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Advanced Irrigation Management for Container-Grown Ornamental Crop Production

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Container-grown plants are constrained with regard to root growth, and are affected by factors including container size, substrate, weather, nutrition, and irrigation. Typical soilless substrates will hold less plant-available water than a typical field soil, making water management a critical component of any container-grown plant production system. A well-designed and managed irrigation system, which works in concert with the aforementioned factors, can provide the necessary quantity of water to support plant growth in an efficient manner.

This publication will discuss irrigation management practices to assist growers in more effectively managing the irrigation of containerized ornamental crops. Below, we will review key principles of 1) irrigation system design and maintenance, 2) irrigation system performance assessment, and 3) irrigation scheduling (or management) as they pertain to micro- and overhead-irrigation of container-grown crops.

Cover photo: Jim Owen

Irrigation System Design and Maintenance Considerations

Efficient irrigation begins with a properly designed system. Growers are encouraged to seek the services of professionally trained irrigation consultants, manufacturers and service companies to acquire the necessary specifications and expertise to properly design or maintain an irrigation system. A well-designed and efficient irrigation system can reduce energy costs and environmental impacts while providing more flexibility in scheduling irrigation (timing, sequence, and duration of ongoing irrigation events) and result in improved crop health.

To properly design or understand an irrigation system, one must identify a quality water source (i.e. ground or surface water), how the water will be delivered (i.e. pump and main line characteristics) and know the available **flow rate**, measured in gallons per minute (GPM) or gallons per hour (GPH). The available flow rate is determined by the quantity of water available and the method of water delivery at the **point of connection** (POC). If connected to a municipal water supply, the maximum flow rate is fixed. If connected to a pump that draws water from a well or a surface water supply, your pump's performance determines the actual flow rate. Keep in mind that local regulatory standards may limit the quantity of water that may be drawn from municipal sources or wells.

When designing a new system, consider the possibility of future expansion. It's much easier to add onto an irrigation system if it's key components, namely

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supply line and pump capacities, already meet the needs of the expanded design. Variable frequency drive (VFD) pumps are recommended as they automatically adjust to a range of flow rates and pressures, depending on the number of zones operating at a given time, and, therefore, are an excellent choice for future expansion. Variable frequency drive pumps also afford irrigation managers a great deal of flexibility as pumps change output to match a grower-determined irrigation plan, rather than the grower having to cater his or her irrigation schedule to a fixed pump output, which ultimately results in reduced energy costs.

One must also know the pressure, measured in pounds per square inch (PSI), at which the system will operate. Pressure will vary throughout an irrigation system and is affected by the nature of the POC, elevation changes (essentially the weight of the water column above a fixed point creates pressure), and **friction loss** between water and pipes. There are several ways to measure pressure. **Static pressure** is a measure of pressure when water is not moving, taking into account only changes in elevation. **Dynamic pressure** is a measure of pressure when water is moving, taking into account friction loss and any changes in elevation, and is commonly referred to as **working pressure**. Both static and dynamic pressure can be measured using pressure gauges at any location in an irrigation system when water is at rest or moving or may be calculated using estimated values for elevation change and friction loss depending on pipe diameter and construction material (Figure 1).

