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Nursery Irrigation: A Guide for Reducing Risk and Improving Production

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1. INTRODUCTION

Water scarcity is a growing concern in the U.S. and beyond and is projected to become more severe. Competition for water exists among agricultural users, municipalities and industrial plants and is fueled by increases in population, urbanization of rural areas, increases in agricultural irrigation, climate change and salt water intrusion. Currently, many sources of freshwater in the U.S. are at risk of depletion. Careful use of freshwater is becoming increasingly important as a result of this trend (Figure 1).

Figure 1. Irrigation pond below desirable water level

Photo credit: Anthony V. LeBude

Agriculture, primarily irrigating crops, accounts for about 80% of ground and surface (consumptive) water use in the United States. As of 2013, over 55 million acres of U.S. land were irrigated. Irrigation water can be delivered through a variety of methods and each of these can vary substantially in their efficiency. Modifying irrigation systems and practices to use water more efficiently is becoming more important in the U.S. as increasing regulations continue to restrict water use, and droughts lead to depleted surface water and over-reliance on groundwater.

Water is essential to the survival of all types of plants. Water serves as a solvent to transport nutrients to cells and remove waste, maintains turgor pressure for physical structure, regulates temperature and supports photosynthetic reactions. Water management is crucial to the success of a nursery. In order to produce premium plants in a short amount of time, irrigation water must be managed to keep the container substrate moisture content at appropriate levels. Too much or too little irrigation can have negative consequences. Underwatering has traditionally been the greater concern to growers because of more immediate and obvious effects on plant appearance and growth. Water deficit elicits a number of responses in plants in an effort to conserve water. As plants become dry, the stomata begin to close and cellular growth slows. If water stress is not alleviated, photosynthesis will cease and the plant will stop assimilating carbon from the atmosphere into plant tissue; normal metabolism will also be disrupted. Because of these responses, plants experiencing water stress will be smaller, look less attractive and may require a longer growing period resulting in greater inputs and reduced nursery profits (Figure 2).

Figure 2. Underwatering has dramatic consequences

Managing irrigation systems to avoid water deficits can lead to wasteful overwatering practices (Figure 3). In addition to the wasted water, too much irrigation can create a good environment for disease proliferation (especially root rots) while making plants less resilient to stress. This can directly lead to smaller, less robust root systems (Figure 4). Overapplying water has some other unintended consequences that are becoming more appreciated in nursery crops production. For example, overirrigating can lead to excess leachate from the container. Leachate can carry away nutrients from fertilizer and active ingredients from pesticides and other chemicals, leaving crops at risk for nutrient deficiencies and pest damage. Fertilizers, plant growth regulators and pesticides may need to be applied more frequently or at higher rates when overwatering increases leachate above recommended rates.

Figure 3. Overwatering can cause nutrients and pesticides to leach from containers, create worker safety issues and reduce plant quality and health

Figure 4. Root rot from overirrigating

There is also concern that leached agrichemicals could contaminate both natural waterways and water that is retained on site and applied to crops. All of these factors give growers an incentive to take a close look at issues surrounding access to water, future competition for water, the true cost of over- and underirrigating and risk due to drought and other causes of an inadequate water supply.

CURRENT TENNESSEE WATER REGULATIONS

California, Florida, North Carolina, Oregon, Texas and other states currently have regulations that limit the amount of water nurseries can consume. Tennessee, however, has enjoyed a relatively stable and adequate water supply and therefore does not (as of yet) have strict water laws. Tennessee water laws are based on traditional riparian rights that give landowners the right to use any body of water on or adjacent to their property. However, this does not mean that a landowner owns the water. Unless there is surface water (a pond, lake, etc.) that is confined to a single property and not fed by a groundwater source (spring or aquifer), all water within the borders of Tennessee is owned by the state of Tennessee. Water is shared among all landowners surrounding or above a water source. Rights to the water are equal regardless of the size of the land owned, number of years owned or the length of waterfront property. Water can be pumped from a source as long as it does not limit or injure a neighbor’s ability to use the water source (Figure 5).

In Tennessee (with the exception of Shelby county), no special permit is required to drill a well, but it must be installed by a licensed contractor following Tennessee Department of Environment and Conservation's (TDEC) Division of Water Supply (DWS) rules and regulations. While it was once okay to notify the government within 60 days of a well's construction, now a well owner or the driller acting on behalf of the owner must notify the TDEC commissioner prior to a well's installation.

Figure 5. Tennessee waterways adjoining a property may be used for irrigation

While there are intake methods that do not require a structure, building an intake structure to withdraw water from public surface water sources such as streams, rivers or lakes may require a special permit from the Aquatic Resource Alteration Program (ARAP) (Figure 6). These regulations were established to prevent the building process or structure from disrupting the water quality, flow rate, water level and/or ecology of the resource. Before construction can begin, an application must be filed stating the proposed withdrawal rates and withdrawal schedule. Depending on the source, maximum withdrawal rates may be set. Certain sources may even have a minimum water level at which no withdrawals may be made. These regulations protect the future of these natural resources and the businesses that rely on them.

Figure 6. In Tennessee, special permits may be required to use a public waterway in any way that may stir up sediment

EPA-USDA WATER QUALITY TRADING INITIATIVE AND FUTURE WATER REGULATIONS

In 2013, the U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) became partners in promoting water quality trading and other market-based approaches that recognize the value of water quality benefits that are created on forests and farms. Water quality markets provide a financial incentive for conservation practices that improve soil and protect water resources. The underlying principle behind water quality trading is that sources of pollution in a watershed encounter different costs associated with controlling that pollution. A water quality trading program allows an entity to purchase the environmental equivalent or (better) pollution reductions from another entity who can achieve these reductions at a lower cost. The end result is that the water quality goals are met but at a lower cost. The goal behind the joint USDA and EPA agreement is that water quality is improved in a way that also benefits companies and agricultural enterprises economically (Figure 7). The program is being supported by Conservative Innovation Grants.

