Irrigation Strategies to Conserve Water in Container Nurseries

This document will discuss a number of methods that can be used to determine irrigation application rate and evaluate irrigation drip and overhead system performance. Furthermore, additional considerations for irrigation management will be reviewed to assist growers to more efficiently manage irrigation of containerized crops.

Irrigation Maintenance and Design Considerations

Efficient irrigation begins with good irrigation design by irrigation and pump specialists or professionally trained or certified personnel within the company. A system should be designed to ensure a pump produces proper pressure (feet of head) within given pump efficiency, compensates for changes in elevation and has appropriate pressure for critical points or nozzles. Furthermore, the irrigated area should be broken into an adequate number of zones sized to water crops with similar needs within a zone and also have manageable flow rates (gallon per minute). The system and pump capacity should also be designed to accommodate future expansion. Irrigation manufacturers, representative consultants and service companies can provide the needed specifications and expertise to properly design or maintain your irrigation system to obtain the highest performance and minimal energy needs while balancing irrigation scheduling (time applied and amount irrigated) to maximize overall crop health production efficiency.

The main irrigation system design factor used by an irrigator is the water application rate. This indicates you how much water is being applied over time at a certain level of pressure. Gallons of water per minute (GPM) is the most common value used for individual drip emitters, spray stakes and sprinklers, while inches per hour is used for the overall sprinkler system. This value helps the irrigator to determine how long to run the water. It is used for all types of irrigation systems whether they are newly designed or they are an older and more established one. The application rate must be measured in the field to obtain accurate values.

Overhead irrigation systems should be designed to provide uniform coverage taking into consideration topography and environmental conditions. Overhead nozzles or sprinkler heads that produce larger droplets minimize evaporation and inefficiencies due to wind. Furthermore, trajectory angle and riser height for each sprinkler should be considered to minimize water loss via wind and evaporation. If risers are greater than 8 feet high, then it may be more efficient to use drip irrigation. Irrigators must ensure that sprinkler risers remain vertical. For high wind areas growers may need to use windbreaks or alter the spacing of sprinklers based on specifications provided by an irrigation supplier.

Overhead irrigation systems should:

- have adequate pressure at the critical nozzle that is farthest away from the pump or at the highest elevation
- provide head to head coverage taking into consideration wind
- use nozzles that produce larger droplets
- use lower trajectory angle sprinkler heads and replace worn nozzles
- use sprinkler risers less than 8 feet high that are vertical

Micro-irrigation systems require greater monitoring and maintenance to make certain all plants receive the water they need. Emitters or stakes should be chosen and placed to ensure the irrigation application adequately reaches the entire root zone. System uniformity is best obtained by using pressure compensated emitters or stakes. The system design must compensate for elevation changes or topography, and ensure that the length of distribution lines is within manufacturer and system specifications. Lateral lines with flushing end caps can also improve system efficiency. The water used for micro-irrigation will require greater filtration and could require treatment to prevent algae or bacteria from plugging emitters.

Micro-irrigation or drip systems should:

- use nozzles or emitters to ensure the entire root zone receives adequate water
- have adequate filtration and water treatment
- have lateral line length within system pressure specifications for a given emitter or stake
- compensate for elevation changes or topography
- receive regular monitoring to ensure emitters and spray stakes are watering properly

There are several terms that you should be conversant with if you are going to be the irrigation manager for your nursery:

Table 1: Irrigation terms and acronyms

Term	Acronym
Irrigation Scheduling	
Application Rate	AR
Application Uniformity	
Christiansen's Coefficient of Uniformity	CCU
Distribution Uniformity	DU
Interception Efficiency	IE
Application Efficiency	AE
Leaching Fraction	LF
Scheduling Coefficient	SC
Evapotranspiration	ET

These will be defined and discussed below.

Application Rate

Application rate (AR) can be measured as a function of flow rate at either the pump or sprinkler or by using the catch-can method. The catch-can method is preferred because the data can be utilized to calculate sprinkler uniformity and assist with scheduling irrigation. To monitor both irrigation system application rate and irrigation uniformity simultaneously, a grid of catch cans can be set up to cover the irrigated area. The layout of catch-cans for each test should be recorded noting the spacing of catch cans, time of day, notable weather conditions, and location of overhead irrigation sprinklers or micro-irrigation emitters. As rule of thumb, catch-cans should be spaced no greater than 10 percent of the sprinkler throw radius, regardless of the rule, a minimum of 30 to 60 catch-cans should be used depending on the size of zone being tested. Placing a metal washer in the bottom of each catch-can will help prevent the catch-cans from tipping over. If you are testing a drip or micro-irrigation system a larger container might be needed. Place micro-sprinklers directly in the container and make sure that all of the water is collected and emitter or stake outlet is not hindered. You can randomly select 16 to 24 emitters that are distributed throughout the field.