Irrigation Association Friction Loss Chart 2008

Schedule 40 PVC IPS Plastic Pipe

ASTM D1785 C=150

psi loss per 100 feet of pipe

Nominal size	1/2"		3/4"		1"		1-1/4"		1-1/2"		2"		2-1/2"		3"		4"		6"	
Avg. ID	0.602		0.804		1.029		1.360		1.590		2.047		2.445		3.042		3.998		6.031	
Pipe OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625	
Avg. wall	0.119		0.123		0.143		0.150		0.155		0.164		0.215		0.229		0.251		0.297	
Min. wall	0.109		0.113		0.133		0.140		0.145		0.154		0.203		0.216		0.237		0.280	
Flow {gpm}	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss	Velocity {ft/s}	psi loss
1	1.13	0.50	0.63	0.12	0.39	0.04	0.22	0.01	0.16	0.00										
2	2.25	1.82	1.26	0.44	0.77	0.13	0.44	0.03	0.32	0.02	0.19	0.00								
3	3.38	3.85	1.89	0.94	1.16	0.28	0.66	0.07	0.48	0.03	0.29	0.01								
4	4.50	6.55	2.52	1.60	1.54	0.48	0.88	0.12	0.65	0.06	0.39	0.02	0.27	0.01						
5	5.63	9.91	3.16	2.42	1.93	0.73	1.10	0.19	0.81	0.09	0.49	0.03	0.34	0.01						
6	6.75	13.89	3.79	3.40	2.31	1.02	1.32	0.26	0.97	0.12	0.58	0.04	0.41	0.02	0.26	0.01				
7	7.88	18.48	4.42	4.52	2.70	1.36	1.54	0.35	1.13	0.16	0.68	0.05	0.48	0.02	0.31	0.01				
8	9.01	23.66	5.05	5.79	3.08	1.74	1.76	0.45	1.29	0.21	0.78	0.06	0.55	0.03	0.35	0.01				
9	10.13	29.43	5.68	7.20	3.47	2.17	1.99	0.56	1.45	0.26	0.88	0.08	0.61	0.03	0.40	0.01				
10	11.26	35.77	6.31	8.75	3.85	2.63	2.21	0.68	1.61	0.32	0.97	0.09	0.68	0.04	0.44	0.01				
12	13.51	50.14	7.57	12.27	4.62	3.69	2.65	0.95	1.94	0.44	1.17	0.13	0.82	0.05	0.53	0.02				
14	15.76	66.71	8.84	16.32	5.39	4.91	3.09	1.26	2.26	0.59	1.36	0.17	0.96	0.07	0.62	0.03				
16	18.01	85.42	10.10	20.90	6.17	6.29	3.53	1.62	2.58	0.76	1.56	0.22	1.09	0.09	0.71	0.03	0.41	0.01		
18	20.26	106.24	11.36	25.99	6.94	7.82	3.97	2.01	2.90	0.94	1.75	0.28	1.23	0.12	0.79	0.04	0.46	0.01		
20			12.62	31.59	7.71	9.51	4.41	2.45	3.23	1.14	1.95	0.33	1.36	0.14	0.88	0.05	0.51	0.01		
22			13.89	37.69	8.48	11.35	4.85	2.92	3.55	1.37	2.14	0.40	1.50	0.17	0.97	0.06	0.56	0.02		
24			15.15	44.28	9.25	13.33	5.29	3.43	3.87	1.60	2.34	0.47	1.64	0.20	1.06	0.07	0.61	0.02		
26			16.41	51.36	10.02	15.46	5.74	3.98	4.20	1.86	2.53	0.54	1.77	0.23	1.15	0.08	0.66	0.02		
28			17.67	58.91	10.79	17.73	6.18	4.56	4.52	2.13	2.73	0.62	1.91	0.26	1.23	0.09	0.71	0.02		
30			18.94	66.94	11.56	20.15	6.62	5.19	4.84	2.42	2.92	0.71	2.05	0.30	1.32	0.10	0.77	0.03		
32					12.33	22.71	7.06	5.85	5.16	2.73	3.12	0.80	2.18	0.34	1.41	0.12	0.82	0.03	0.36	0.00
34					13.10	25.41	7.50	6.54	5.49	3.06	3.31	0.89	2.32	0.38	1.50	0.13	0.87	0.03	0.38	0.00
36					13.87	28.24	7.94	7.27	5.81	3.40	3.51	0.99	2.46	0.42	1.59	0.14	0.92	0.04	0.40	0.01
38					14.64	31.22	8.38	8.04	6.13	3.76	3.70	1.10	2.59	0.46	1.68	0.16	0.97	0.04	0.43	0.01
40					15.41	34.33	8.82	8.84	6.46	4.13	3.89	1.21	2.73	0.51	1.76	0.18	1.02	0.05	0.45	0.01
42					16.18	37.58	9.26	9.67	6.78	4.52	4.09	1.32	2.87	0.56	1.85	0.19	1.07	0.05	0.47	0.01
44					16.95	40.96	9.71	10.54	7.10	4.93	4.28	1.44	3.00	0.61	1.94	0.21	1.12	0.06	0.49	0.01
46					17.73	44.47	10.15	11.45	7.42	5.35	4.48	1.57	3.14	0.66	2.03	0.23	1.17	0.06	0.52	0.01
48					18.50	48.12	10.59	12.39	7.75	5.79	4.67	1.69	3.28	0.71	2.12	0.25	1.23	0.07	0.54	0.01
50					19.27	51.90	11.03	13.36	8.07	6.25	4.87	1.83	3.41	0.77	2.20	0.27	1.28	0.07	0.56	0.01
55							12.13	15.94	8.88	7.45	5.36	2.18	3.75	0.92	2.42	0.32	1.40	0.08	0.62	0.01
60							13.24	18.72	9.68	8.75	5.84	2.56	4.09	1.08	2.65	0.37	1.53	0.10	0.67	0.01
65							14.34	21.72	10.49	10.15	6.33	2.97	4.44	1.25	2.87	0.43	1.66	0.11	0.73	0.02
70							15.44	24.91	11.30	11.65	6.82	3.41	4.78	1.43	3.09	0.50	1.79	0.13	0.79	0.02
75							16.54	28.31	12.10	13.23	7.30	3.87	5.12	1.63	3.31	0.56	1.91	0.15	0.84	0.02
80							17.65	31.90	12.91	14.91	7.79	4.36	5.46	1.84	3.53	0.63	2.04	0.17	0.90	0.02
85									13.72	16.69	8.28	4.88	5.80	2.06	3.75	0.71	2.17	0.19	0.95	0.03
90									14.52	18.55	8.76	5.43	6.14	2.29	3.97	0.79	2.30	0.21	1.01	0.03
95									15.33	20.50	9.25	6.00	6.48	2.53	4.19	0.87	2.42	0.23	1.07	0.03
100									16.14	22.55	9.74	6.59	6.82	2.78	4.41	0.96	2.55	0.25	1.12	0.03
110											10.71	7.87	7.51	3.31	4.85	1.14	2.81	0.30	1.23	0.04
120											11.68	9.24	8.19	3.89	5.29	1.34	3.06	0.36	1.35	0.05
130											12.66	10.72	8.87	4.52	5.73	1.56	3.32	0.41	1.46	0.06
140											13.63	12.30	9.55	5.18	6.17	1.79	3.57	0.47	1.57	0.06
150											14.61	13.97	10.24	5.89	6.61	2.03	3.83	0.54	1.68	0.07
160											15.58	15.75	10.92	6.63	7.05	2.29	4.08	0.61	1.79	0.08
170													11.60	7.42	7.50	2.56	4.34	0.68	1.91	0.09
180													12.28	8.25	7.94	2.85	4.59	0.75	2.02	0.10
190													12.97	9.12	8.38	3.15	4.85	0.83	2.13	0.11
200													13.65	10.03	8.82	3.46	5.11	0.92	2.24	0.12
220													15.01	11.96	9.70	4.13	5.62	1.09	2.47	0.15
240													16.38	14.06	10.58	4.85	6.13	1.28	2.69	0.17
260															11.46	5.63	6.64	1.49	2.92	0.20
280															12.35	6.46	7.15	1.71	3.14	0.23
300															13.23	7.34	7.66	1.94	3.37	0.26
320															14.11	8.27	8.17	2.19	3.59	0.30
340															14.99	9.25	8.68	2.45	3.81	0.33
360															15.87	10.29	9.19	2.72	4.04	0.37
380																	9.70	3.01	4.26	0.41
400																	10.21	3.31	4.49	0.45
420																	10.72	3.62	4.71	0.49
440																	11.23	3.95	4.94	0.53
460																	11.74	4.28	5.16	0.58
480																	12.25	4.64	5.38	0.63
500																	12.76	5.00	5.61	0.68
Working pressure	600 psi		480 psi		450 psi		370 psi		330 psi		300 psi		280 psi		260 psi		220 psi		180 psi	

Shaded area represents velocities over 5 ft/s. Use with caution.

Figure 1. Sample friction loss chart per 100 feet of pipe. Friction losses vary with pipe material and the addition of other components, such as fittings. Additional charts and resources can be found through the Irrigation Association at: http://www.irrigation.org/Resources/Tools___Calculators.aspx

Changes in elevation throughout an irrigation system may increase or decrease water pressure. Water elevation is referred to as **feet of head**, where 2.31 vertical feet of water elevation is equal to 1.00 PSI. For example, imagine a pipe that runs up a hill with 10 feet of vertical elevation change. The pressure at the bottom of the pipe will be 4.3 PSI greater than at the top (10 feet ÷ 2.31 feet per PSI = 4.3 PSI).

Pressure will generally be highest near the POC and least at the farthest sprinkler from the POC, due to the loss of pressure as water passes through pipes, fittings, valves, and emitters. Friction loss is a function of flow rate (GPM or GPH), the pipe material (PVC, aluminum, etc.) and the pipe length. Friction loss can be easily determined using friction loss charts (Figure 1) that are available through irrigation or plumbing supply companies and the Irrigation Association. Note that **water velocity**, a function of a pipe's internal diameter (ID) and flow rate, should not exceed five feet per second to minimize friction loss and **water hammer**. Water hammer is water compression, or a surge in pressure, that occurs when water suddenly changes direction or velocity, and may damage pipes. Changes in pipe size, sudden opening of valves, starting pumps, and trapped air within the system are factors that may contribute to water hammer. **Thrust blocks** (Figure 2) should be installed on main and sub-main lines (larger pipes from which several smaller pipes branch) to minimize pipe movement from water hammer. In addition, **air relief valves** (Figure 3), placed at high points and at the end of supply lines, may be used to exhaust air while the system is being charged (water is filling pipes) or during operation, and may prevent water hammer and potential damage to main and sub-main lines. Furthermore, **pressure regulators**, that either stand alone or are incorporated into valves, can be used to reduce pressure to the desired working pressure. Lastly, **backflow preventers** are recommended and, are often a required component that ensures water flows one direction through a system. This prevents any chemicals, such as injected fertilizers, disinfectants, or pesticides from flowing back into the water source, so backflow preventers are typically installed immediately after a municipal or potable water connection.

