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Leaching Fraction: A Tool to Schedule Irrigation for Container-Grown Nursery Crops

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Irrigation management of nursery crops grown in containers (fig 1.) can be difficult since many factors influence the decision of when and how much to irrigate. These factors include weather, substrate properties, crop water use, crop canopy, irrigation system performance, and water quality. In making the decision to irrigate, many growers rely on their experience with the crop and the substrate in which it is grown, current weather conditions, or forecasts. In the absence of experience, the irrigation program is usually based on a set schedule and volume to ensure crops are watered thoroughly, which is commonly too much. Overwatering avoids the risk of crops drying out but can lead to inefficient use of production inputs, including water and agrichemicals, as well as exacerbating pathogen problems in production.

Figure 1. Image of a Mid-Atlantic container nursery. (Photo by Matthew Sawyer, CEO of Bennett's Creek Nursery, Inc.)

leaching fraction noun

leach·ing frac·tion | \ˈlēch-iŋ \ ˈfrak-shən\

Definition: A measured loss of water and water-soluble minerals from the substrate of container-grown plants due to known amounts of irrigation. Leaching fraction is calculated as the ratio of water volume that leaches from a container to the volume of water applied by irrigation.

Root words: Leach: water or solution passed through a container. Fraction: numerical quantity of rational numbers represented by quotient that is produced by the division of two numbers.

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Soilless substrates have a relative high porosity and low water holding capacity when compared to soils. These physical properties allow growers to apply heavy and frequent irrigation to reduce the perceived risk of crop water stress or salt accumulation. Therefore, growers do not have to determine whether plants need irrigation because leaching is very high and the potential risks associated with overwatering are low. However, overapplication of water results in nutrients (and potentially pesticides and plant growth regulators) leaching from the container, longer pumping times (i.e., electricity cost and pump wear), increased use of chlorine and other water treatments, potential environmental impacts, and decreased access time for workers. Additionally, overirrigation often favors pathogens that cause root rot. While these inefficiencies may be less obvious than plants succumbing to insufficient water, overirrigation can negatively affect nursery profitability.

Monitoring leachate can be a helpful tool to successfully schedule irrigation and avoid the inefficiencies associated with overirrigation. Leachate — the volume of water that drains from a container after irrigation is completed — can be compared to the volume of water applied during an irrigation event. This ratio is called the leaching fraction. Leaching fractions can be used first to survey whether different taxa grown within a single irrigation zone are getting the appropriate amount of water and that information can form the basis for determining the appropriate amount of water to apply. By comparing the measured leaching fractions with the desired leaching fraction for that zone, producers can adjust the irrigation run time accordingly to apply the desired volume.

Monitoring leaching fraction and using it to manage salt levels in the container substrate solution is a particularly important use of leaching fraction when using saline irrigation water. Saline water can occur when using recycled water from runoff recycling systems, municipal tertiary treated recycled water, or poor-quality groundwater. Recycled water is lower quality water compared to potable water, and may include elevated salt concentrations. In addition, salt-water intrusion or leaching of salts into groundwater (e.g., tile drainage) can result in saline source water.

The objectives of this publication are to (1) describe irrigation scheduling and the factors that affect it, (2) explain the concept of leaching and methods for measuring leaching fraction and how to use that information to schedule irrigation, and (3) illustrate how to manage high salinity in irrigation source water through leaching.

Irrigation Scheduling

Irrigation scheduling determines both the frequency and volume of irrigation to apply to ensure that container-grown crops do not suffer from water stress or high salinity. This publication will first define the variables that affect irrigation scheduling and then describe two methods to measure leaching fraction. Both offer a low-cost means to schedule irrigation or control salt buildup from poor water quality using fewer inputs. As a result, growers will gain a valuable tool for irrigation scheduling that does not require specific information about weather, crops, available water, substrates, or irrigation systems.

