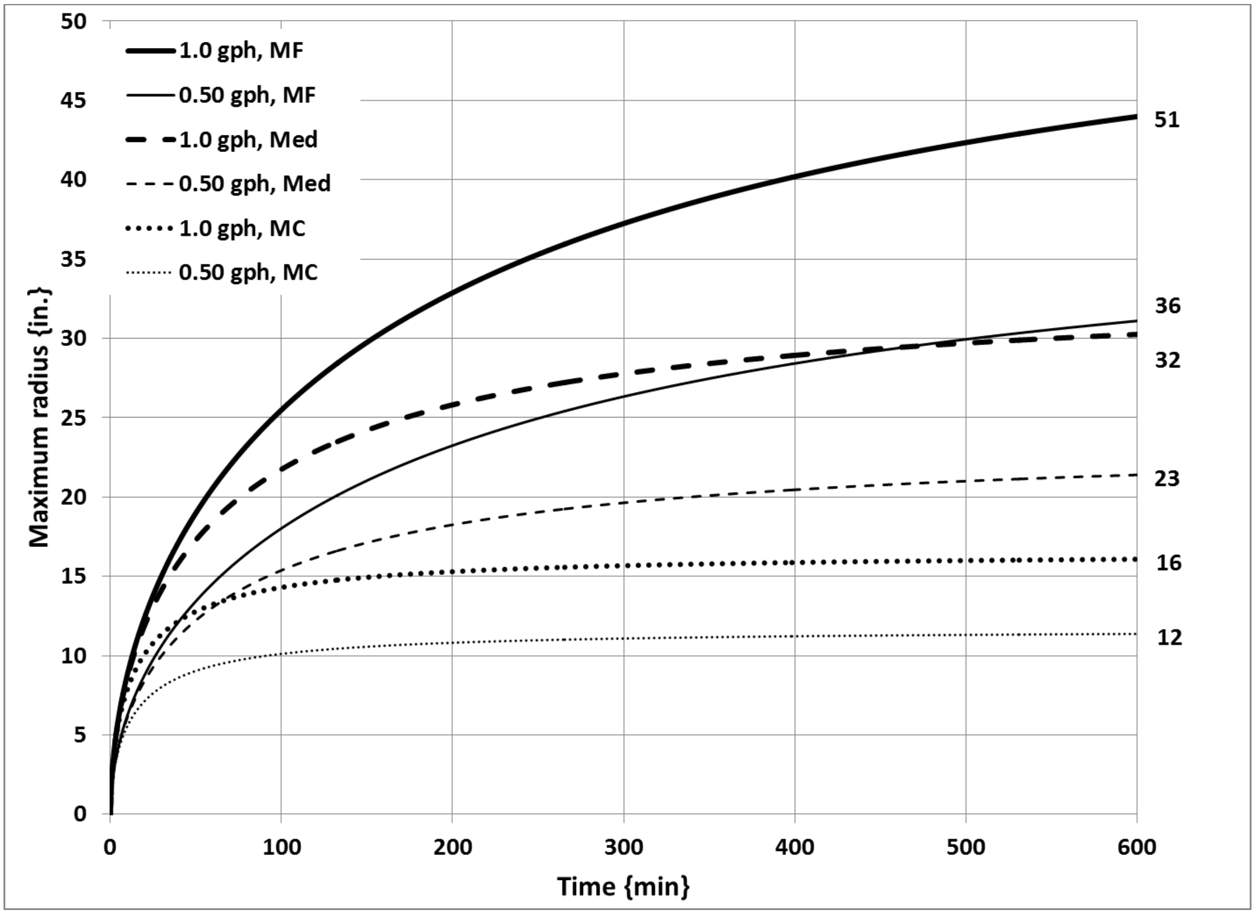
Model Assumptions

1. The important assumptions made in the model are as follows:
2. The emitter flow rate is high enough to cause some ponding on the surface.
3. The ponded area spreads to form a wetted area.
4. The wetted area will grow at least until it equals the emitter flow rate divided by the infiltration rate, and normally grows much larger.
5. Vertical water movement is controlled by the saturated hydraulic conductivity.