It is usually not feasible for an entire nursery to be irrigated all at once due to pressure or flow rate limitations, so the irrigated area must be divided into subsets of the entire irrigation system, or an adequate number of **irrigation zones** that are controlled independently. Furthermore, zones must be sized properly to ensure that the entire nursery can be irrigated regularly, and that irrigation occurs before water stress occurs. Dividing an irrigation system into multiple zones allows crops to be grouped based on water need, decreases flow requirements (fewer emitters are operating at once), and ensures that each zone operates at its optimal working pressure, which makes the entire system more manageable (fewer or smaller pumps). Each irrigation zone may have a unique irrigation requirement and subsequent flow rate, which depends on the water requirements of the crops grown in that zone, substrate, production method (pot-in-pot, above-ground containers, etc.), and water application method (micro irrigation versus sprinklers). A zone should be designed (pipe dimensions, number and type of nozzles) to irrigate crops with similar water needs (i.e., similar taxa at same stage of production, comparable substrate physical properties, and a relatively similar container size and **interception efficiency**), while operating at an adequate pressure and flow rate of less than five feet per second measured at a **critical point** in the system. A critical point is the furthest point from the valve or pump where flow and pressure may be lowest, and potentially inadequate for the specific nozzle being used. In some irrigation systems, such as those with overhead impact sprinklers, pressure can be measured at the nozzle using a pitot tube (Figure 4) or a screw-on pressure gauge. Each type of emitter or nozzle has a manufacturer-specified operating pressure

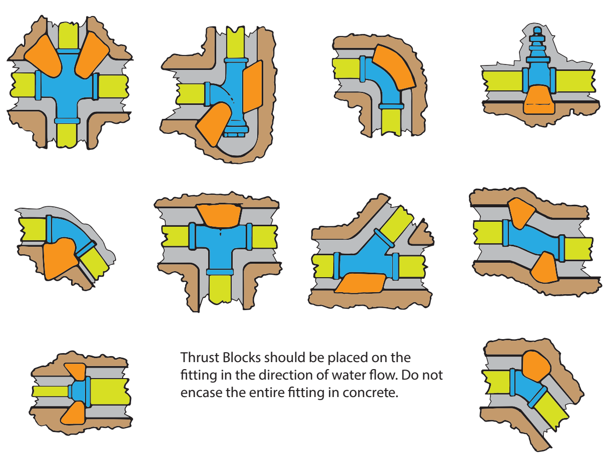

Figure 2. Thrust block (orange in figure) placement.

Figure 3. Backflow preventer (center) and air relief valve right.)

Figure 4. Pitot tube for measuring dynamic or working water pressure at the nozzle. (Photo courtesy of David Ross, Univesity of Maryland.)

range that needs to be taken into consideration when designing a system or when replacing existing nozzles.

Overhead Irrigation System Design

Overhead irrigation systems (Figure 5) apply water from above the plant canopy via emitters or sprinklers. In general, overhead irrigation systems are most efficient for irrigating containers smaller than 7-gallons and that are spaced together closely (so most of the water is captured by the plant and does not fall between containers). These systems should be designed to provide uniform coverage, while taking into consideration topography and environmental conditions, namely wind. Zones should be designed to have **head-to-head coverage** (Figure 6), in which the spray radius (distance a sprinkler projects water) is equal to the distance between sprinklers. The overhead sprinklers and nozzles that produce the most uniform coverage are those with **matched precipitation rates** (MPR), meaning they apply the same volume of water to a given area over a unit of time, regardless of **arc** (90, 180 or 360 degrees; Figure 6).

Appropriate nozzles should be used and maintained to provide the desired spray radius and droplet size. Water application efficiency and uniformity can be

Figure 5. Overhead irrigation system. (Photo by Matthew Chappell.)

reduced due to the effect of evaporation and wind drift. Overhead nozzles that produce larger droplets are less prone to these effects and are therefore favorable. Sprinkler nozzles wear with time, resulting in a wider orifice and decreased efficiency. An easy test to determine nozzle wear is to insert the base of a drill bit that is the same diameter as the orifice of

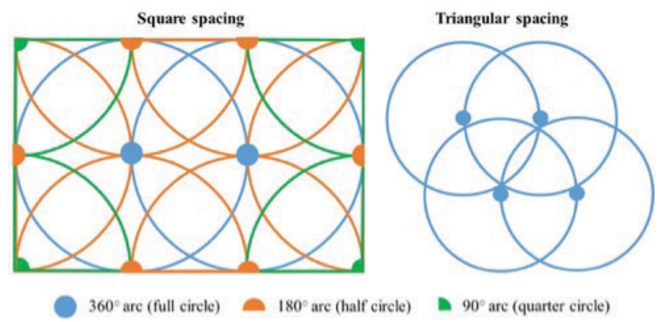

Figure 6. Overhead view of a hypothetical irrigation zone showing head-to-head coverage (each sprinkler reaches adjacent sprinklers) and typical sprinkler arcs for square and triangular sprinkler orientations.

a new nozzle. If the bit fits an old nozzle loosely, it likely needs to be replaced.

Moreover, sprinklers on tall risers with a **high trajectory angle** are more susceptible to wind drift and evaporation. Therefore, if risers are greater than 6 feet high, it might be more efficient to use a microirrigation system design that applies water directly to the surface of the substrate and is less affected by environmental conditions. Risers must remain perpendicular to the ground to operate efficiently, and they need to be stabilized. On large slopes, the midslope riser(s) should be positioned halfway between vertical and perpendicular to the slope. (i.e., half the angle of slope). To reduce wind drift, growers might need to use **windbreaks** to irrigate during periods of low wind or excessive evaporation or to reduce spacing between sprinklers to achieve the desired coverage.

Microirrigation System Design

Within a microirrigation zone, containers are irrigated individually through an emitter or **spray stake** (Figure. 7) that should be chosen and positioned to ensure that water adequately reaches the entire root zone. Microirrigation systems are generally most effective for 7-gallon and larger containers and have a great potential for water savings because they apply water directly to the substrate. However, microirrigation systems require greater monitoring and maintenance to ensure that all plants receive the water they need. Water is emitted through much smaller orifices than those used in overhead systems, and as a result, water filtration (approximately 120

Overhead irrigation systems should:

- Use matched precipitation rate sprinklers.
- Have adequate pressure and flow at the critical nozzle point.
- Provide head-to-head coverage while taking wind into consideration.
- Use nozzles that produce larger droplets.
- Use lower trajectory angle sprinkler heads and replace worn nozzles.
- Use sprinkler risers that are less than 6 feet high and vertically oriented.

Microirrigation or drip systems should:

- Use emitters or microsprays that ensure the entire root zone receives adequate water.
- Have adequate filtration and water treatment.
- Meet the pressure specifications for a given emitter or spray stake.
- Compensate for elevation changes or topography.
- Be monitored regularly to ensure all plants are receiving water.

mesh; this varies with type of emitter) and possibly water treatment (e.g., filtration, chlorination, etc.) are recommended to prevent algae, bacteria, or sediment from plugging emitters. Selecting the proper emitter or microspray based on the substrate properties is also important. In general, drip emitters are better-suited for finer-textured substrates that allow for greater lateral diffusion of applied water; microsprays are better-suited for coarse-textured substrates because applied water is distributed or sprayed over a greater portion of the substrate surface.

Like overhead irrigation, good design of a microirrigation system ensures that the lengths of distribution lines are within manufacturer and system specifications (pressure and flow rate). The following system components are recommended to improve system efficiency. Pressure-compensating emitters or spray stakes can improve system uniformity by equalizing the pressure at each emitter. Lateral lines can be equipped with flushing end caps to ensure that all emitters irrigate for the same duration (improved uniformity); however, there is a minor trade-off with water application efficiency due to water draining from end caps between irrigation events. The use of polyethylene pipe with a white surface will help reduce water temperature in the summer.

Figure 7. Illustration of microirrigation system to water a containerized ornamental shrub using spray stakes. (Photo by James Owen.)