Variables That Affect the Frequency and Volume of Irrigation

Irrigation scheduling must take into account the entire production system. Factors to consider include the performance of the irrigation system, the changes in day-to-day weather, water quality, substrate, and the crop(s) produced.

Irrigation System

An irrigation system applies water at a given rate (e.g., inches per hour) and at a certain level of uniformity within an irrigation zone based on irrigation design, maintenance, and routine audits. A system with poor uniformity does not apply water evenly over the entire irrigation zone. Growers typically compensate for poor uniformity by increasing the amount of water applied so that plants in drier spots receive a sufficient amount of water. Proper irrigation system design and maintenance along with periodic audits increases irrigation uniformity. When the irrigation system runs efficiently, the amount of time the system operates to irrigate or leach the crop can be minimized. Both water and energy are saved.

Weather

Daily weather drives crop water needs through water lost through transpiration and the evaporative losses from the soil surface (together, transpiration and evaporation are termed "evapotranspiration" or ET). High temperatures, high light intensity, low relative humidity, and wind increase ET rates causing water in the substrate available to plants to be depleted faster and irrigation to be applied more frequently.

Water Quality

The quality of the water used for irrigation can also affect the volume that should be applied to crops. The total salinity of the water, as measured by its electrical conductivity, and the crop sensitivity to salinity will directly affect the leaching fraction necessary to maintain salt levels within tolerable levels (table 1). As water is used by plants, salts are left behind in the substrate and are concentrated in the water that remains (fig. 2). Leaching is necessary to flush water from the container that has accumulated salts.

Table 1. Recommended leaching fractions (LF) to manage salinity of container media based on electrical conductivity of the water applied (EC_A). (Adapted from Evans [2017])

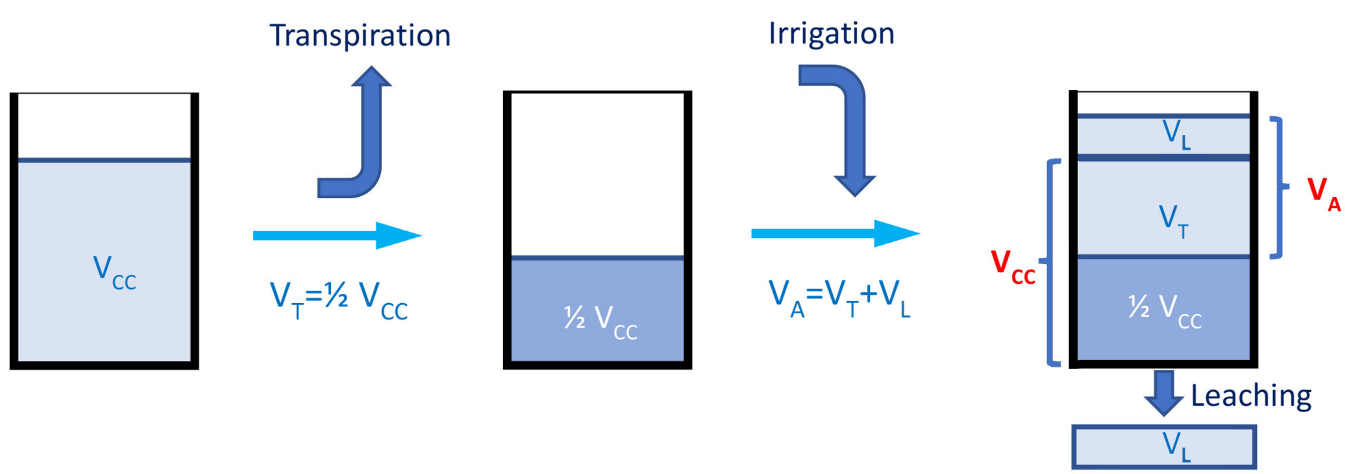
Electrical conductivity of applied water (EC_A; $dS \cdot m^{-1}$)	Leaching fraction (LF)
>2.0	0.3
1.5	0.2
<1.0	0.1