Figure 7. Water quality trading can create partnerships between the agriculture community and other water consumers

Athough Tennessee currently has a sufficient water supply, water use within the state has been increasing. Between 2007 and 2012, the number of irrigated acres in Tennessee increased by almost 80 percent. As this number continues to increase, so too may the need for water regulation. The rest of this guide provides strategies and techniques to reduce risk related to water quantity and quality with the goal of helping Tennessee nurseries remain competitive while becoming more sustainable.

Success Story

The Switch to Drip Saved Water and Fertilizer

J. Frank Schmidt and Son Nursery

J. Frank Schmidt and Son Nursery relied exclusively on overhead irrigation to provide water to their field grown liners. They hand moved lines from field to field to permanent risers. Between the inherent inefficiency of overhead irrigation systems, minimum wage increases, overtime needed by the irrigation crew, safety concerns from moving heavy pipes with wet, slippery surfaces and water quality decline in certain wells, it became logical to consider changing to drip irrigation. So, Sam Doane, Production Horticulturist at J. Frank Schmidt and Son Co., prepared a labor savings analysis for the owners that showed the return on investment for the infrastructure expense was two years, what previously required 16 people could now be done by three workers, and by the end of the third year water use would decrease 30 percent! Sam began converting the Canby, OR farm to drip irrigation. By switching to subsurface drip, Sam noticed that the application was much more efficient. The next step was to develop an irrigation program suited to this more efficient delivery. Sam worked with Rich Regan at Oregon State University to use soil moisture sensors that provide real-time measurements and to develop crop coefficients in order to determine how much water the plants needed. They currently use 10-HS and GS1 soil moisture sensors with Em50 data loggers (Decagon Devices, Inc.) as the basis for irrigation decision making. By using several probes at each location, this equipment provides volumetric water content (VWC) of the soil at different depths. Instead of using the numerical values for VWC, Sam has found that monitoring trends is far easier and just as reliable. To use the sensor readings as absolute values (irrigate when the soil reaches a certain VWC) each sensor would need to be calibrated to the unique physical properties of the soil. By using relative comparisons over time, Sam is able to see when peak water uptake occurs (the probe readings are going from higher to lower VWC over time) at each depth and when water uptake slows (probe readings are relatively stable over time). Decreasing water uptake implies that the soil is drying (or that the plant is done growing or the root has died) and signals the need for irrigation.

Previously, J. Frank Schmidt and Son had switched from broadcast to banded fertilizer applications to conserve fertilizer. While converting to drip irrigation presented a challenge for watering in a granular fertilizer application, it opened the door to a new possibility. Sam could deliver fertilizer right to the root zone by injecting fertilizer through the drip irrigation system. By simultaneously irrigating and fertilizing, J. Frank Schmidt and Son Nursery lowered overall fertilizer use by 30 percent! Sam calculated that the return on investment of adopting fertigation was less than a year!

Success story provided by Sam Doane, J. Frank Schmidt and Son Co.

For more information see: http://c.ymcdn.com/sites/www.oan.org/resource/resmgr/imported/pdf/JFankCaseStudy.pdf

2. WATER SOURCES

Water sources for agricultural production in Tennessee include municipal water, well water and various types of surface water. The characteristics of these sources of water are diverse and pose unique benefits and challenges.

MUNICIPAL WATER

Municipal water is generally one of the more expensive primary sources of irrigation water. However, it is a good option if property is without a good ground or surface water supply. Municipal water is treated for human consumption, contains little to no contaminants and generally does not contain sediment (Figure 8). As a result, less filtering and maintenance are required and it rarely clogs irrigation lines or nozzles. This source is frequently used as a backup or secondary source of water because it is expensive but typically reliable.

Figure 8. Municipal water can be a good option for small nurseries

GROUND WATER: WELLS

If there is a good groundwater source on the property, drilling a well may be very advantageous. Wells are typically more expensive to install than surface water pumps but are inexpensive to operate once installed. However, if the water level in the well is low, sediment from the bottom may cause lines or emitters to clog, increasing maintenance expense.

Additionally, if a water shortage did occur, the groundwater may not have time to recharge between irrigation events, in which case an alternative water source would have to be used to irrigate.

SURFACE WATER: PONDS/RIVERS/CREEKS

In order to use surface water sources, a body of water must be on or adjacent to your property (Figure 9). More regulations apply to pumping water from a public surface water source than pumping groundwater and a permit may be needed to build an intake structure. However, once the water intake system is established, the cost of using the water is relatively low as it typically only involves the energy cost to run the pump and irrigation system. Sediment from surface sources may clog pumps, irrigation lines and emitters, as well as generally increase wear on irrigation system parts and thereby increase maintenance costs. Water from surface sources may contain plant or animal pathogens or other contaminants such as agricultural pesticides, sewage or weed seeds.

Important Things to Keep in Mind:

Having access to only one type of water source increases the risk that a nursery will run out of water.

Having a backup water supply such as a storage tank, reservoir, or city water will decrease a nursery's risk.

Consider investing in back-up pumps and generators in case of an emergency.

Figure 9. Ponds can be a great source of irrigation water

Success Story

A Twist on Leaching Fraction Leads to Nursery-Wide Savings

Saunders Brothers Nursery

Efficient use of water affects a nursery's bottom line as irrigation costs and managing irrigation contribute considerably to operating costs. In addition, environmental regulations are increasing, requiring more record keeping of water consumption, and in some cases limiting agricultural water use. With this in mind, Saunders Brothers set out to refine their irrigation scheduling. In March 2012, they began measuring leaching fraction of their woody crops throughout their 75 acres. Leaching fraction is the amount of water drained divided by the amount applied. It is an easy, practical way to fine tune irrigation applications to the needs of the crop. Leaching fraction is often done by collecting the volume of irrigation and leachate. Saunders Brothers took a novel tactic and used weight to measure both leachate and irrigation volume, using the fact that one milliliter=one gram*. The advantages of this were that they could take leaching fraction measurements in plants spaced pot-to-pot and that capture factor was accounted for. Capture factor refers to branch architecture characteristics that channel water to the root zone that would not fall directly into the pot. Using an empty container to measure irrigation can cause artificially high leaching fractions because this does not account for capture factor. They checked 3 plants in each house every 3 weeks. By adjusting their irrigation to a leaching fraction of 10-20 percent, they were able to decrease the volume of water used (and chlorine) from April to August an average of 43 percent compared to their most recent 3-year average.