Irrigation System Performance Assessment

Major design considerations for an irrigation system have been covered thus far. This section will shift focus to discuss how to evaluate the performance of an existing irrigation system. Irrigation assessments or audits can provide insight into how efficiently water is applied to crops and can be used to improve system design, make maintenance decisions, and properly manage or schedule irrigation. A review of the mathematical order of operations have been provided to assist as you work through the examples below.

Mathematical Order of Operations

- Perform all calculations in parentheses.
- Simplify any exponents.
- Perform all division and multiplication calculations from left to right.
- Perform all addition and subtraction calculations from left to right.
- Solve equation.

Water Application Rate

The primary factor for irrigation system design is water **application rate**. This indicates how much water is applied over a given time and working pressure. Application rates for individual emitters, spray stakes, and sprinklers are typically measured in GPM or GPH, while inches per hour is used to describe the overall irrigation system. Application rate is used to help the irrigator determine how long an irrigation event will last. An irrigation supplier can model, usually at no cost, the theoretical application rate and uniformity within an overhead irrigation zone. However, the actual application rate must be measured in the field to obtain accurate values that take into account nuances of environment and design that affect each system differently. Application rate can be calculated using the flow rate (AR_F), the flow rate at the sprinkler (AR_S), or the catch-can method (AR_C).

Application Rate Using a Flow Meter

The calculation of AR_F is based on the flow rate and is the simplest and least-precise method. The AR_F calculation method accounts for everything downstream of a flow meter (fig. 8). Flow meters are commonly installed at the pump and would result in an ARF calculation that applies to all zones supplied by that pump at a given time; therefore, an irrigation manager has to record flow rates before and after a given irrigation zone runs to calculate that specific AR_F of the zone(s), individually or as a whole. A flow meter can also be installed at the main or submain lines to easily determine the rate at which water is delivered to a given zone on a zone-by-zone basis. To conduct this measurement, monitor the amount of water supplied to a given zone and the time it took to apply that volume of water and follow the calculations in example 1. This method is relatively less precise due to the loss of water from leakage, poor nozzle performance, and wind drift downstream of the flow meter.

Figure 8. Flow meter for measuring the volume of water through pipes. (Photo: Anthony LeBude)

Example 1. How to Calculate Application Rate Using a Flow Meter:

To determine application rate using a flow meter (AR_F), use the equation:

$$AR_F \text{ (in/hr)} = (Q \times t) \div (Ac \times 27,154),$$

Where,

Q = flow rate (GPM)

t = time (minutes)

Ac = acreage irrigated

27,145 = gallons per acre-inch of water

Example:

If Q = 150 GPM, t = 90 minutes, and Ac = 1 acre,

AR_f = (150 GPM x 90 min) ÷ (1 acre x 27,154)

= 0.50 inch/hr.

Application Rate Using Sprinkler Flow Rates

Application rate can be more precisely determined by measuring the flow rate at individual sprinklers (AR_S). An AR_S calculation accounts for leaks, friction loss, or pressure changes throughout the system, especially in large zones. The flow rate is generally measured at one or several nozzles and is used to estimate the AR_S for the rest of the zone. To calculate AR_S for a zone, measure the flow rate at several sprinkler heads by placing a piece of hose over a nozzle to direct the water to a bucket, or place a plastic bag over a sprinkler to collect water for a known amount of time during a normal irrigation event (this includes running other zones that would normally be in operation at the same time as the zone of interest), record the volume of water collected and the time it took to collect that water, and follow the calculations in example 2. By repeating this procedure at several different sprinklers (three to five sprinklers distributed evenly throughout the zone, depending on the size of the zone), an average can be calculated, leading to a more accurate result.

To calculate AR_S, one must know the area a sprinkler distributes water to. The area depends on the orientation of the sprinklers (i.e., square or triangular; fig. 6). For square spacing, area (A_{sq}) can be determined using the formula for the area of a square: A_{sq} = length × width, where length and width are the distances between risers or sprinklers. For triangular spacing, area (A_{tr}) can be determined using the formula for the area of a triangle: $A_{tr} = 0.5 \times$ base × height (fig. 9). Then follow the sample calculation in example 2.

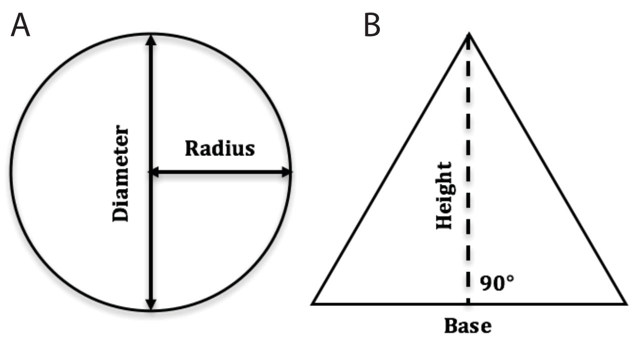

Figure 9. A, illustration of the diameter and radius of a circle; the area of a circle = πr^2, where $\pi = 3.14$ and r = radius. B, the base and height of a triangle; the area of a triangle = $0.5\ b \times h$, where b = length of the base and h = height.

Remember that neither AR_F nor AR_S provide a measure of how much water is actually applied to an individual plant. They measure the rate at which water is either applied to a zone (AR_F) or emitted from a sprinkler (AR_S).

Application Rate Using Catch Cans

The catch-can method (AR_C) estimates the volume of water that falls to the ground and is potentially intercepted by plants. This method accounts for variation in system design, pressure loss, wind drift (at the time of measurement), and topography and is therefore a more-accurate measurement than ARF or ARS. However, it is labor-intensive because it requires the grower to organize and measure a grid of catch cans. Despite the labor involved, catch cans are preferred because the data can be used to calculate application uniformity and to provide quality information to assist with irrigation scheduling (see the following sections on application uniformity and irrigation management).

Example 2. How to Calculate the Application Rate for an Irrigation Zone Using Individual Sprinkler Volumes (AR_s):

To determine AR_s, use the equation:

AR_s (in/hr) = (96.3 x Q) ÷ (A_s)

96.3 = A conversion factor (area and flow)

Q = Average sprinkler flow rate (GPM) determined using the time to fill a bucket of known volume, or measuring the volume of water captured after set amount of time.

A_s = Area irrigated by a given sprinkler (square feet).

Example:

If Q = (7 GPM + 9 GPM + 8 GPM) ÷ 3 sprinklers = 8 GPM and A_s = 40 ft x 40 ft = 1600 ft^2

AR_s = (96.3 x 8 GPM) ÷ (1600 ft^2) = 0.48 inch/hr

The catch-can method is conducted by placing a grid of catch cans large enough to hold the volume of water applied during a normal irrigation cycle in the irrigated area. If you use cans with straight walls, you can simply measure the height (inches) of the water in each container. If you use tapered containers (something like a red Solo cup), you'll have to measure the volume in each container with a graduated cylinder or measuring cup.

As a rule of thumb, catch cans should be spaced no farther apart than 10 percent of the sprinkler's throw radius. In other words, if the sprinklers shoot water 20 feet, catch cans should be spaced no more than 2 feet apart. A minimum of 32 to 64 catch cans is recommended, depending on the size of the zone being tested. Results will be most accurate if the catch cans are placed at canopy height, which can be accomplished by setting them on upside-down containers. Placing a metal washer in the bottom of each catch can will help prevent wind and irrigation from tipping them over.