Crop Type

Water use and salinity tolerance differ among nursery crops. The volume of water needed is also influenced by the time of year because of crop growth patterns, daily changes in the weather, and ET rates. Furthermore, the size or location of the container, plant spacing, substrate used, plant canopy diameter and height, cultural practices (e.g., pruning), and use of plant growth regulators and fertilizers will affect water capture and use. Leaching fraction measurements allow growers to more finely distinguish the variation in plant water use across different taxa. For example, some plants will use less water than others; measurement of the leaching fraction will indicate this regardless of substrate, container, or weather. Using this information, growers are able to group plants into irrigation zones to more effectively minimize water application and agrichemical leaching and to increase oxygen availability to plant roots by not overwatering.

Measuring Leaching Fraction

Leaching fraction is a good indication of whether or not the volume of water applied through irrigation is reaching its intended target, saturating the substrate,



1. Container has just been irrigated, and the substrate is at container capacity (V_{CC}).
2. Water is lost through transpiration (V_T) and for this example is ½ of Vcc.
3. The water remaining in the container is ½ of V_{CC}.
4. Irrigation applies water (V_A) to replace transpiration losses (V_T) and the volume to be leached (V_L).
5. Since irrigation (V_A) applied more water than the substrate can hold (V_{CC}), excess water leaches (V_L) from the container and carries salts with it.

Figure 2. After irrigation, the substrate holds the maximum amount of water (V_{cc}). Irrigation replaces the water depleted from the substrate due to evapotranspiration (V_T). Additional water (V_L) also needs to be applied so that salts dissolved in the substrate water will be removed (leached) from the container. (Modified from Evans [2017] by L. Oki.)

and adequately leaching salts. Technically, the leaching fraction is the volume of water leached from the bottom of a container divided by the volume of water applied to that container (leaching fraction = water leached ÷ water applied).

Volume-Based Measure of Leaching Fraction

To measure the volume of water applied, an open container is placed near the plants being irrigated to capture the applied water. Place a similarly sized container (lined with plastic) or a bucket with tight seal under the test plants (figs. 3 and 4) to make sure that no water enters either the empty or planted container from the sides. One hour after the entire irrigation cycle is completed (e.g., if using cyclic irrigation, wait until the last cycle is complete), measure the volume of the water leached from the planted container and the empty container. From these two measurements, the leaching fraction can be determined. For example, if 1,000 mL of water is applied via irrigation (empty container) and 250 mL leaches from the bottom of the planted container, that is a leaching fraction of 0.25 (i.e., 25% of the total volume of water applied was leached from the container).

Crop Canopy Affects 'Capture Factor' During Irrigation

Crop canopy architecture can greatly affect leaching fraction when using overhead irrigation. Plants with a vase-shaped architecture (e.g., gardenia, witch hazel, cherry laurel) can act as funnels and capture more water than other crops by harvesting water that would otherwise fall outside the edge of the container. This results in more water directed toward the substrate than would otherwise fall there. Consequently, a volume-based leaching fraction can exceed 1.0, which is equivalent to capturing more than 100% of the water applied to an open container without a plant. Plants with umbrella-shaped canopies (e.g., cotoneaster, juniper, azalea) shed water away from the container, thus not capturing as much water as an open container without a plant. Leaching fractions will be reduced in this instance. When irrigating different plants within the same irrigation zone, growers can determine which plants are harvesting more, less, or the same amount of water as applied to that zone. Growers can regroup plants in the future according to canopy architecture and water use.