Sprinkler Application Rate (inches/hr) is the amount of water applied to a given area. An overview of water application rate can be determined by installing a water meter to measure flow and volume. The simplest way to determine application rate to use the flow rate method as follows:

AR_F (inch/hr) = (q × t) ÷ (Ac × 27,154)

Where, q = flow rate in gpm, t = time in minutes, Ac = acreage irrigated, 27,145 gallons per acre-inch of water

If, q (flow rate) = 200 gpm, t (time) = 90 minutes, Ac (acreage irrigated) = 1 acre

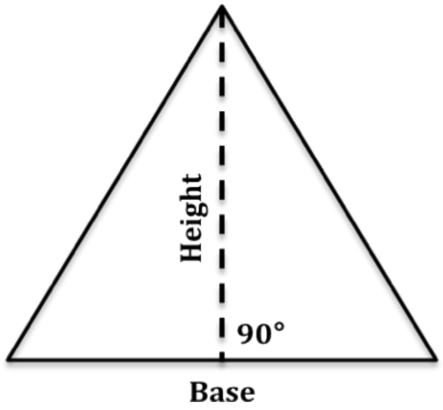
Then, AR_F = (150 gpm × 90 min) ÷ (1 acre × 27,154 gal) = 0.50 inch/hr

To calculate the specific application rate for a given zone, measure the flow rate at a sprinkler head. This can be done by capturing water from the nozzle using a hose or plastic bag at a given sprinkler. Note that the arc of the sprinkler may affect the accuracy of this method.

AR_S (inch/hr) = (96.3 × Q) ÷ (As)

Where 96.3 is a constant for conversion of area and flow into common units, Q = average sprinkler flow rate in gallons per minute (GPM) determined by time to fill a bucket with a known volume. As = area irrigated by a given sprinkler in feet which is calculated for square spacing as length x width or for triangular spacing as 0.5 x base x height.

Figure 1: Illustration of the base and height of a triangle



If, Q (average sprinkler flow rate) = (7 gpm + 9 gpm + 8 gpm) ÷ 3 sprinklers = 8 gpm, As (sprinkler area) = 40 ft × 40 ft = 1600 ft^2

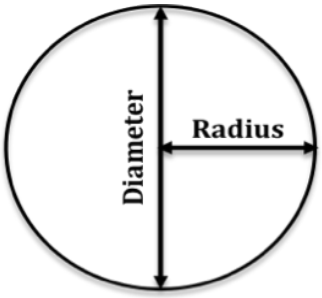
Then, AR_S = (96.3 × 8 gpm) ÷ (1600 ft^2) = 0.48 inch/hr

The most precise method to obtain the specific application rate for a given zone is to use the catch can volumes (mL) as follows:

AR_C (inch/hr) = (V× 60) ÷ (Ar × t × 2.54)

Where V = average can volume in mL, 60 minutes per hour, Ar = area of top of containers in cm^2 = (3.14 x $radius^2$), t = time in minutes, and 2.54 per cm of inch of water applied

Figure 2: Illustration of the diameter and radius of a circle



If, V (average can volume) = (23 mL + 38 mL . . .27 mL + 32 mL) ÷ 40 cups = 30 mL, t (duration of test) = 30 minutes, Ar (container top area) = 3.14 × [(8 cm diameter ÷ 2)(8 cm diameter ÷ 2)] = 50 cm^2

Then, AR_C = (30 mL × 60 min/hr) ÷ (50 cm × 30 min x 2.54 cm) = 0.47 inch/hr

Application Uniformity

Application uniformity (AU) is a measure of water distribution as a function of application rate across a given irrigated area. If catch-can data is used from the area of interest, then the measure of uniformity takes into account climatic conditions, system pressure, nozzle spacing, droplet size, and nozzle trajectory. Measures of uniformity are statistical measurements of the overlapping pattern of overhead irrigation sprinklers or variability from emitters in a micro-irrigation zone. Two commonly used measures of uniformity are Christiansen's Coefficient of Uniformity (CCU) and Distribution Uniformity (DU).