Once the catch cans are set up, run the irrigation system for a length of time that is similar to a normal irrigation set with similar flow and pressure conditions (i.e., same number of zones operating as during a typical, daily irrigation event). After the irrigation has ended, record the volume of water in each catch can (using a graduated cylinder or similar measuring device) while noting the layout of catch cans (spacing and location), time of day, notable weather conditions, and the location of sprinklers. Follow the calculations in example 3.

This method can also be adapted to test a drip or microirrigation system by using a larger volume container (such as a milk jug or similar volume container) to collect irrigation water. Place emitters or spray stakes directly into the container and make sure that water doesn't spray out of the container and that the flow of water from the emitter or spray stake outlet is not hindered. Randomly select 16 to 24 emitters that are distributed throughout the zone in pot-in-pot production or through the field if growing plants in the soil.

Example 3. How to Calculate Application Rate Using the Catch-can Method (AR_C):

To determine AR_C, use the equation:

AR_C (in/hr) = (V x 60) ÷ ($A_{catch\text{-}can}$ x t x 2.54)

Where,

V = average catch-can volume in mL

60 = minutes per hour

$A_{catch\text{-}can}$ = area of catch-can (cm^2); The area of a circle = πr^2, where $\pi = 3.14$

r = radius (half the diameter of the circle).

t = time (minutes) that irrigation ran

2.54 = cm per inch

Example:

If,

V = (23 mL + 38 mL + 30 mL + 27 mL + 32 mL… + 35 more cup volumes) ÷ 40 cups = 30 mL

$A_{catch\text{-}can}$ (r = 4 cm) = 3.14 • 4 cm x 4 cm = 50 cm^2

t = 30 minutes;

Then,

AR_C = (30 mL × 60 min) ÷ (50 cm^2 × 30 min x 2.54 cm) = 0.47 in/hr.

Application Uniformity

Application uniformity describes how evenly water is distributed by the overlapping pattern of overhead sprinklers or the variability between emitters in a microirrigation system. These measurements are affected by climatic conditions, system pressure, nozzle spacing, droplet size, and trajectory. Two commonly used measures of uniformity are **Christiansen's coefficient of uniformity** (example 4) and **distribution uniformity** (example 5).

Christiansen's coefficient of uniformity is one of the most commonly used methods; it takes into account the wettest and driest areas in an irrigation zone. Distribution uniformity is also widely used, it but differs from CCU in that it is only based on the driest areas in an irrigation zone and assumes that wetter areas are receiving an adequate amount of water. These wet and dry areas are identified using catch cans, as described in the ARC section above. In fact, both calculations can be done at the same time. The DU coefficient can be used to identify poor uniformity and, preferably, to modify the system design to improve uniformity or increase irrigation times to ensure that dry regions of the zone receive enough water until the underlying problem can be addressed.

After calculating CCU or DU, compare numbers in table 1 to determine if uniformity is within acceptable limits. It is recommended that the CCU or DU be approximately 83 percent or greater. If uniformity is 70 to 80 percent, water is not being evenly applied to all the plants in the irrigation zone, and action is needed. Table 2 provides some possible sources of non-uniformity and how they could be addressed. In general, it's possible to increase irrigation duration to ensure that dry areas receive the intended volume. However, if the CCU or DU is very low (<70 percent), it's likely that many of the plants will be overwatered because they will receive extra water when the volume

Example 4. How to Calculate Christiansen's Coefficient of Uniformity (CCU):

Use the following formula:

CCU (% uniformity) = {1- [x÷(m x n)] } x 100

x = Sum of the absolute values[1] of the deviation between the mean average catch-can volume and individual catch-can volumes.

m = Mean (also known as average) of all the catch-can volumes.

n = Number of catch-cans used in the sample.

Example:

If,

x = (3 mL + 8 mL . . . 7 mL + 2 mL) = 200 mL,

m = (23 mL + 38 mL . . .27 mL + 32 mL) ÷ 40 catch-cans = 30 mL,

and n = 40 catch-cans.

Then,

CCU = { 1.0 – [200 ÷ (30 × 40)] } x 100 = 83%.

[1]Absolute value is the positive deviation between mean volume and individual volume. For example, if the average catch-can volume is m = 30 mL, ane one of the catch-can volumes is 38mL, the deviation is -8, but the absolute value is 8.

Side note: The units don't matter when calculating uniformity, so long as they are the same throughout.

of irrigation (frequency or duration) is increased to meet the needs of the dry areas. After changes have been made to improve application uniformity, reevaluate the improvements by performing another test, and evaluate at least annually thereafter.

Interception Efficiency

Interception efficiency is defined as the percentage of the applied (via overhead irrigation) water intercepted (captured) by plants or containers relative to the total amount applied. Plants and containers will intercept more water (interception efficiency increases) as the spacing between containers decreases. For example, if empty containers were laid can tight on a gravel container pad, approximately 90 percent of the irrigation applied to the area would be intercepted by the containers. If the containers were spaced farther apart, then some water would fall between the containers and the interception efficiency would be less. To calculate interception efficiency, follow the instructions in example 6.

Example 5. How to Calculate Distribution Uniformity:

Use the following formula to calculate DU:

DU (% uniformity) = (q ÷ m) × 100,

where

q = average volume of the lowest 25 percent of the catch can volumes [for example, if you collect 40 measurements and rank them from lowest to highest, the lowest 10 values (25% of 40 = 10) are used to calculate the average], and

m = mean (average) volume of all of the catch cans.

Example:

If q = (20 mL + 20 mL + . . . + 26 mL + 27 mL) ÷ 10 catch cans = 24 mL, and

m = 30 mL (from previous example),

DU = (24 ÷ 30) × 100 = 80%.

Note: The units don't matter when calculating uniformity as long as they are the same throughout.

Table 1. Application uniformity rating using either Christian's Coefficient of Uniformity (CCU) or Distribution Uniformity (DU) for container nurseries.

Uniformity coefficient	Application uniformity rating (%)		
	Poor	Acceptable	Excellent
CCU	<82	83-90	>90
DU	<78	79-85	>85

Table 2. Possible causes of low water application uniformity and how they could be addressed.

Cause	How to proceed.
Leaks.	Repair the leak.
Worn nozzles.	Replace nozzles.
Risers aren't vertical or they sway during irrigation.	Stabilize risers. One approach is to drive rebar or a stake into the ground to which risers can be tied.
Different nozzles or sprinkler types in the same zone.	Replace mismatched nozzles, sprinklers, spray stakes or emitters with the appropriate model/size.
Too many zones or sprinklers running at once.	Adjust irrigation schedule to match pump output.
Mechanical wear of the pump.	Contact the manufacturer or a service representative for guidance. Provide regular maintenance to the pump.
Inadequate pump flow rate or pressure.	This may be caused by any of the previous reasons. Address previous issues first, then revisit pump flow rate and pressure. If the problem persists, contact the pump manufacturer or service representative for guidance.
Lack of head-to-head coverage.	This may be a result of any of the previous causes or an improperly designed system. Address the simple solutions first and then evaluate the cost of retrofitting the system to meet design standards.
Wind drift.	Consider planting windbreaks in key locations that block the prevailing wind.

Example 6. How to Calculate Interception Efficiency

Use the following formula:

IE (% efficiency) = $(A_{container} \div A_P) \times 100$,

where

$A_{container}$ = area of the top of containers (in^2; the area of a circle = πr^2, where $\pi = 3.14$ and r = radius [half the diameter of the circle]), and

A_P = area (in^2) used by the container and the individual plant, based on the container spacing in the bed.