The volume-based method is a rough estimate of leaching fraction because the true volume of water entering the planted container is not known — only the

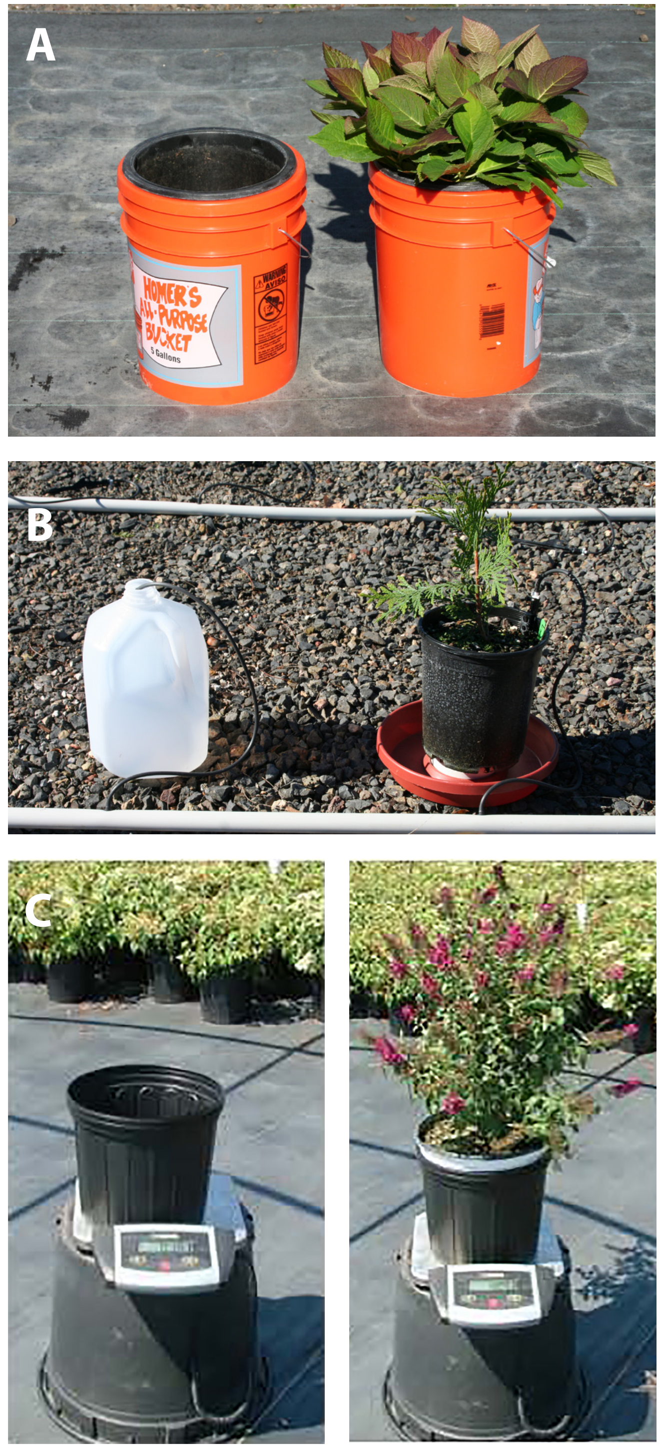


Figure 3. (A) Setup of empty, unplanted container (left) and planted container (right) nested in 5-gallon buckets with holes cut in the lids to measure volume-based leaching fraction. (B) Volume of micro-irrigation water applied by placing spray stake in a 1-gallon milk jug and placing the planted container on pipe ring in a plant saucer (right) to measure volume-based leaching fraction. (C) Weight measurement of solid (no drainage holes) container to catch leachate (left) and planted container nested in leachate-collecting container (right). (Images by Jim Owen [A, B] and Jane Stanley [C].)

Determining Leaching Fraction Using the Volume Method

1. Place container-grown plants snugly in similarly sized buckets to ensure all water applied to the plant must drain through the substrate and leach out the bottom of the container. If leak-proof buckets are not available, line a production container of the same diameter with a plastic bag.

2. Place a corresponding bucket or plastic-bag-lined container adjacent to each container used in Step 1. If using micro-irrigation, place emitter in a milk jug or rinsed bottle to capture all water applied (fig. 3a.)