Model features

The model was designed to develop the time relationship among wetted pattern radius, emitter flow rate and soil type. Figure 3 shows that relationship for three soils and two emitter flow rates. This figure shows that the wetted radius continues to grow in time until a maximum is reached. Higher flow rates lead to larger wetted patterns. Lower saturated hydraulic conductivities lead to larger wetted surface area. Given a soil, the wetted radius can be increased by running longer until a maximum is reached. That maximum can be increased by increasing the emitter flow rate. Note that the maximum wetted radius is larger than shown on the graph because radii continue to grow beyond the time shown in the graph.

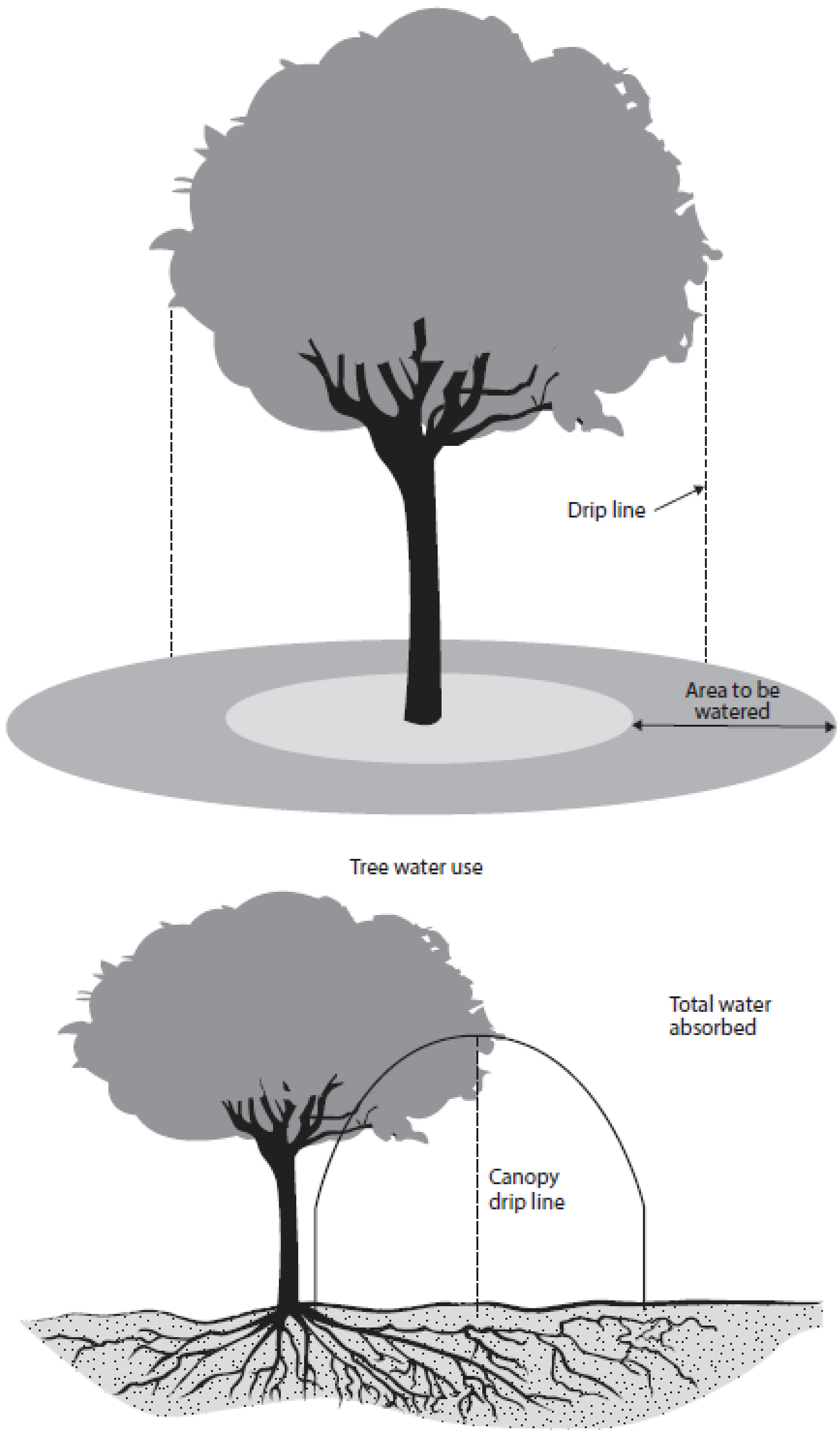
Figure 3. Wetted radius for three soils and two emitter flow rates.