Because they irrigated more efficiently, they leached less fertilizer from the container, which has since allowed them to decrease fertilizer applications by up to 1/3 on some crops. After experiencing the benefits of a leachate based program at Saunders Brothers Nursery, Tom Saunders puts it this way, "To be honest, I cannot understand why all nurseries would not start irrigating using this type of technology."

*Plants were weighed before and after irrigation. The change in weight was the water applied.

Success story provided by Tom Saunders and Jane Stanley, Saunders Brothers Nursery and Tom Yeager and Jeff Million, University of Florida, IFAS

For more information see: Using Leaching Fractions to Maximize Irrigation Efficiency© by Jane Stanley. 2012 Proceedings of the International Plant Propagators' Society. Pages 331-334.

3. WATER TESTING

Testing irrigation water helps determine if a water supply is suitable for irrigation. Understanding the composition and/or contamination of a nursery's irrigation water can help prevent several problems, including those associated with pH and salinity. When using a new water source, it is particularly important to collect samples several times a year for the first few years. These early test results will set a benchmark and help detect fluctuations and problems in future years, such as chemicals leaching into the water. Afterwards, water should be tested at least yearly, if not seasonally.

Nursery growers in areas where industrial development and other land use changes have taken place have found it helpful to have baseline readings from previously conducted water quality tests and have also benefited from routine monitoring to detect changes from the established level of water quality. If you rely on a river or creek, routine monitoring above your intake pipe can help establish the quality of water received and document if changes upstream are impacting your water quality. Likewise, testing downstream of the nursery can also be helpful in establishing to your neighbors that you are not creating a water quality problem (Figure 10).

Figure 10. Sample water to test quality in a river or creek both above and below a nursery

When testing a river or creek, timing in relation to rainfall is important. Keep in mind that testing at the point of first flush (first rain after a dry spell) will result in higher levels of contaminants than testing during dry weather or at the end of a few days of rain. When testing, consider recent weather and document it along with the results. Ideally, schedule sampling to occur under relatively similar conditions with respect to when precipitation last occurred.

COLLECTING WATER SAMPLES

For all water sources, rinse a pint-sized, plastic container, such as a Nalgene bottle, three times with the irrigation water. Next, fill completely, and seal with the lid while the bottle is underwater to prevent air bubbles. Use a sterile bottle if testing for biological contaminants. Resample if air bubbles or debris are trapped in the bottle. It is best to send the sample to a lab immediately, but if that is not feasible, the sample should be refrigerated and tested within 24 hours. Some labs provide collection bottles.

- **Surface water**: Collect from below the surface of the water but not so deep as to capture debris from the bottom; submerge bottle upside down, then turn upright to collect water
- **Well water**: Run irrigation for five minutes, then collect water
- **City water**: Municipal water data can be found online or follow instructions for well water

WHERE TO SEND SAMPLES

There are several labs in Tennessee and around the country that conduct water quality tests. However, many of these labs test for drinking suitability only and may not conduct tests specific to irrigation water quality, such as those that detect salinity and nutrient levels. Labs that specifically test irrigation water include:

- Waypoint Analytical: http://waypointanalytical.com
- Penn State: http://agsci.psu.edu/aasl/water-testing/irrigation-water-for-nurseries-and-greenhouses
- AgSource Laboratories: http://agsource.crinet.com/page5632/IrrigationWaterTesting
- Brookside Laboratories, Inc.: http://www.blinc.com/plant.htm

HOW TO INTERPRET WATER TEST RESULTS

A great place to start is your county extension agent, or your area or statewide nursery, irrigation or water quality specialist. Utah State University Extension has a very informative website: http://extension.usu.edu/waterquality/htm/wqtool. When test results are entered, this website contains information about whether the results are in the proper range for irrigating crops.

WATER PH

pH is a measure of relative acidity or basicity as indicated by the hydrogen ion (H^+) concentration of a solution. Water pH influences soil and container substrate solution pH and is a major concern in container production because soilless substrate is often less complex than soil (lacks ions that would buffer the pH by attaching to free H^+ and OH^-). Therefore, container production is generally more susceptible to fluctuations of pH caused by irrigation water. Substrates high in perlite, sand and other inert particles are especially susceptible to pH fluctuations.

Changes in pH can cause nutrients in the substrate to become unavailable to the plant (see table), thus hindering growth and/or plant health (Figure 11), and in the case of *Hydrangea macrophylla*, changing flower color. High pH (basic) water can cause soluble fertilizer to precipitate (solidify and thus become unavailable to the plant) and also reduce the efficacy of some chemicals (e.g. pesticides and growth regulators). Low pH (acidic) water can cause equipment to corrode and some pesticides to have reduced efficacy. Either problem can lead to higher maintenance and pesticide costs. Water pH also influences how effectively certain water treatments, such as chlorine, work.