3. Operate a normal irrigation cycle.

4. One hour after irrigation ceases, collect and measure water leached from containers with plants.

5. Measure water collected in the empty containers.

6. Calculate leaching fraction for each plant by dividing water leached (from Step 4) by the amount of water applied (from Step 5). Equation:

$$\text{Leaching fraction} = \frac{\text{planted container leachate (leached)}}{\text{empty container with water (applied)}}$$

amount that leaches out. Measuring leaching fraction using the weight-based method will measure the change in weight between irrigation events; thus, the difference is the volume of water applied to that plant. These numbers can also account for the effect of the canopy architecture on harvesting water, which is known as the "capture factor."

Weight-Based Measure of Leaching Fraction

A grower can calculate a leaching fraction, less than or equal to 1.0, accounting for the capture factor, by using an industrial or wash-down bench scale to measure leaching fraction via the weight-based method. In the metric system, 1 milliliter of water (1 ml) weighs 1 gram (1 g); therefore, when we measure a plant's weight in grams and then irrigate and re-weigh, the difference in weight (g) is the volume (ml) of water applied. Prior to irrigating, weigh the empty bucket or container manufactured without drainage holes (fig. 3c) that will collect the leachate and the planted container. Then, nest them, being sure there is a tight seal between the bucket and container sidewalls; this ensures that water only enters the bucket after it has infiltrated and flowed through the substrate. To ensure leachate is not reabsorbed by the substrate during the one hour that drainage is occurring after irrigation, a grower can place a spacer between the plant container and the container collecting the leachate. Initiate the irrigation event and wait one hour after irrigation ends. Unnest the containers and weigh the bucket with leachate and subtract its pre-irrigation weight to get the weight of just the leachate. Then weigh the planted container again and subtract its pre-irrigation weight to determine the weight of the water that was retained in the planted container. Add the weight of the leachate with the weight of the water retained in the planted container to determine the weight of the irrigation water that was applied. Calculate leaching fraction by dividing the weight of the leachate by the weight of the irrigation water that was applied.

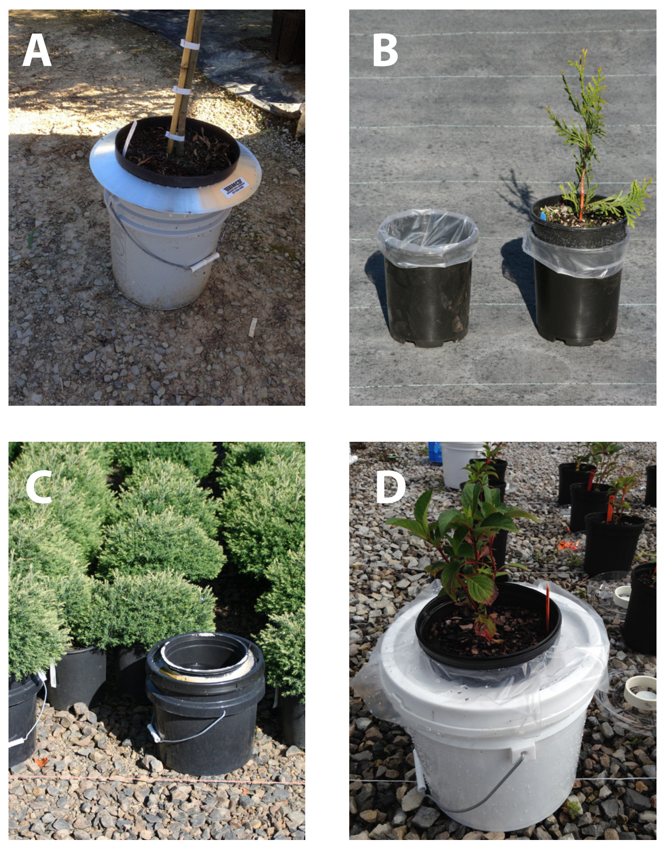


Figure 4. Photos illustrate (A) saucer, (B) plastic bag, (C) caulked bucket, and (D) plastic skirt method employed at nurseries to accurately capture water and leachate for small and large containers when using the volume-based leaching fraction method.