Where the water needs to be on established trees and shrubs

On established trees and shrubs, it is important to place the emitters where the roots are. Even in very arid climates, the roots tend to be located around the drip line of the tree. Most of the water absorbed by the roots will come from there, and not near the trunk. Figure 4 shows where an established tree will absorb water.

Figure 4. Emitter placement relative to tree drip line.



Tree roots can extend 1½–4 times beyond the canopy.

On an established tree, the area from which the tree draws water can be quite large. This probably involves several emitters on one, two or three concentric circles depending on the diameter of the tree canopy. This is another consideration for a design model, and should be added to the list.

Putting on the right amount of water

In many landscape systems, drip irrigation is designed per tree. Several key questions must be addressed in the design and operation. The general rule for trees that shade 80 percent or less of the area is to design the system so that about 75 percent of the canopy area is wetted. The number of emitters, flow rate of the emitters, and run time all affect the wetted area for any given soil.
A new standard has been developed by the American Society of Agricultural and Biological Engineers (ASABE) with active participation by the Irrigation Association (IA) that gives guidelines for the amount of water needed for turf, flowers, woody plants and desert plants. Table 1 gives the annual average fraction of ET_o for acceptable appearance of established woody and desert landscape plants (ANSI/ASABE S623 OCT2015, Determining Landscape Plant Water Demands. *The ANSI designation indicates that the standard has been accepted by the American National Standards Institute*).

Plant type	Recommended plant factor
Woody plants and herbaceous perennials, wet*	0.7
Woody plants and herbaceous perennials, dry	0.5
Desert plants	0.3

* For tropical plants with precipitation the majority of months, a plant factor of 0.7 applies. Where monsoonal climates are present, 0.7 applies for the wet season and 0.5 during the dry season.

Source: ASABE S623

Areas with 20 inches or more of annual precipitation, especially if it occurs during the growing season, should be considered "wet." Areas with less than 20 inches but more than 10 inches of precipitation during the growing season should be considered "dry" and may require drought tolerant plants for survival without minimal irrigation. Areas with less than 10 inches of annual precipitation are considered desert and appropriate plants should be selected. Even they will need some irrigation at critical times to maintain an acceptable appearance.

Calculating Landscape Water Requirements

Before the number or size of emitters can be selected, the peak water demand for a period of time needs to be determined. The following equation can be used taking into account ET, landscape coefficient, and planting area and converting it to gallons per day or per week:

$$Q = \frac{A \times ET_o \times K_L \times 0.623}{E_a}$$

where
Q = gallons of water for a period of time such as a day or week
A = canopy area of plant × 0.75 for applying water to 75 percent of the area {ft2}
ET_o = peak ET for a specific period such as day or week
K_L = landscape coefficient
0.623 = conversion to gallons
Ea = irrigation application efficiency
0.85 for hot, arid climate
0.90 for moderate climate
0.95 for cool climate

Tree Drip Calculator Model

The tree drip calculator model incorporates the information provided by the designer as previously noted, considers ASABE Standard S623, and gives the designer alternatives for the design. A screen shot of the model is shown in Figure 5.