Figure 11. Changes in pH can cause nutrient deficiencies

- pH scale is 0 to 14
  - ∞ 0 (more acidic)

7 (neutral), 14 (more basic or alkaline)

- A pH of 7 is neutral, but the ideal irrigation water pH is dictated by the crop
    - ∞ Between 5.4 and 7.0 is generally desirable for nursery crop irrigation water
        - -- Between 4.5 and 6.5 is generally desirable for substrate solution
- Monitor pH periodically with a meter or litmus paper
- Adjusting the buffering capacity of the substrate can help resolve pH issues
    - ∞ Often easiest to lower the pH by reducing or even eliminating the lime in container substrate, depending on the individual crop
    - ∞ Raise pH with lime or base-forming fertilizers such as calcium nitrate
    - ∞ Lower pH with acid-forming fertilizers such as urea and/or sulfur-coated fertilizers
    - ∞ If substrate is commercially blended, discuss current problems with your sales representative to see if they can offer a substrate more suited to your needs

Effect of pH on Plant Nutrient Uptake			
Low pH		High pH	
Increases uptake of:	*Decreases uptake of:*	*Increases uptake of:*	*Decreases uptake of:*
Iron	*Molybdenum*	*Molybdenum*	*Iron*
Manganese	*Calcium*		*Manganese*
Zinc	*Magnesium*		*Zinc*
Copper			*Copper*
			Boron

Adapted from Bailey et al. 1999

However, just knowing the pH is not enough to manage irrigation water for a crop. Understanding alkalinity and its role in managing pH is crucial.

ALKALINITY

Alkalinity is an indication of a water supply's ability to neutralize acids. A water source's alkalinity is a measure of how easy or difficult it will be to change the pH of that water. It also describes the water's ability to act as a pH buffer in the soil or container substrate. The term alkalinity is not the same as alkaline, which refers to a pH greater than 7. In areas where there are limestone formations, like much of Tennessee, high alkalinity is most likely caused by high bicarbonate and carbonate ions. Hydroxide ions, ammonia, borates, organic bases, phosphates and silicates are all minor contributors to alkalinity (Figure 12).

- High alkalinity: water may increase the pH of the soil or container substrate solution
- Low alkalinity: water may not buffer acidic fertilizers, which will decrease the pH of the soil/substrate solution
- The more substrate in a container, the more tolerant the plant is to high alkalinity

Figure 12. Seedlings and plugs are particularly sensitive to alkalinity

- Field production is less susceptible to alkalinity problems
  - Saline soils can also have high alkalinity due to sodium carbonates, which can influence the alkalinity of the soil water solution
    - In this situation, don’t allow plants to become dry
    - The combination of high salt and alkalinity is more harmful to plants than salinity alone
- Neutralize water alkalinity with acid; common acids used include sulfuric, phosphoric, nitric and citric
  - Injecting acid is a complex and potentially dangerous process; consult a professional
  - Calculators for determining the amount of acid to add include:
    - NC State University Alkalinity Calculator http://www.ces.ncsu.edu/depts/hort/floriculture/software/alk.html
    - University of New Hampshire Alkalinity Calculator - ALKCALC https://extension.unh.edu/Agric/AGGHFL/alk_calc.cfm
- An alternative would be to change or blend water sources
  - Rain water, ponds and water purified with reverse osmosis often have little, if any, alkalinity
  - These sources can also be blended with the current water source to minimize some of the alkalinity issues

Alkalinity Guidelines for Container Production (meq/L)	
Plugs or seedlings	*0.75-1.3*
<4” pots or shallow flats	*0.75-1.7*
4-5” pots or deep flats	*0.75-2.1*
>5” pots/long-term crops	*0.75-2.6*

Adapted from UMass Extension 2014

WATER SALINITY

Water salinity is a measure of the total dissolved salts in the water. A primary cause of salinity is excess sodium (Na), but other salts contribute to salinity as well. We can easily measure electrical conductivity (EC) of irrigation water or substrate solution with an EC meter to estimate salinity. Relatively speaking, pure water is a poor conductor of electricity while the more salty water is, the better electrical conductor it is (Figure 13). Using this method, the source(s) of the salinity is not known.

Figure 13. Use an EC meter to estimate water salinity

- High salinity can lead to reduced seed germination, root development, growth and plant establishment
- Excess salt may pull water from plant roots, resulting in root death and inability of the plant to absorb water
- When irrigation is applied by overhead sprinklers, excess salinity can lead to foliage damage

- Irrigation water with greater than 1 mS/cm for seedlings and plugs and 1.5 mS/cm for field crops is considered to have a high salinity level (measured before any additives such as fertilizer)
- Underirrigation can cause salt buildup in the substrate due to inadequate leaching

Strategies to mitigate irrigation water salinity in container production:

- Increase irrigation to keep the salts in the soil/substrate solution and allow plants to uptake water
- Reduce fertilizer rates and use less soluble fertilizer
- Use fine-textured substrate
- Switch to plants that tolerate moderate to high levels of salts (Figure 14)

High salt levels are not common in Tennessee soils. However, if it becomes a problem, growing salt tolerant crops is one management technique. For more information on managing high salt levels in soil, contact your county extension agent or statewide extension specialist.

Figure 14. Roses **do not** *tolerate salinity well and may need to be watered from an alternate source*

PLANTS THAT TOLERATE HIGH LEVELS OF SALTS (UP TO 8 MMHOS/CM):

- *Acer buergerianum, A. campestre*
- *Cortaderia selloana*
- *×Cupressocyparis leylandii*
- *Gleditsia triacanthos*
- *Hedera helix*
- *Juniperus procumbens*
- *Picea pungens*
- *Pinus nigra*
- *Platinus ×acerifolia*
- *Pyrus calleryana*
- *Quercus robur, Q. rubra*
- *Salix babylonica*
- *Salvia spp.*
- *Taxodium distichum*
- *Vinca major*

PLANTS THAT HAVE A MODERATELY HIGH TOLERANCE (UP TO 6 MMHOS/CM):

- *Achillea spp.*
- *Artemesia stelleriana*
- *Asclepias tuberosa*
- *Coreopsis grandiflora*
- *Forsythia ×intermedia*
- *Juniperus chinensis, J. communis, J. conferta, J. horizontalis, J. virginiana*
- *Myrica pensylvanica*
- *Parthenocissus quinquefolia*
- *Pinus sylvestris, P. thunbergii*
- *Populus deltoides*
- *Sedum spp.*
- *Thuja occidentalis*