Christiansen's Coefficient of Uniformity (CCU) is one of the most commonly used methods for evaluating sprinkler system uniformity. Both the wettest and driest areas in a distribution area are considered.

$CCU = \{ 1.0 - [x \div (m \times n)] \} \text{ x } 100$ = uniformity (%)

Where x = sum of the deviations of each catch-can volume from the average volume, all values are positive or absolute values. A mean of 30 mL and a catch-can volume of 38 mL would have a deviation of 8 (30-38 = -8 = 8), m = mean value of all catch-can volumes and n = number of catch-cans

If, x (sum of catch-can deviations) = (3 mL + 8 mL . . . 7 mL + 2 mL) = 200 mL,
m (average catch-can volume) = (23 mL + 38 mL . . .27 mL + 32 mL) ÷ 40 catch-cans = 30 mL, n (number of catch-cans) = 40 catch-cans. Note that numbers do not have units when calculating uniformity.

Then, $CCU = \{ 1.0 – [200 \div (30 \times 40)] \} \text{ x } 100 = 83\%$

Distribution Uniformity (DU) is another widely used coefficient in which the wettest areas in a distribution are not considered. The wettest area is determined by catch-can data. This coefficient is often used for drip emitter, micro-sprinkler, and spray stake irrigation systems. Emitter application rate for micro-irrigation systems are best defined as volume of water applied per unit of time. Gallons per hour is the most common unit, however liters per hour can be used for scheduling.

$DU = (q \div m) \times 100$ = uniformity (%)

Where q = average volume of 25% of the lowest catch-can volumes and m = mean value of all catch-can volumes.

If q (average lowest 25% of lowest catch-can volumes) = (20 mL + 20 mL . . . 26 mL + 27 mL) ÷ 10 catch-cans = 24 mL and m (average catch-can volume) = (23 mL + 38 mL . . .27 mL + 32 mL) ÷ 40 catch-cans = 30 mL. Note that numbers do not have units when calculating uniformity.

Then $DU = (24 \div 30) \times 100 = 80\%$

Compare your numbers to the following to see where your nursery ranks.

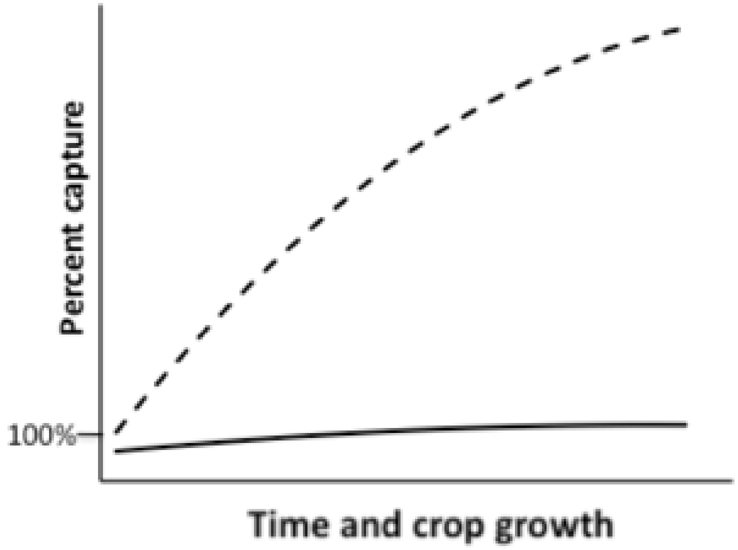
Table 2: Application uniformity rating using either coefficient of uniformity or distribution uniformity for container nurseries in the pacific northwest (Adapted from handout titled 'Strategies for improving irrigation application efficiency' presented by Rich Regan, OSU Extension Horticulturist, at the Practical Nursery Irrigation Workshop held at the North Willamette Research and Extension Center in 2008).

	Application Uniformity Rating (%)		
Uniformity Coefficient	**Poor**	**Acceptable**	**Excellent**
Christian's coefficient of uniformity (CCU)	<82	83-90	>90
Distribution uniformity (DU)	<78	79-85	>85

Interception Efficiency

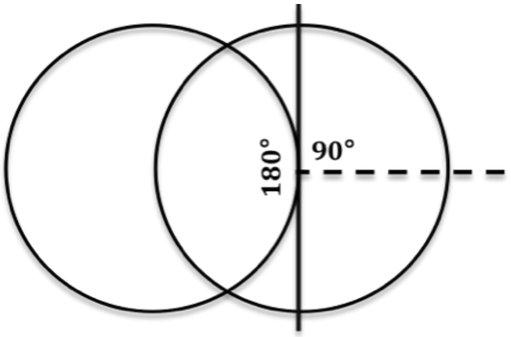
Interception efficiency (IE) is defined as the water applied via overhead irrigation that is intercepted by each container in relation to the area each plant uses. Interception efficiency is directly related to container spacing. IE typically increases with decreasing spacing. However, shape and size of canopy can also affect IE. Vase shaped plants such as *Gardenia* have been shown to intercept water beyond the container diameter via foliage, whereas umbrella shaped or small leaved plants may actually prevent water from getting inside the top of the container, decreasing interception efficiency.