Figure 5. Tree Drip Calculator Model

A	soil	medium		IA Soil type
I-0	R_s	18.0	{in}	Row spacing
I-1	W_{Wdes}	19.8	{in}	Desired width of wetted pattern
I-2	canopy dia	10	{ft}	Tree canopy diameter
I-3	root depth	18	{in}	Root depth
I-4	ETo	0.23	{in/d}	Reference evapotranspiration
I-5	Wet	0.70	{dec}	S623 climate description
I-6	q_{daily}	7.99	{gal/day}	Daily water requirement
B	E_S	18	{in}	Emitter spacing
B1	$E_{S\ Rec}$	11	{in}	Recommended emitter spacing
C	q_e	0.50	{gph}	Emitter flow rate
C1	$q_{e\ Rec}$	0.56	{gph}	Recommended emitter flow rate
R-1	AR	0.36	{in/hr}	Application rate
R-2	IR	0.40	{in/hr}	Infiltration rate
R-3	t_{max}	17.3h	1037 min	Max. time to avoid deep percolation
R-4	t_{daily}	0.46 h	27.4 min	Time daily to meet Eto
R-5	t_{rec}	0.50 h	30.2 min	Recommended run time
D	t_{sel}	28	{min}	Selected run time
R-6	W_{Wres}	19.2	{in}	Resulting width of wetted pattern
R-7	IN	1.02	{days}	Irrigation interval
R-8	# emitters	35	2 circles	Number of emitters used
R-9	circle dia's	9.0	7.5	{ ft}
R-10	flow per tree		0.29	{gpm}

The following are guidelines for the inputs and outputs. The "A" section is input. Yellow background cells are input values determined by the designer. Blue background cells are values that the designer can select from a list of values. The green values are calculated based on yellow inputs. The "B" and "C" sections have one blue selectable cell in which the designer should try to match the green recommended value. The results are shown in the "R" labeled values and one selection is required in "D" for the selected run time. In this example, the soil is medium, row spacing is 18 inches, the width of the desired pattern is 19.8 inches (the program defaults to 110% of row spacing to ensure overlap), canopy diameter is 10 feet, root depth is 18 inches, and ET_o is 0.23 in/day. The 75% wetted area requirement is met by the number of emitters in the given number of rows. Climate is "wet" by ASABE S623. The resulting values are K_L = 0.70, and q_{daily} is 7.99 gal/day. The recommended emitter spacing is 11 inches. The closest available value of 12 was selected. The recommended emitter flow rate is 0.56 gph, and the selected value of 0.50 is the closest available. The application rate is 0.36 in/hr which is less than the infiltration rate of 0.40 in/hr. The maximum time the system can be run without deep percolation is 17.3 hours, and the required daily time to meet ET is 27 minutes. The recommended time to achieve 75% area wetted is 30 minutes and 28 minutes was selected. This results in a width of the wetted pattern of 19.2 inches (which is slightly less than the desired width). The irrigation interval is 1.02 days, meaning that the system would be run daily. This requires 35 emitters in 2 rows, one at 7.5 feet diameter and one at 9.0 feet diameter.

An alternative would be to select an emitter spacing of 12 inches and an emitter flow rate of 0.40 gph and run the system 38 minutes three out of five days. Figure 6 shows this alternative. Note that this requires 53 emitters. This is probably not as good a design as the first alternative with 18 inch emitter spacing. A bit of experimentation with the model will soon lead the designer to understand that there are multiple viable designs.

Figure 6. Tree Drip Calculator, Alternative Choice

A	soil	medium		IA Soil type
I-0	R_s	18.0	*{in}*	Row spacing
I-1	W_{Wdes}	19.8	{in}	Desired width of wetted pattern
I-2	canopy dia	10	*{ft}*	Tree canopy diameter
I-3	root depth	18	*{in}*	Root depth
I-4	ETo	0.23	*{in/d}*	Reference evapotranspiration
I-5	Wet	0.70	*{dec}*	S623 climate description
I-6	q_{daily}	7.99	*{gal/day}*	Daily water requirement
B	E_s	12	*{in}*	Emitter spacing
B1	$E_{s\ Rec}$	9	*{in}*	Recommended emitter spacing
C	q_e	0.40	*{gph}*	Emitter flow rate
C1	$q_{e\ Rec}$	0.37	*{gph}*	Recommended emitter flow rate
R-1	AR	0.43	*{in/hr}*	Application rate
R-2	IR	0.40	*{in/hr}*	Infiltration rate
R-3	t_{max}	*17.3h*	*1037 min*	Max. time to avoid deep percolation
R-4	t_{daily}	*0.38 h*	*22.6 min*	Time daily to meet Eto
R-5	t_{rec}	*0.67 h*	*40.2 min*	Recommended run time
D	t_{sel}	38	*{min}*	Selected run time
R-6	W_{Wres}	19.4	*{in}*	Resulting width of wetted pattern
R-7	IN	*1.68*	*{days}*	Irrigation interval
R-8	# emitters	*53*	*2 circles*	Number of emitters used
R-9	circle dia's	*9.0*	*8.0*	*{ ft}*
R-10	*flow per tree*		*0.35*	*{gpm}*