PLANTS THAT ARE INTOLERANT AND MAY NEED TO BE DISCONTINUED OR WATERED FROM A DIFFERENT SOURCE:

- *Abelia ×grandiflora*
- *Acer rubrum, A. saccharinum*
- *Aesculus spp.*
- *Betula nigra, B. pendula*
- *Buddleia davidii*
- *Buxus sempervirens*
- *Cedrus atlantica, C. deodara*
- *Cornus mas*
- *Corylus avellana*
- *Crataegus phaenopyrum*
- *Dianthus barbatus*
- *Diospyros virginiana*
- *Euonymus alatus*
- *Fagus sylvatica*
- *Fraxinus americana*
- *Ginkgo biloba*
- *Ilex opaca*
- *Juglans nigra*
- *Koelreuteria paniculata*
- *Lagerstroemia indica*
- *Lantana spp.*
- *Liriodendron tulipifera*
- *Mahonia aquifolium*
- *Nandina domestica*
- *Ophiopogon japonicas*
- *Ostrya virginiana*
- *Pachysandra terminalis*
- *Picea abies, P. glauca*
- *Pinus strobus*
- *Plantanus occidentalis*
- *Prunus tomentosa*
- *Quercus bicolor*
- *Rhododendron spp.*
- *Rosa spp.*
- *Sorbus aucuparia*
- *Tilia americana, T. cordata*
- *Tsuga canadensis*
- *Ulmus americana*
- *Vinca minor*

Adapted from Costello et al. 2003

NUTRIENTS

Nutrients from agricultural and urban areas can easily enter water sources in runoff. Sometimes soluble nutrients are added to irrigation water to fertigate. Regardless of the origin, irrigation water containing nutrients can cause problems at the nursery. Nutrients can clog emitters, reduce a plant’s ability to absorb other nutrients and leave a residue that blocks sunlight, reducing photosynthesis and typically rendering plants unmarketable. Below are descriptions of nutrient-related issues and tips on how to diagnose and manage them.

Although nutrients may be listed on the water test results, do not make fertilizer decisions based on them. Instead, use results from both soil/substrate and plant tissue tests to understand nutrient levels in the root zone and what plants are able to take up.

High Iron Levels in Irrigation Water:

The appearance of a red-brown residue on leaves is a relatively common problem. This rust-colored residue is iron and it can be a problem in quantities as little as 0.1 ppm (Figure 15).

Figure 15. Iron in water can leave a residue on plants as well as the greenhouse structure

To alleviate this problem:

- Pump water into a containment pond before use, allowing some of the iron in the water to settle
- Ensure that the irrigation intake is at least 18 inches below the surface to prevent vortices that may stir up settled iron and other sediment
- Position the intake so that it is not close to the bottom of the pond to avoid pumping iron sediment

A related problem causes a bluish bronze sheen on leaves. This discoloration is caused by iron-fixing bacteria and can be a problem when well and pond water are used. Iron-fixing bacteria prevent iron in the water from precipitating so this is a more difficult problem to address.

- Ensure that the irrigation intake is at least 18 inches below the surface as more bacteria are at the surface
- An aeration pump in pond water will aid in oxidation and cause iron to precipitate, decrease the bacteria population and move bacteria to the edges and coves, away from the intake; follow with filtration
- If aeration doesn't work another option is injecting a sanitizing agent, such as chlorine, to oxidize the iron

Improving Water Quality Through Aeration

Several nutrient issues can be prevented by aerating a water source. Aeration provides oxygen to fish and aerobic bacteria that break down organic compounds and excess nutrients. Water plants, surface aerators and natural water movement all aerate surface water. Jet or bubble aeration systems may need to be installed to aerate well and deep surface water.

causing it to precipitate; follow with filtration

- ∞ Injecting chlorine eliminates both rust and blue bronze deposits on leaves; filter the precipitating iron before water reaches irrigation lines or else risk clogging, especially in drip systems (Figure 16)

Figure 16. Iron deposits can easily clog an irrigation or a mist system

Calcium in Irrigation Water

In areas where limestone is prevalent, there may be large amounts of calcium dissolved in irrigation water. Once in the irrigation system, calcium may precipitate as calcium carbonate, harden and clog nozzles, emitters and irrigation lines.

- Injecting acid into the irrigation water prevents calcium from precipitating out of the solution, allowing it to pass easily through the irrigation system
- It is much easier to prevent clogs than it is to fix them once the calcium carbonate has hardened; this is another benefit of water quality testing on a regular basis

Other Nutrients

These nutrients can occur above recommended levels in irrigation water causing problems.

Problematic Nutrient Levels in Irrigation Water				
Nutrient	Concerns	No Problem (ppm)	Increasing Problem (ppm)	Severe Problem (ppm)
Copper	Unattached ions are toxic to most plants	<0.2	0.2-5.0	>5.0
Magnesium	Ions bind with calcium ions to form lime deposits, contributing to hard water and salinity problems	<20	20-40	>40
Manganese	Coats leaves, decreasing plant photosynthesis	<0.2	-	>0.2
Potassium	Increases the K concentration in plant tissue, leading to a decreased ability of the plant to take up other nutrients	<20	20-50	>50
Sulfate	Contributes to salinity, reduces growth and can cause plant damage	<100	100-200	>200
Sodium	Causes leaf burn and increases corrosion rates	<70	70-200	>200

Adapted from UMass Extension 2014

DIAGNOSING CLOGGED EMITTERS

Why do emitters clog? Micro-organisms, poor water quality and sediment can all lead to clogged emitters (Figure 17).

Figure 17. Sediment in Irrigation lines

The following table is a quick diagnosis guide for determining the cause of clogged emitters.