Example:
Let's use a typical 3-gallon container as an example. These containers typically have a diameter of 10 inches and a radius of 5 inches.

1. The radius is used to calculate $A_{container}$:

$A_{container} = 3.14 \times (5 \text{ in} \times 5 \text{ in}) = 79 \text{ in}^2$.

2a. If containers have square spacing and are on 15-inch centers, A_P is calculated as follows:

$A_P = 15 \text{ in} \times 15 \text{ in} = 225 \text{ in}^2$, and

IE = $(79 \text{ in}^2 \div 225 \text{ in}^2) \times 100 = 35\%$.

2b. If containers use triangular spacing, A_P is calculated using a multiplier of 0.866:

A_P = (15-in spacing on center × 15-in spacing on center) × 0.866 = 195 in^2, and

IE = $(79 \text{ in}^2 \div 195 \text{ in}^2) \times 100 = 40\%$.

Note: Interception efficiency can be calculated using metric or standard units as long as they are the same throughout the calculation.

During production, containers have plants growing in them, and the shape and size of the plant canopy can affect interception efficiency. For example, the foliage of vase-shaped plants such as Gardenia sp. has been shown to act like a funnel and to capture water beyond what an empty container would capture alone. In this case, interception efficiency could increase because the canopy helps prevent water from falling between containers. In contrast, umbrella-shaped canopies, or plants with leaves that deflect water away from the container such as Cotoneaster sp., might actually decrease interception efficiency. Over an entire production cycle, plants that capture more water via vase-shaped foliage will require less total irrigation time because they are more efficient at capturing water, especially as they approach a salable size. Conversely, plants that shed water could require longer or more-frequent irrigation to supply adequate water, especially as they approach a saleable size (fig. 10).

A common reason for interception efficiency to be low is for an irrigation zone to be only partially occupied by plants. In this case, water is unnecessarily applied to areas where there are no plants. To prevent this, isolation or ball valves can be plumbed into each overhead sprinkler, allowing a grower to shut off individual sprinklers when they are not needed. Be aware that reducing the number of operating sprinklers will increase the pressure on other sprinklers and the whole system, altering system performance. This is less of an issue when using variable frequency drive pumps because they automatically compensate for pressure and flow changes, though pressure regulators or pressure regulating solenoids plumbed into each zone could help with this problem. Monitor pressure and flow throughout the system to maintain consistent system performance and reduce the risk of damaging infrastructure.

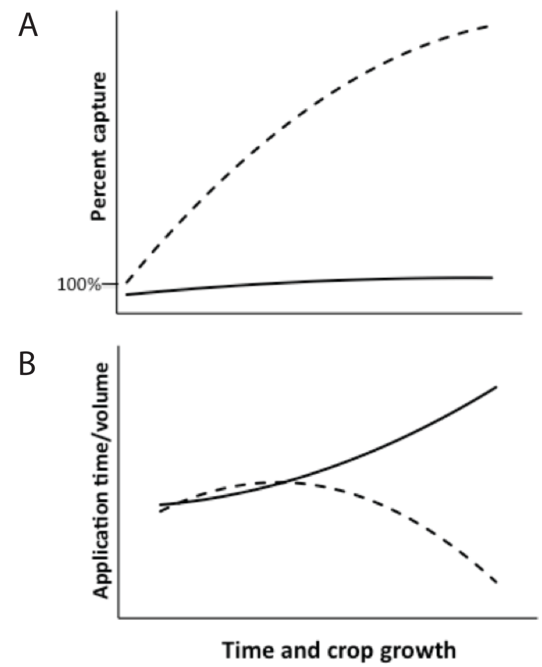

Figure 10. A, the effect of canopy architecture on overhead irrigation interception efficiency (i.e., percent capture). Values above 100 percent for vase-shaped plants indicate that plant foliage outside the container captures water and funnels it into the container, thus capturing more water than would be measured in containers without plants. B, the affect of canopy architecture on application time (i.e., water application duration) and volume of water applied to vase- (dashed) or umbrella- (solid) shaped plants over production time and crop growth. (Adapted from Williamson, Warren, and Bilderback, Timing of Overhead Irrigation Affects Growth and Substrate Temperature of Container-Grown Plants. In "Proceedings of the Southern Nursery Association Research Conference: Forty-ninth Annual Report," edited by B.L. James, 77-80.)

Interception efficiency calculations are simply the percentage of the irrigation zone that is occupied by containers. As a result, this calculation integrates plant spacing (density), container size, and, indirectly, the irrigation method. If interception efficiency is subtracted from 100 percent, you will know the percent of applied overhead irrigation that theoretically does not fall in the containers (using step 2b in example 6, it would be 60 percent). Microirrigation systems have nearly 100 percent interception efficiency because all of the water is applied directly to the containers. As a general rule, growers should consider irrigating plants grown in containers larger than 5 or 7 gallons via microirrigation because the large spacing between containers typically results in an interception efficiency below 25 percent (75 percent not intercepted). Not only can plant spacing contribute to a low interception efficiency, indicating wasted water, it also affects runoff volume and overall loss of applied nutrients and pesticides. Triangular spacing increases interception efficiency by 5 to 10 percent (table 3).

Table 3. The relationship between container diameter (inches), container spacing (center-to-center; inches), area of container top (A_R; in²), total area occupied (A_P; in²) and irrigation interception efficiency (IE) for both square and triangular container spacing.

			Square Spacing		Triangular Spacing	
Container diameter (in)	Spacing on center (in)	A_R (in²)	A_P (in²)	IE (%)	A_P (in²)	IE (%)
5	0	20	25	79	22	91
5	7.5	20	56	35	49	40
5	10	20	100	20	87	23
10	0	79	100	79	87	91
10	15	79	225	35	195	41
10	20	79	400	20	346	23
20	0	314	400	79	346	91
20	30	314	900	35	779	40
20	40	314	1600	20	1386	23
20	60	314	3600	9	3118	10

Container area = π r² or 3.14 x radius x radius. A_p (square spacing) = distance between containers² = distance between containers x distance between containers. A_p (triangular spacing) = distance between containers² x 0.866 = distance between containers x distance between containers x 0.866.

Figure 11 shows how interception efficiency is inversely related to container spacing in another way. Using a triangular pattern of container spacing is inherently more efficient — in terms of interception efficiency — than square spacing. However, the higher efficiency of the triangular spacing method is greatest when containers are close together and least when spaced farther apart, at which point there is not much difference in interception efficiency between square and triangular spacing methods. Regardless of container size or spacing method, interception efficiency is greatest when containers are closer together.

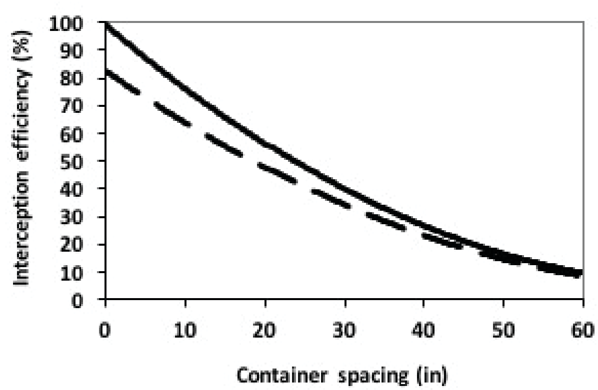

Figure 11. Effect of increased container spacing on interception efficiency for triangular (solid line) and square (dashed line) spaced containers.