Application Rate Exceeds Infiltration Rate

Number of Rows of Emitters

As a general rule, if the tree canopy diameter is 16 feet or less, two rows are adequate. For canopy diameters 18 feet or more, three rows are needed. The row spacing is set equal to the emitter spacing to ensure overlap, and the center of the rows is set at the tree canopy diameter. The designer can override the row spacing and set it other than equal to the emitter spacing.

Design Charts

A series of design charts has been developed using the tree drip calculator. They are show in Figures 7, 8 , and 9 for three soils and three climate conditions per ANSI/ASABE S623.

Figure 7. Design/operating alternatives for "wet" climate. ETo = 7 in./month where dc {ft} is canopy diameter, di is the diameter of the inner circle, dm is the next circle, and do is the third circle (if necessary), all in ft.

IA soils – moderately coarse, wet										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	24	1.00	49	3	19	2	5.0	7.0		
10	24	1.00	57	3	25	2	7.0	9.0		
12	24	1.00	66	3	31	2	9.0	11.0		
14	24	1.00	50	2	38	2	11.0	13.0		
16	24	1.00	56	2	44	2	13.0	15.0		
18	24	1.00	66	3	71	3	13.0	15.0	17.0	
20	24	1.00	48	2	80	3	15.0	17.0	19.0	
22	24	1.00	52	2	90	3	17.0	19.0	21.0	
24	24	1.00	56	2	99	3	19.0	21.0	23.0	
IA soils – medium, wet										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	24	1.00	32	2	19	2	5.0	7.0		
10	24	1.00	38	2	25	2	7.0	9.0		
12	24	1.00	44	2	31	2	9.0	11.0		
14	24	1.00	50	2	38	2	11.0	13.0		
16	30	1.00	70	2	35	2	12.5	15.0		
18	30	1.00	57	2	55	3	12.0	14.5	17.0	
20	30	1.00	61	2	62	3	14.0	16.5	19.0	
22	36	1.00	82	2	57	3	15.0	18.0	21.0	
24	36	1.00	88	2	63	3	17.0	20.0	23.0	
IA soils – moderately fine, wet										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	36	1.00	52	2	12	2	4.0	7.0		X
10	36	1.00	60	2	16	2	6.0	9.0		X
12	36	1.00	70	2	20	2	8.0	11.0		X
14	36	1.00	78	2	24	2	10.0	13.0		X
16	36	1.00	87	2	28	2	12.0	15.0		X
18	36	1.00	70	2	44	3	11.0	14.0	17.0	X
20	36	1.00	76	2	50	3	13.0	16.0	19.0	X
22	36	1.00	82	2	57	3	15.0	18.0	21.0	X
24	36	1.00	88	2	63	3	17.0	20.0	23.0	X

Figure 8. Design/operating alternatives for "dry" climate. ETo = 7 in./month where dc {ft} is canopy diameter, di is the diameter of the inner circle, dm is the next circle, and do is the third circle (if necessary), all in ft.