Problematic Nutrient Levels in Irrigation Water	
Cause	Signs, Diagnosis, Treatment
Biological	Slimy organic substance. Sanitizing agent may be needed. Treat irrigation system from the point of contamination through end of lines or problems will re-occur.
Chemical	Hardened residue/buildup, often light in color. Soaking in vinegar may dissolve the nutrients that have solidified. Send the solution to a lab to identify the specific cause and treatment.
Sediment	Fine particles. Soaking in water will cause particles to settle to bottom of the container. Improve water filtration system.

Adapted from “Designing an Effective Water Treatment System” presentation by Dr. Paul Fisher at the It’s All About Water And Increasing Your Bottom Line Conference, July 28, 2015, Grand Rapids, Michigan.

Success Story

Saving Water, Increasing Plant Survival by Refining Container Substrate

Holly Hill Farms

Holly Hill Farms had to irrigate their container nursery constantly to keep the plants from drying out, driving up pumping costs and management time. *Rhododendron, Kalmia, Leucothoe* and *Pieris* were particularly troublesome. They sometimes experienced a 50 percent loss with *Rhododendron*. Why? Brothers David and John Farrow determined that the problem was their very porous substrate (nearly 100 percent pine bark and a small percentage of sand). While it had served them well previously in preventing black root rot of hollies, it was time for a change. Their porous substrate dried out quickly, causing their irrigation pump to run all day just to keep up. They turned to Andrew Ristvey, Extension Specialist with the University of Maryland. Andrew helped Holly Hill Farms develop a new substrate with higher water holding capacity and less air-filled porosity that allowed them to better manage their irrigation timing. In just one year, Holly Hill Farms reduced its pumping time from 10 to 8 hours per day, which decreased electric bills by 7-8 percent, reduced its labor cost as John didn't need to monitor container moisture levels as closely and minimized the need for irrigation while overwintering. In the new substrate, plants also develop roots and establish faster, making them marketable sooner. Another benefit to increasing the substrate moisture retention was reducing nutrient loss through leaching, which improved nutrient management and reduced fertilizer expenses. And because they no longer have to constantly run irrigation within their current production area, they will now be able to expand production. The Farrows were awarded the Conservation Operation of the Year from their Soil Conservation District in 2010 and certified as an Agricultural Conservation Steward by the Farm Stewardship Conservation and Assessment Program of the Maryland Association of Soil Conservation Districts in 2015 for their dedication and hard work to protect natural resources. Holly Hill Farms is the first nursery certified as an Agricultural Conservation Steward!

Note: While changing the substrate was the right decision for this nursery, it is a big change that should be closely weighed. Changing the substrate affects both nutrient and water management.

Success story provided by David and John Farrow, Holly Hill Farms and Andrew Ristvey and John Lea-Cox, University of Maryland

For more information see: http://www.cecilscd.com/2010copyr.htm

4. CULTURAL PRACTICES THAT CAN REDUCE WATER USE

There are many strategies that can improve irrigation efficiency and decrease water use before the irrigation system is turned on. These include grouping plants according to water needs, adjusting plant spacing and selecting the proper substrate.

PLANT WATER REQUIREMENTS

Different plant species use different amounts of water. Grouping plants that have similar water needs into different irrigation zones and irrigating accordingly is one way to conserve water (Figure 18).

- Smaller containers dry out more quickly and need to be watered more often than larger containers
- Larger plants generally require more water per irrigation event than smaller plants; however, larger containers can retain more water between irrigation events

Figure 18. Succulents have similar water needs and thus should be grouped together

Although plant size does influence water use, judging a plant's water use based upon its size alone could lead to under- or overwatering.

PLANTS WITH HIGH WATER REQUIREMENTS

- *Acer rubrum*
- *Betula spp.*
- *Cercis canadensis*
- *Cotoneaster spp.*
- *Eupatorium purpureum*
- *Hibiscus rosa-sinensis*
- *Hydrangea macrophylla*
- *Impatiens hybrids*
- *Juniperus virginiana*
- *Lagerstroemia indica*
- *Rhododendron spp.*
- *Salix spp.*
- *Vitex agnus-castus*

PLANTS WITH LOW WATER REQUIREMENTS

- *Ajuga reptans*
- *Aucuba japonica*
- *Bougainvillea glabra*
- *Carpinus caroliniana*
- *Cornus spp.*
- *Euonymus japonicus*
- *Gelsemium sempervirens*
- *Hedera helix*
- *Ilex vomitoria*
- *Juniperus horizontalis*
- *Juniperus squamata*
- *Lantana camara*
- *Lonicera sempervirens*
- *Mahonia bealei, M. fortunei*
- *Ophiopogon japonicus*
- *Photinia ×fraseri*
- *Prunus caroliniana*
- *Rhaphiolepis spp.*
- *Tilia spp.*
- *Vaccinum spp.*

For plants not listed above, the amount of water used (evaporated and transpired) in a 24-hour period can easily be determined by weighing the plant containers. On a day with typical weather conditions, weigh 1 hour after irrigation ceases and again 24 hours later to determine the daily water use. Comparisons can be constructed by weighing different plant species at the same time. Plants with similar water use can be grouped together. In order for the weight difference to be comparable across plant species, all plants should be watered at the same time to help eliminate outside influences such as wind, sun intensity and other environmental factors. Also, to categorize plants as high, medium or low water users, use plants in the same container size and at same stage of production. For accurate, automated measurements, soil moisture sensors (See Scheduling Irrigation) can be used.