Figure 3: Effect of canopy architecture on overhead irrigation interception efficiency as percent of water captured for a vase- (- - -) or umbrella- (—) shaped plant over production time and crop growth (Adapted from Williamson et al. 2004. Timing of overhead irrigation affects growth and substrate temperature of container-grown plants. Southern Nursery Association Research Proceedings pp 77-80)



To increase IE, isolation or ball valves can be plumbed into each overhead sprinkler. This addition of increased control will allow individual sprinklers to be turned off when not needed. It should be noted that system performance may change when number of operating sprinkler heads change for a given zone, therefore one should determine if the irrigation system is able to compensate for changes in pressure and flow. Another consideration is to use irrigation design that utilizes 90 and 180 degree nozzles to ensure roads and other non-growing areas do not receive water.

Figure 4: Illustration of head to head coverage and degree throw of sprinkler heads (•)



Interception efficiency is calculated as follows:

IE = ($A_R \div A_P$) × 100 = efficiency (%)

Where A_R = area of top of containers in cm^2 = ($3.14 \times radius^2$) and A_P = area utilized by the individual plant in inches taking into account spacing.

If A_R (container top area) = 3.14 × [(10 in diameter ÷ 2)(10 diameter ÷ 2)] = 79 in^2 and A_P = (container area utilized) = 15 in spacing on center × 15 in spacing on center = 225 in^2. Note for triangular spacing A_P is calculated using a multiplier of 0.866 as follows: (15 in spacing on center × 15 in spacing on center) x 0.866 = 195 in^2

Then IE = (79 in^2 ÷ 225 in^2) × 100 = 35 %

Interception efficiency is expressed as a percentage in terms of area, integrating plant density or spacing, container size and irrigation method. Interception efficiency subtracted from 100 provides the percentage of applied overhead irrigation that does not fall on the container surface. Plants that are micro-irrigated have near 100% IE. Growers should consider irrigating plants grown in containers larger than #5 or #7 via micro-irrigation because large spacing typically results in an IE below 25%. Furthermore, plant spacing affects runoff volume and overall loss of applied nutrients. Triangular spacing increases IE by 5% to 10 (Table 3).

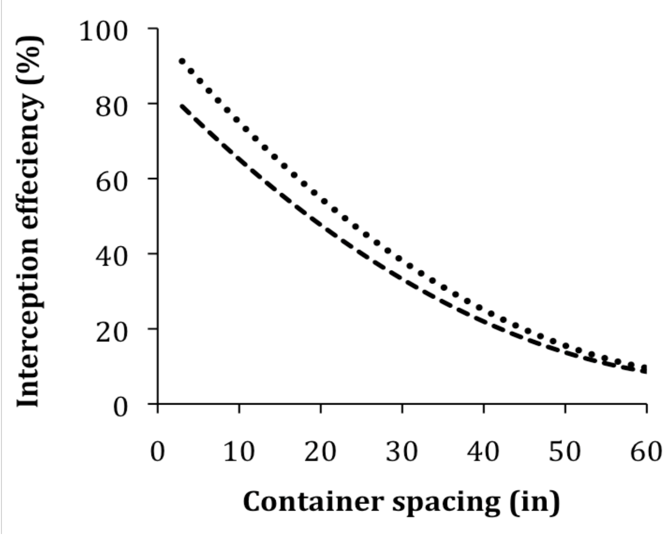
Table 3: Effect of container diameter (in), distance spaced on centers (in), and spacing orientation (square or triangular) on area utilized (in^2) and subsequent irrigation interception efficiency (IE)

Container Diameter	Spacing on Centers	Square Spacing		Triangular Spacing	
		Area	IE	Area	IE
5	0	25	79	22	91
5	7.5	56	35	49	40
5	10	100	20	87	23
10	0	100	79	87	91
10	15	225	35	195	41
10	20	400	20	346	23
20	0	400	79	346	91
20	30	900	35	779	40
20	40	1600	20	1386	23
20	60	3600	9	3118	10

Container area = 3.14 (top $radius^2$)
Square spacing = Spacing on $center^2$
Triangular spacing = Space on centers x space on centers (0.866)

Another way to look at interception data is through graphs, which show that regardless of container size or spacing method, efficiency decreases as spacing increases. Also, the figure shows that the increased efficiency gained via triangular spacing decreases as container spacing increases, eventually equaling that of square spacing.