Water Application Efficiency

Application efficiency (example 7) is a measure of irrigation performance that quantifies the amount of water retained in the substrate after irrigation relative to the total amount that was applied. This is an important measurement because after irrigation, a portion of the retained water is available for use by the plant. Application efficiency is most easily determined by measuring the **leaching fraction** (example 7) of an irrigation event, which is the fraction of the total applied irrigation volume that leaches from a container. Leaching fraction is a simple tool that takes into account the effects of crop water use, substrate, container size, crop growth stage, and canopy architecture.

To calculate leaching fraction, the leached volume is divided by the total applied volume. The answer can be multiplied by 100 to convert to a percentage and easier interpretation. A high application efficiency (low leaching fraction) means that most of the applied irrigation water was held in the container, whereas a low application efficiency (high leaching fraction) means that excess water drained from the base of the container and became runoff or wasted water. As a word of caution, if application efficiency is too high, one might not be watering adequately, and the entire root zone might not be receiving water during irrigation. This may lead to wilting, desiccation, or salt (fertilizer) buildup in the substrate. A leaching fraction of approximately 15 percent (0.15) is recommended.

To calculate leaching fraction in an overhead irrigation system, nest containers from the irrigation zone into other impermeable containers, such as buckets. Make sure the container fits snugly into the bucket so no irrigation water is collected by the bucket — a lid might need to be modified (e.g., cut a container-sized hole into it) to ensure the proper fit. Next, nest empty containers (same size as those in the irrigation zone) within buckets. The water collected in these buckets represents the total volume applied to the plants. Thirty minutes to one hour after irrigation ends, measure the volume of water in each set of buckets and calculate the leaching fraction. To adapt this procedure for a microirrigation system, plants can be placed on a tray with a raised center to collect the water leached, and an unused emitter can be placed in a milk jug or bucket to capture water applied. Whether measuring leaching fraction in an overhead or microirrigation system, leaching fraction will vary among different locations throughout the zone. By measuring leaching fraction on several (five or more) plants within the zone, an average can be calculated, which will provide more-accurate results.

In general, leaching fraction is a reliable measurement that is quite valuable in irrigation management. However, there are several factors that growers must consider when interpreting leaching fraction measurements. The same factors that were previously mentioned to affect interception efficiency, such as canopy size, shape, and leaf orientation, can affect leaching fraction. For example, vase-shaped plants such as Gardenia sp., which act like a funnel, could actually capture and leach more water than is captured by the empty container, resulting in a leaching fraction that is greater than 100 percent (1.0). In contrast, umbrella-shaped canopies or plants with downward-oriented leaves that deflect water, such as Cotoneaster sp., can cause a very low leaching fraction. These factors will be most pronounced later in the production cycle when plant canopies are larger and should be taken into account when using leaching fraction to adjust irrigation.

Example 7. How to Calculate Leaching Fraction and Application Efficiency

To calculate LF and AE, use the following formula:

$LF = (W_L \div W_A)$ W_L = water volume leached from container,

where

W_A = water volume applied to container through overhead or microirrigation, and

$AE = 1.0 - L_F \times 100$.

Example:

If W_L = 200 mL and W_A = 400 mL, and

LF = (200 mL ÷ 400 mL) = 0.50,

then AE = (1.0 – 0.50) × 100 = 50%.

In this example, only half of the water intercepted by the plant and container is held by the substrate.

Note: Because containers with funneling plant canopies can collect more water than what is usually captured by the container alone, leaching fraction can exceed 1.0 or 100 percent.

Irrigation Scheduling

A well-managed **irrigation schedule** will coordinate irrigation times in order to efficiently supply crops with an appropriate volume of water lost through **evapotranspiration**. However, determining the appropriate amount of water to apply can be complicated. The amount of time an irrigation event is scheduled to run is determined based on the flow rates of individual emitters and the desired amount of water to be applied to the crop. However, factors such as weather, substrate properties, crop water use, canopy architecture, irrigation type, irrigation application uniformity, irrigation efficiency, interference with general crop production activities, and the time it takes to fill empty irrigation lines can substantially complicate the schedule. Growers often make decisions based on an educated guess after observing the wetness of their substrates and checking the current weather conditions and forecasts. Growers can also choose a coarse-textured substrate that holds less water to allow them to overirrigate (longer or more frequent runs) to ensure that the crop will not undergo water stress and subsequently produce less growth. This approach can be effective in minimizing crop risk; however, overirrigation will increase irrigation-related costs (e.g., pumping, labor, system maintenance, etc.) and disease pressure and could cause fertilizers to leach. There is also an increasing concern in some regions about water availability due to reduced groundwater supplies and increased competition for water between agricultural and urban areas.

A Quick Tip

You can easily determine the amount of time an irrigation system should run to apply the appropriate amount of water using the water-holding capacity of your substrate, several spare containers, and plastic bags. For most thoroughly irrigated substrates, the total volume of water held in the container after irrigation will be approximately 33 percent of the container volume. Finer-textured peat-based substrates might hold a little more, and coarser-textured bark-based substrates could hold a little less.

Line several containers (same as the containers used in the zone) with plastic bags (make sure they hold water) and place them throughout the zone. Run the irrigation system and record how long it takes to fill the lined containers halfway. This is a very rough measurement, but it is a very easy starting point for fine-tuning your irrigation.

When to Irrigate

As a rule of thumb, it is best to run overhead irrigation before dawn, throughout the morning, or in the late afternoon or early evening, but no later than an hour before dusk. This will help minimize the loss of water through evaporation. Watering near or after dusk can prevent water from evaporating from foliage and promote moisture-related pathogens. When using microirrigation, it is best to apply water when plants are actively transpiring, from the late morning to the late afternoon.

A rain event of 0.25 to 0.50 inch should provide enough water to substitute for the next irrigation event. Therefore, it is recommended that **rain sensors** are incorporated into irrigation systems to automatically modify preprogrammed irrigation schedules and account for any rainfall.

Cyclic Irrigation

Cyclic irrigation is dividing the total daily volume of water into several smaller applications that occur throughout the day. This technique is most commonly seen with microirrigation systems but can be used for overhead applications as well. Cyclic irrigation increases application efficiency, can reduce the substrate and plant canopy temperature, and can supply water in a manner that matches plant demand throughout the day.

Leaching-Fraction-Based Irrigation

In addition to evaluating application efficiency, leaching fraction measurements can also be used to schedule irrigation. To do so, a grower must first conduct a leaching fraction analysis on the previous irrigation event and calculate an average, measured leaching fraction (LF_M) for that irrigation. This value is then compared against a grower-determined target LF (LF_T) and is used to calculate the amount of time the irrigation clock should be adjusted (T_A) to achieve the LF_T at the next irrigation. If LF_M is higher than LF_T, then the length of the next irrigation event should be reduced. For an example of how to calculate T_A, see example 8. This method works best when LF_M and LF_T do not differ widely, and continued use will improve leaching-fraction-based irrigation.

Example 8. How to Schedule Irrigation Using Leaching Fraction

Use the following formula:

$T_A = t \times (LF_T - LF_M)$,

where

T_A = time adjustment needed for the next irrigation (min),

t = length of time the last irrigation ran (min),

LF_T = target LF, commonly 0.15 to 0.30 (depending on irrigation system efficiency), and

LF_M = average measured leaching fraction of the previous irrigation event.