Adapted from Costello et al. 2003 and SNA BMP manual 2013

- Solid-walled containers require less water, while porous containers such as root pruning containers or those made with porous materials often require more water and/or more frequent irrigation
    - This is due to water evaporating from the sides of the container
- Container color influences container temperature, which affects evaporation from the substrate
    - As a result, dark colored containers require more water than light colored containers
- Plants with thick, waxy leaves lose less water and therefore do not need to be irrigated as often as plants with leaves that are not waxy (Figure 19)
- Shaded plants do not require as much water as plants in full sun, which transpire more and lose more water to evaporation from the substrate (Figure 20)
- Newly planted liners need more frequent irrigation events than well-rooted plants that can access more of the container volume for water

Figure 19. Waxy-leaved plants lose less water through transpiration

Figure 20. Plants in shade require less water

- Vase-shaped canopies have a high capture factor and funnel water into the container, increasing interception efficiency and requiring less irrigation run time than umbrella-shaped or spreading canopies which may deflect water away from the container (Figure 21 and 22)
    - Umbrella-shaped canopies with smaller leaves may deflect less water than those with larger leaves

Figure 21. Vase-shaped canopies funnel water into plant containers

Figure 22. Umbrella-shaped canopies direct water outside of plant containers

Capture Factor Case Study:

Plants either funnel water into their containers, shed water outside their containers or do not influence the amount of water entering their containers. Research conducted at the University of Tennessee found that Yoshino cherries shed water and have a capture factor of 0.8 while Kwansan cherries funnel water towards their base and have a capture factor of 1.7. Placed in the same irrigation zone, containers of Kwansan cherries received more than twice as much water as containers of Yoshino cherries. This example is based on 5 foot tall trees in #5 (4.5 L) containers using impact sprinklers. The plant species as well as plant size, plant spacing, container size and irrigation type will all affect the capture factor. As this case study shows, capture factors very widely, even between closely related plant species and is something worth accounting for when deciding what plants to place together in an irrigation zone!

CONTAINER SPACING (OVERHEAD IRRIGATION ONLY)

Container spacing is a major factor in using water applied by overhead irrigation systems efficiently; proper spacing optimizes plant growth and the production area. Too much space between containers decreases the number of plants that can be grown in a given block and increases the amount of water that is wasted.

- In general, the further apart containers are spaced, the more irrigation water that lands between containers and is wasted (Figure 23)

Figure 23. Widely spaced plants and partially harvested blocks waste water and space

  - Surface area covered by containers is 91 percent at best and drops drastically as containers are spaced further apart
  - In most cases, 50-75 percent of overhead irrigation does not contact the substrate surface and instead falls between containers
  - Evapotranspiration rate also increases as container spacing is increased due to:
    - Increased air circulation between containers
    - Increased sunlight penetration to container sidewalls
  - When spaced so that branches overlap, vase-shaped plants intercept water that would otherwise be intercepted by neighboring plants. Therefore, closely spaced vase-shaped plants may need longer irrigation events relative to those at wider spacing because each plant may not receive the same amount of water as when spaced farther apart
- Consider planting into the final container size and placing pots with no space in-between (pot-to-pot) until plant canopies begin to overlap in order to maximize water intercepted and retained from overhead irrigation and rainfall (Figure 24)
  - This can reduce labor needed to space smaller containers multiple times

Figure 24. Planting in the final container and spacing close together captures the most overhead irrigation

  - Until plants establish, the substrate will stay very moist, decreasing irrigation application amount even further
  - Plant species must be tolerant of moist root conditions
- Placing containers in an offset (rather than square) pattern will enable more of a plot’s surface to be covered by containers (Figure 25)
  - An offset pattern increases irrigation efficiency by 5 to 10 percent when compared with a square pattern

Figure 25. Pots in an offset pattern utilize space more efficiently than those arranged in a square pattern

Surface Area Covered by 1- and 3-gallon Containers Placed at Various Spacings and Patterns			
Space Between Containers (inches)	1-gallon Square Pattern (%)	1-gallon Offset Pattern (%)	3-gallon Square Pattern (%)
0	79	91	78.5
1	58	67	66.1
2	44	51	56.4
4	28	33	42.5
6	20	23	-
12	9	10	-

Adapted from Furuta 1974 and Beeson and Knox 1991

- Growers using overhead irrigation for containers larger than a 7-gallon should consider switching to microirrigation as the interception efficiency of watering these widely-spaced containers drops below 25 percent

Overhead irrigation is generally most efficient with proportionately smaller plants in larger containers that are placed pot-to-pot. As the plant grows into its container and covers the pot surface, the percent of irrigation captured by the substrate drops significantly because it is intercepted by the canopy and ultimately evaporates.

SUBSTRATE SELECTION

The substrate used in container production can affect how often a grower needs to irrigate. Different substrates have different physical properties that influence the water holding capacity of the substrate and the portion of stored water that is available to plants.

- Particle size affects both total water holding capacity and the available water of a substrate
  - ∞ Small particles = small pore space
    - -- Small pore spaces increase water retention and decrease aeration
  - ∞ Large particles = large pore spaces
    - -- Large pore spaces allow water to drain, decreasing water holding capacity and increasing aeration
- As organic matter decomposes, particle size decreases (Figure 26)
- 100 percent pine bark has relatively low moisture retention and requires more irrigation events
  - ∞ If pine bark dries out too much it becomes hydrophobic, making it hard to rewet
  - ∞ Adding peat increases the amount of water a pine bark-based substrate can hold

    - Adding sand does not appreciably change the total amount of water a container can hold, but it increases the portion of water that is available to plants compared with 100 percent pine bark (1/2 in. screened)

Figure 26. As organic matter breaks down, substrate particle size decreases

- Even when substrate composition seems identical from one shipment to another, physical properties may vary due to differences in particle size (Figure 27)
- Increasing the water holding capacity or the ratio of available water to unavailable water can decrease irrigation frequency
    - Overirrigating when using highly moisture retentive substrates can create an environment favorable to pathogens that cause root rot

Figure 27. Substrate properties may be different even if ordering from the same company

The Percentage of Available and Unavailable Water in Various Substrates			
Substrate	Container Capacity** (% vol)	Water Available to Plants (% vol)	Water Unavailable to Plants (% vol)
Pine bark* (100%)	65	33	32
Pine bark: sand (80:20)	66	41	25
Pine bark: peat (90:10)	68	36	32
Pine bark: perlite (70:30)	56	23	33
Pine: peat: perlite (70:15:15)	71	43	28
Pine bark: peat: rice hulls (3:2:2)	69	34	35
Pine bark: soil (9:1)	59	33	26
Normal ranges	45-65	23-35	23-35

Adapted from Bilderback et al. 2005

*1/2” pine bark

**container capacity = maximum water holding capacity

RAINY DAYS

Some rain events can replace an irrigation event. If daily water needs are met by a rain event, irrigation should be shut off either manually or with automatic rain delay sensors. Not only does this save water, but also reduces nutrient leaching from the substrate. Rainfall is also more effective at penetrating plant canopies than overhead irrigation.