Figure 5: Effect of triangular (••••••) or square (------) container spacing on irrigation interception efficiency with increased space between containers



Application Efficiency

Application efficiency (AE) is defined herein as the amount of water stored or retained in a container divided by the total amount of water applied to that container. Unlike IE, the surrounding area or water not intercepted by the container is not included. Application efficiency is commonly determined by calculating leaching fraction (LF) as follows:

LF = ($W_L \div W_A$) = fraction leached

Where W_L = water volume (mL) leached from container and W_A = water volume (mL) applied to container

If W_L (water volume leached) = 200 mL and W_A (water volume applied) = 400 mL

Then LF = (200 mL ÷ 400 mL) = 0.50, note LF can exceed 1.0 due to factors affecting IE.

Leaching fraction is a simple way to account for the effects of crop water use, substrate, container size, crop growth stage, and canopy architecture. In overhead irrigation systems, leaching fraction is measured by nesting containers, both with (water leached) and without plants (water applied), in buckets. When micro-irrigating, plants are commonly placed on a tray with raised center (water leached) and an unused emitter is placed in a milk-jug or bucket (water applied). Leaching fraction should be taken on a number of plants within the zone so an average can be determined. Data collected for leaching fraction is also useful determining application rate on a per container basis and provides insight into variability in the nursery growing system.

Figure 6: Leaching fraction set-up for overhead (left) and micro-irrigation (right).

Irrigation Scheduling

Irrigation Scheduling is used to determine the quantity and time of day water should be applied to maximize use by the crop. Determining the amount of water to apply to nursery crops can be a guessing game. Irrigation management of nursery crops grown in containers can be difficult to assess because of the numerous factors that are challenging to account for on a day-to-day basis. These factors include weather, substrate, crop water use, crop canopy architecture, irrigation type, precipitation rate, irrigation distribution, and irrigation efficiency to name just a few. Therefore, many growers are likely to make an educated guess based on the current wetness of their substrate, current weather conditions, and the weather forecast. Other nursery managers may choose a coarse substrate that will allow them to over-irrigate to ensure that the crop will not undergo water stress and have reduced growth. These are both suitable approaches when attempting to minimize crop risk; however, over irrigation is also affecting the cost to produce a containerized nursery crop. Excessive or unneeded irrigation leaches water and applied nutrients from the container, not allowing them to be utilized by the plant. In addition, over application of water results in longer pumping time (electric cost and pump wear), decreased access time for workers, and increased disease pressure. There is also an increasing concern nationally over water quantity with decreased ground-water supplies and competition for groundwater with urban areas.

As a rule of thumb, it is best to minimize water loss of overhead applied water via evaporation by watering predawn throughout the morning, or alternately water in late afternoon to an hour before dusk. It is best not to water near or after dusk to prevent possible increased incidence of pathogens. When using micro-irrigation, it is best to apply water when plants are actively transpiring from late morning to late afternoon. Micro-irrigation is commonly applied in split or cyclic applications (total volume to be applied divided by the number of events in one day). Split applications or cyclic irrigation, regardless if applied via overhead or micro-irrigation, increase application efficiency and decrease the potential for letting pockets of the substrate become hydrophobic or repel water. Ease and uniformity of substrate wetting can be further increased by the use of wetting agents. Furthermore, a rain event of ¼ to ½ inch should substitute for the next irrigation event. Irrigation systems should incorporate rain sensors to automatically alter irrigation schedule.

One of the oldest methods used to schedule irrigation is to simply pick-up containers to see their relative weight and determine if water is needed. In the past growers have taken it a step further by regularly measuring the weight of containers to determine if irrigation was needed. Consequently, the average increase in weight by measuring before and after the container is irrigated can also serve as a catch-can to make inference to the needed application rate to irrigate to container capacity. This is possible because 1 gram of water and 1 milliliter (mL) of water are equivalent.