IA soils – moderately coarse, dry										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	24	2.00	17	3	19	2	5.0	7.0		X
10	24	2.00	14	2	25	2	7.0	9.0		X
12	24	2.00	16	2	31	2	9.0	11.0		X
14	24	2.00	18	2	38	2	11.0	13.0		X
16	24	2.00	20	2	44	2	13.0	15.0		X
18	24	2.00	16	2	71	3	12.0	15.0	17.0	X
20	24	2.00	17	2	80	3	15.0	17.0	19.0	X
22	24	2.00	18	2	90	3	17.0	19.0	21.0	X
24	24	2.00	20	2	99	3	19.0	21.0	23.0	X
IA soils – medium, dry										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	30	3.00	23	3	14	2	4.5	7.0		X
10	30	2.00	27	3	19	2	6.5	9.0		X
12	30	2.00	20	2	25	2	8.5	11.0		X
14	30	2.00	22	2	30	2	10.5	13.0		X
16	30	2.00	25	2	35	2	12.5	15.0		X
18	30	2.00	20	2	55	3	12.0	14.5	17.0	X
20	30	2.00	22	2	62	3	14.0	16.5	19.0	X
22	30	2.00	24	2	70	3	16.0	18.5	21.0	X
24	30	2.00	26	2	77	3	18.0	20.5	23.0	X
IA soils – moderately fine, dry										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	36	1.00	55	3	12	2	4.0	7.0		X
10	36	1.00	64	3	16	2	6.0	9.0		X
12	36	1.00	50	2	20	2	8.0	11.0		X
14	36	1.00	56	2	24	2	10.0	13.0		X
16	36	1.00	62	2	28	2	12.0	15.0		X
18	36	1.00	56	2	44	3	11.0	14.0	17.0	X
20	36	1.00	56	2	50	3	13.0	16.0	19.0	X
22	36	1.00	58	2	57	3	15.0	18.0	21.0	X
24	36	1.00	62	2	63	3	17.0	20.0	23.0	X

Figure 9. Design/operating alternatives for "dry" climate. ETo = 7 in./month where dc {ft} is canopy diameter, di is the diameter of the inner circle, dm is the next circle, and do is the third circle (if necessary), all in ft.

IA soils – moderately coarse, desert										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	24	2.00	17	5	19	2	5.0	7.0		X
10	24	2.00	16	4	25	2	7.0	9.0		X
12	24	2.00	19	4	31	2	9.0	11.0		X
14	24	2.00	21	4	38	2	11.0	13.0		X
16	24	2.00	18	3	44	2	13.0	15.0		X
18	24	2.00	19	4	71	3	12.0	15.0	17.0	X
20	24	2.00	20	4	80	3	15.0	17.0	19.0	X
22	24	2.00	17	3	90	3	17.0	19.0	21.0	X
24	24	2.00	18	3	99	3	19.0	21.0	23.0	X
IA soils – medium, desert										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	30	2.00	19	4	14	2	4.5	7.0		X
10	30	2.00	22	4	19	2	6.5	9.0		X
12	30	2.00	24	4	25	2	8.5	11.0		X
14	30	2.00	20	3	30	2	10.5	13.0		X
16	30	2.00	23	3	35	2	12.5	15.0		X
18	30	2.00	24	4	55	3	12.0	14.5	17.0	X
20	30	2.00	20	3	62	3	14.0	16.5	19.0	X
22	30	2.00	21	3	70	3	16.0	18.5	21.0	X
24	30	2.00	23	3	77	3	18.0	20.5	23.0	X
IA soils – moderately fine, desert										
dc	Es	qe	RT	IN	No.	Rows	di	dm	do	AR > IR
8	36	1.00	55	5	12	2	4.0	7.0		X
10	36	1.00	51	4	16	2	6.0	9.0		X
12	36	1.00	59	4	20	2	8.0	11.0		X
14	36	1.00	51	3	24	2	10.0	13.0		X
16	36	1.00	56	3	28	2	12.0	15.0		X
18	36	1.00	60	4	44	3	11.0	14.0	17.0	X
20	36	1.00	49	3	50	3	13.0	16.0	19.0	X
22	36	1.00	52	3	57	3	15.0	18.0	21.0	X
24	36	1.00	56	3	63	3	17.0	20.0	23.0	X

Summary

In summary, a good drip irrigation design for established trees and shrubs involves choosing the emitter spacing, emitter flow rate and total number emitters so that the proper amount of water is placed where the tree needs it. The operation of the system must be such that the system is run long enough to achieve the desired wetted area and not exceed the root depth with a reasonable run time and irrigation interval.

An excel program, Tree Drip Calculator, was introduced which enables the designer and operator to evaluate choices in the design and operation of the system. A set of tables for assisting the design and operation without running the calculator was also presented.