Determining Leaching Fraction Using the Weight-Based Method

1. Weigh an empty bucket that will capture leachate.
2. Weigh the planted container.
3. Nest the plant container inside the empty bucket.
4. Operate irrigation for a normal cycle.
5. One hour after irrigation ceases, unnest the containers.
6. Weigh the bucket with leachate and subtract the pre-irrigation weight in Step 1 to get the leachate weight.
7. Weigh the planted container and subtract its pre-irrigation weight (Step 2) to get the weight of the water retained in the container.
8. Add the weight of the leachate (Step 6) with the amount retained in the container (Step 7) to determine the total amount of irrigation water applied.
9. Divide the leachate weight (Step 6) by the weight of the total amount of irrigation water applied (Step 8) to get the leaching fraction. Equation:

$$\text{Leaching fraction} = \frac{\text{weight of leachate (leached)}}{\text{weight of water applied (applied)}}$$

Making Measurements Count

Measure as many plants as practical in each zone to estimate its average leaching fraction. Include a minimum of three plants across the irrigation zone in different areas such as near an irrigation riser and near the edge of a bed. By measuring several plants within the zone, a more accurate estimate of leaching fraction can be calculated. Try using different species as well, especially ones with different water needs, canopy types, and cultural practices (e.g., pruned or unpruned) within the same zone.

Measuring multiple plants of a single species will also allow you to make an inference about irrigation uniformity within a block of plants. If a large amount of variability occurs when measuring one species within a production block, the nursery manager should investigate if there are system inefficiencies. Inefficiencies can be caused by poor distribution uniformity, poor crop uniformity, and variation in potting practices that can affect how much water a container retains.

Measurements should be taken approximately one hour after an irrigation event or the last cyclic irrigation cycle on clear, sunny days with average or above-average temperatures. Avoid conducting tests after rain events that fully saturate substrates, as this does not mimic a normal irrigation event. These tips will ensure results that reflect maximum water use.

Leaching Fraction as a Tool To Adjust Application Volume

Leaching fraction measurements can be used to schedule irrigation. To do so, a grower must have first conducted a LF measurement during the previous irrigation event and calculated an average measured LF_M $[(LF_1 + LF_2 + LF_3 + LF_4) \div 4 = LF_M]$. This value is then compared against a grower-determined target, LF (LF_T), that is typically 0.15 (15%) to 0.30 (30%), based on irrigation system, desired moisture of substrate, and routine use or timeliness of using leaching fraction method to adjust application volume. Higher leaching fractions mean more water is being passed through containers, and thus, higher volumes of irrigation. LF_M is used to calculate the amount of time the irrigation clock should be adjusted (T_A) to achieve the target leaching fraction (LF_T) at the next irrigation (see example below). If LF_M is higher than LF_T, (i.e., more water is being leached from the bottom of the container than intended), the length of the next irrigation event should be reduced. This method works best when LF_M and LF_T do not differ widely, and continued use will improve LF-based irrigation scheduling. If LF_M and LF_T differ greatly or weather differs greatly from day to day, adjustments will need to be more frequent, and/or the calculated irrigation volume adjustments may be inaccurate.

When initially using leaching fraction for irrigation scheduling, maintain a high leaching fraction (approximately 0.5 [50%]) and evaluate two to four crops with varying canopy architecture and water requirements within a zone. In the beginning, measure leaching fraction frequently (approximately every two weeks) until a better understanding is developed of how water use increases as plants grow past the container edge through the growing season.