Leaching fractions can also be used to schedule irrigation; however one should note that spatial variability, crop type and size diversity, and drastic weather changes will make any irrigation scheduling difficult. Leaching fraction as a tool for irrigation scheduling improves as the target and measured leaching fraction become more similar. A target leaching fraction can be subtracted from average measured leaching fraction per irrigation zone to determine the time adjustment (T_{adj}) for clocks as follows:

> T_{adj} = t (tLF – mLF) = clock time adjustment (min)
>
> Where t = water application time (min), tLF = target LF which is commonly between 0.2 and 0.4 and mLF = average measured leaching fraction
>
> If t (application time) = 90 min, tLF (target LF) = 0.4, and mLF (measured LF) = 0.65
>
> Then T_{adj} = 90 min (0.40 – 0.62) = -20 min, thus the new irrigation time would be 90 min – 20 min = 70 min

Guidelines for individual crop water use and relative crop evapotranpiration (water loss via evaporation from the surface of the substrate and water loss via transpiration from the plant) can be used to assist with irrigation scheduling. Plant water use can assist with grouping crops with similar water requirements. Estimated evapotranpiration can be used to make inferences into percent daily water use based on weather.

Table 4: Fraction of maximum crop evapotranspiration of 0.3 in of water per day from May to August in the Willamette Valley based on average daily temperature (Midnight to Midnight) and climate conditions (Adapted from a handout titled 'Estimated Daily Reference Crop ET' presented by Rich Regan, OSU Extension Horticulturist, at the Practical Nursery Irrigation Workshop held at the North Willamette Research and Extension Center in 2008.)

Climate Conditions (May to August)	Average Daily Temperature		
	55	65	75
Clear and Sunny	0.8	1.0	1.2
Partly Cloudy	0.8	0.8	1.0
Cloudy	0.6	0.8	0.8

This information can be used to make inferences to what fraction of the typical irrigation set needs to be applied or to make inference to on average how much water was lost by a crop and container over a typical day, respectively.

Table 5: Gradient of relative crop water requirements for container grown ornamental woody plants (Adapted from a handout titled 'Relative crop water requirements of container grown woody landscape plants' presented by Rich Regan, OSU Extension Horticulturist, at the Practical Nursery Irrigation Workshop held at the North Willamette Research and Extension Center in 2008.)

Relative Crop Water Requirements of Selected Containerized Crops During Production				
High	↔	**Medium**	↔	**Low**
Chamaecyparis pisifera		*Berberis thunbergii*		*Chamaecyparis obtusa*
	Cotoneaster dammeri		*Abies balsamea*	
Forsythia x intermedia		*Juniperus horizontalis*		*Daphne x burkwoodi*
	Juniperu procumbens		*Acer palmatum*	
Hydrangea macrophylla		*Picea abies*		*Juniperus squamata*
	Picea glauca		*Euonymus fortunei*	
Picea Pungens		*Rhododedron 'PGM'*		*Rhododedron* 'Ramapo'
	Rhododendron 'English Roseum'		*Ilex crenata*	
Prunus x cistena		*Thuga occidentalis*		*Tsuga canadensis*
	Rhododendron 'Girard's Fushia'		*Viburnum davidii*	

Scheduling Coefficient

After determining the water needed to apply, you can use a scheduling coefficient (SC) to adjust the application rate to ensure adequate water is applied. The scheduling coefficient uses catch-can volumes used to calculate application rate (AR_C) and/or uniformity. The scheduling coefficient (SC) is calculated as follows:

SC = V ÷ LV

If V (average cup volume) = (23 mL + 38 mL . . .27 mL + 32 mL) ÷ 40 cups = 30 mL and LV = (lowest catch-can volume) = 23 mL

Then, SC = 30 mL + 23 mL = 1.3 (unitless)

Lastly, SC is multiplied by your desired application rate or application time to ensure the entire area being irrigated receives the desired amount of water. Thus, if all containers need to receive 0.5 inches/hr one would need to water 78 min (60 min x 1.3 = 78 min) to ensure the least irrigated area in the zone receives the needed half-inch of water.

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We provide Irrigation Strategies to Conserve Water in Container Nurseries as an addendum to the Best Management Practices Guide for Climate Friendly Nurseries, a publication by the Climate Friendly Nurseries Project. For more information, and for updates and additions to this work, please visit the Climate Friendly Nurseries Project website at www.climatefriendlynurseries.org. Information included in this document will be further used to produce an Oregon State University Extension publication on the topic in Winter 2010.