Example:

If t = 90 min, LFT = 0.3, and LFM = 0.65,

T_A = 90 min × (0.30 – 0.65) = -31.5 min.

Therefore, the new irrigation time would be 90 min – 31.5 min = 58.5 min.

Scheduling Coefficient

If catch cans were used to determine uniformity coefficients (CCU or DU) as discussed earlier, that data can be used to produce a **scheduling coefficient**. Scheduling coefficients are used to adjust the length of an irrigation event to account for drier areas within the zone that resulted from non-uniform irrigation distribution. Note that this method does not improve application uniformity; it is used to ensure that dry areas in the irrigation zone receive enough water. For an example of how to adjust irrigation using a scheduling coefficient, see example 9.

Example 9. Using a Scheduling Coefficient to Adjust Irrigation

Use the following formula:

SC = V ÷ LV,

where

V = Average catch can volume, and

V_L = Lowest catch can volume.

Example:

If V = (23 mL + 38 mL . . . 27 mL + 32 mL) ÷ 40 catch cans = 30 mL, and

V_L = 23 mL,

then SC = 30 mL ÷ 23 mL = 1.3 (unitless).

To determine the new application time, multiply the scheduling coefficient by the application rate or application time. In this example, if all containers need to receive 0.5 inch per hour, one would need to water for 78 minutes because 60 minutes × 1.3 = 78 minutes (irrigation rate is commonly based on precipitation rate of inches per hour). This would ensure the least-irrigated area in the zone receives the needed 0.5 inch of water.

Note: The units for V and V_L do not matter as long as the same units are used for both.

Plant Groupings

Ideally, an irrigation zone would contain only one plant species in one container size, and the plants would have been potted at the same time so that an irrigation zone can be tailored to meet the water needs for that species. This is often not possible because most nurseries grow a wide variety of species, pot plants year-round, and often have have limited space. Therefore, it is recommended that species with similar water needs are grouped together to make it easier to match water applications to crop demand. For example, if *Hydrangea* sp. (a high water user) and *Juniperus* sp. (a low water user) are placed in the same irrigation zone, irrigation must be scheduled to meet the demands of the Hydrangea sp., the high water user. The result is that Juniperus sp., the low water user, will receive more water than it needs. Table 4 shows the relative crop water requirements for several common woody ornamental crops and could be helpful in determining how to group plants. Dividing areas of the nursery that are dedicated to high, intermediate, or low water use might be easier than combining plant species on a zone-by-zone basis. Additional ornamental crop water requirements can be found in Southern Nursery Association Best Management Practices: Guide for Producing Nursery Crops (see Bilderback et al., 2013, in the list of Additional Resources).

Table 4. Gradient of Relative Crop Water Requirements of Several Container-grown Crops During Production

High		Medium		Low
Chamaecyparis pisifera	*Cotoneaster dammeri*	*Berberis thunbergii*	*Abies balsamea*	*Chamaecyparis obtusa*
Forsythia x intermedia	*Juniperu procumbens*	*Juniperus horizontalis*	*Acer palmatum*	*Daphne x burkwoodii*
Hydrangea macrophylla	*Picea glauca*	*Picea abies*	*Euonymus fortunei*	*Juniperus squamata*
Picea pPungens	*Rhododendron 'English Roseum'*	*Rhododendron 'PGM'*	*Ilex crenata*	*Rhododendron 'Ramapo'*
Prunus x cistena	*Rhododendron 'Girard's Fushia'*	*Thugja occidentalis*	*Viburnum davidii*	*Tsuga canadensis*

Adapted from Regan, R. 2008. Strategies for improving irrigation application efficiency. A handout presented at the Practical Nursery Irrigation Workshop, North Willamette Research and Extension Center, Aurora, OR.

Conclusion

The tools and calculations presented in this publication are intended to assist growers in improving water use efficiency while improving crop health and quality. A well-designed and maintained irrigation system and an understanding of how to routinely measure system performance (efficiency and uniformity) can lead to increased crop quality and greater profits.

Glossary

air relief valve - A valve that allows air to vent from pipes as they are filled with water.

application efficiency (AE) - The volume of water stored or retained in a container divided by the total volume applied to that container.

application rate (AR) - The amount of water applied to a given area over a certain time, usually in inches per hour.

arc - The extent to which a sprinkler or emitter rotates; for example, 360, 180, or 90 degrees.

Christiansen's coefficient of uniformity (CCU) - A common method for evaluating how evenly a sprinkler system distributes water over a given area. Both the wettest and driest areas in an irrigation zone are considered.

critical point - The farthest location (usually a sprinkler or emitter) from the valve or pump, where flow and pressure can be lowest and potentially inadequate for the specific nozzle being used.

cyclic irrigation - The total volume of water to be applied is split into several applications that occur throughout the day.

distribution uniformity (DU) - A common method for evaluating how evenly a sprinkler system distributes water over a given area. Considers the driest 25 percent in an irrigation zone.

dynamic pressure - Water pressure in irrigation pipes when water is flowing. Also known as "working pressure."

emitter - A water application device that drips water at a very low pressure and flow rate.

evapotranspiration (ET) - Water loss to the atmosphere through direct evaporation from the soil or substrate and plant transpiration.

feet of head - A measure of water elevation and its effect on pressure, where 2.31 vertical feet of water elevation is equal to 1 pound of water pressure per square inch (psi).

flow rate - The volume of water that flows through a pipe or sprinkler in a given amount of time, usually measured in gallons per minute or hour (GPM or GPH).

head-to-head coverage - An overhead irrigation system design factor, where the spray radius (distance a sprinkler projects water) is equal to the distance between sprinklers (i.e., the water emitted from one sprinkler reaches adjacent sprinklers).

interception efficiency (IE) - The percentage of water captured by containers relative to the total applied. Commonly calculated using the total area occupied by containers divided by the total area that water is distributed.

irrigation scheduling - Determining when and how much water to apply to meet crop demand while maximizing resource use efficiency.

irrigation zone - A subset of an irrigation system that is controlled independently.

leaching fraction (LF) - A measure of irrigation application efficiency for a containerized crop. The volume of water leached divided by the volume applied.

matched precipitation rate - Sprinklers that emit the same volume of water in a given time regardless of arc.

point of connection (POC) - The water source to which an irrigation system is connected. Usually a municipal source or a pump that draws from ground or surface water.

pressure regulator - A device that can be plumbed into an irrigation system to regulate the working or dynamic pressure.

rain sensor - A device that measures precipitation and provides feedback to an irrigation system. Can be used to tell an irrigation system not to irrigate.

scheduling coefficient (SC) - A unitless value, based on the driest area within an irrigation zone, used to adjust the length of an irrigation event.

spray stake - A water application device that sprays water directly on the substrate surface.

sprinkler - A water application device that projects water over a production area.

static pressure - Water pressure within pipes when water is not moving.

thrust block - Reinforcements installed at strategic locations along main or submain lines to minimize the movement of pipes.

trajectory angle - The angle (measured in degrees) that an overhead sprinkler projects water relative to the ground. For example, a typical impact sprinkler would have a trajectory angle of 11-12 degrees.

water hammer - Water compression that occurs when water suddenly changes direction or velocity, caused by a change in pipe size.

water velocity - The speed at which water moves through a pipe. Usually measured in feet per second.

windbreak - Plants or structures located strategically to block the prevailing wind.

working pressure - Water pressure in irrigation pipes when water is flowing. Also known as dynamic pressure.

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