Once comfortable with managing irrigation based on leaching fraction, try reducing the leaching fraction to approximately 0.15 to 0.30 (15-30%) as suggested by nursery best management practices (Chappell et al. 2013). When maintaining a 30% or lower leaching fraction, the nursery manager will have to monitor more frequently to ensure that plants are adequately watered. It will be important to monitor electrical conductivity by using the pour-through method to ensure salts remains below damaging thresholds. When weather changes quickly, it can be difficult to maintain the target leaching fraction and keep plants watered adequately. For example, if unseasonably hot temperatures occur while plants are leafing out in the Southeast U.S., crop water use can change considerably in a short period of time.

Limitations

Caution should be used when scheduling irrigation using leaching fractions immediately after potting new liners into larger containers. Leaching fraction-based irrigation that is calculated before liners root out can result in overly wet growing conditions. This has been observed in taxa such as hydrangea, in which the plant roots will proliferate (pancake) at the surface rather than explore the entire container, causing issues throughout the production cycle.

A pitfall of using the volume-based method to schedule irrigation is that leaching fractions near or greater than 100% (1.0), as a result of capture factor, will provide incorrect time adjustments for the suggested duration of irrigation. In this situation, the length of time irrigation is applied and subsequent leaching fraction should be reduced at the grower's discretion until leaching is less than 1.0.

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

LF_M = average measured leaching fraction of the previous irrigation event

Example: If $t = 90$ min, $LF_T = 0.3$, and $LF_M = 0.65$,

then

$$T_A = 90 \text{ min} \times (0.30 - 0.65).$$

T_A = –31.5 rounding down to 31 min. Reduce the length of time the last irrigation event ran by 31 minutes.

Therefore, the next event will run for

$$90 \text{ min} - 31 \text{ min} = 59 \text{ min}.$$

To reach the target LF identified by the grower, run the irrigation system for 59 minutes. Check the leaching fraction again after approximately three to five days to ensure that the new target leaching fraction is achieved. After a few days of using this new regime, evaluate success and target level by measuring leaching fraction again on the same plants measured in the previous test.

Success Story

Saunders Brothers Nursery is a commercial wholesale nursery located in central Virginia with approximately 75 acres of container crop production (fig. 5). Facing economic pressures as a result of the 2008 recession, the nursery began to explore ways to decrease their inputs and production costs. By adjusting irrigation practices for all woody crops to yield a leaching fraction of 10-20%, Saunders Brothers Nursery reduced their water use in 2012 by an average of 43% over the previous three years. They made adjustments to irrigation based on both short-term (i.e., daily) and long-term (i.e., seasonal) changes in plant water needs. Short-term adjustments dealt with changes in water usage due to weather, specifically temperature, solar radiation, and ET. Long-term adjustments dealt with changes due to crop status, specifically spacing, pruning, and crop age. Through these approaches, the nursery recorded a decrease in chlorine and electricity usage. Also, reduced leaching of nutrients from excess watering, along with a drier substrate surface between irrigation events, decreased weed seed germination. The nursery was able to reduce fertilizer inputs by 25-35% for certain crops and lengthen time between herbicide applications. The cost per LF measurement was estimated to be $1.19 (based on Adverse Effect Wage Rate of $11.46 per hour and 2.5 person hours per week). The nursery measured eight zones each week (three measurements per zone for 24 total measurements) at an estimated annual cost of $1,490. Saunders Brothers estimated that reduced input costs and reduced plant losses due to improved irrigation practices have saved the company in excess of $70,000.

Figure 5. Satellite image of Saunders Brothers, Inc. container nursery from Google Earth. Downloaded Jan. 2019 from Google Earth.

Conclusion

Determining leaching fraction is a simple, quick, and inexpensive method to evaluate irrigation management. Monitoring leaching fraction allows nursery managers to gain insight on current irrigation practices that account for the production system (container, substrate, and plant), facility infrastructure (irrigation type), and management (application time). This measurement can be used effectively to manage irrigation, minimize runoff of nutrients and water, and consequently decrease the bottom-line cost of operating a nursery.

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