Success Story

A Win-Win Irrigating Field Production: Less Water, More Growth

Waverly Farm

Jerry Faulring was happy with growth and health of his field grown shrubs but became interested in monitoring soil moisture as a tool to improve his use of drip irrigation. Luckily for Jerry, his nursery is in Maryland, right in the backyard of John Lea-Cox, University of Maryland Professor and Project Director of a Specialty Crops Research Initiative grant that was focused on advancing nursery irrigation. As part of the Managing Irrigation and Nutrition via Distributed Sensing project, moisture sensors were installed at Waverly Farm to monitor soil moisture. The volumetric water content (VWC) at the root zone could be viewed in real-time, allowing Jerry to closely monitor the effect of his standard irrigation practice, which was to manually open irrigation valves for 24 hours once every 7 days unless there was one inch of rain. The new system revealed that 2 days after irrigating, his soil was dry within the root zone. In short, he wasn't getting the benefit from a deep, soaking irrigation. Jerry and John installed an automated irrigation system based on the soil moisture sensor data. The irrigation system maintained VWC at 40 percent, a moisture level chosen from their sensor data from previous seasons. First year plantings (lilac) that were watered based on the sensors rather than his traditional method grew about 20 percent taller and had fuller canopies. Jerry also found that using his traditional method on a 500 foot row of plants used 11,000 gallons of water per year while the sensor-based system only used 3,000 gallons, a 266 percent decrease. They concluded that although the traditional method provided more water, the sensor-based system gave the plants water when they needed it and minimized wet and dry extremes, which led to increased growth. This experiment was also conducted on new plantings of dogwood. The same water savings were achieved, but there was not a difference in tree growth, perhaps because dogwoods are very slow growers. Four years ago, Jerry installed flow meters throughout his nursery. The flow meters allow Jerry to calculate his water savings from adopting sensor-based irrigation; he has reduced water use at his nursery about 50 percent, from about 24 million gallons to 9-12 million gallons annually. He calculates that he will double the life of his pumps, from 7 to 14 years, by using sensor-based irrigation. Jerry had at one time been reluctant to use automated irrigation, but is now adopting automated sensor-based irrigation throughout his nursery. He calculates that that he will save money on pumping electricity, maintenance on pumps that are no longer being worked as hard and free up labor that used to manually open and close valves.

Success story provided by Jerry Faulring, Waverly Farm and John Lea-Cox, University of Maryland

For more information see: The Free State Nursery and Landscape News: http://issuu.com/marylandnurserylandscapeassn/docs/free_state_winter_2014_web
Managing Irrigation and Nutrition via Distributed Sensing http://www.smart-farms.net

5. IRRIGATION DELIVERY SYSTEMS

Application efficiency is largely determined by irrigation system design and management. In this section, we will address the benefits and drawbacks of the two most common forms of nursery irrigation systems: overhead irrigation and microirrigation. Before installing either system it is recommended that nursery managers consult an irrigation design and pump professional.

OVERHEAD IRRIGATION

The most common form of irrigation found in container nursery production is overhead irrigation. It is generally used for small containers (7-gallon or smaller) with relatively close spacing and for field production (Figure 28).

Types

- **Overhead Sprinklers/Risers**
    - Mostly used in container production
    - Water is applied over plant canopies
    - System infrastructure (pipes, risers, etc.) is relatively permanent

Figure 28. Overhead irrigation is the most common form of irrigation

- **Traveling Guns** (Figure 29)
    - Used in field production
    - Mainly used to improve liner survival during dry periods after planting
    - A cart (or tractor) is connected to a water supply and contains a hose reel; another cart holds the “gun” that distributes the water
    - Carts can be moved to where they are needed

Figure 29. Traveling guns are great for operations that do not need much irrigation

Advantages:

- Supplies large production areas with water relatively cheaply
- Easy to set up compared with microirrigation
    - After set up, an overhead irrigation system for container production will last for years and will not need to be moved
- Can move and harvest plants easily
- Does not clog as easily as microirrigation
- Easy to see if irrigation is not working properly
- Low maintenance
- Can provide frost protection

Disadvantages:

- Extremely inefficient
  - ∞ Depending on plant spacing, a large amount of water will not reach the root zone
  - ∞ The combined effects of some plant species shedding water outside their containers and the space between containers can result in very low efficiency
    - -- Only 25-40 percent of the irrigation water applied to azalea and pittosporum was captured by containers even when containers were placed pot-to-pot
    - -- Azalea and pittosporum have a capture factor <1; species with a capture factor greater than 1 will have higher results

For more information on how plant spacing affects efficiency, see Cultural Practices That Can Reduce Water Use

For more information on how to calculate capture factor, see Calculations

- Prone to poor distribution uniformity and must be checked regularly (see Calculations)
- If irrigation water has high salt levels or other contaminants, foliar damage such as residue, leaf burn and foliar diseases could occur (Figure 30)

Figure 30. Using overhead irrigation with poor quality water can lead to foliar issues

- Foliar diseases can also occur as a direct result of plant canopies staying wet
- Plants receive little to no water if they tip over (Figure 31)
- Traveling guns require initial set up each season and must be moved from area to area to irrigate and are thus labor intensive compared with microirrigation

Figure 31. Plants that blow over do not receive irrigation from an overhead system

MICROIRRIGATION

The two types of microirrigation common in nursery production are drip irrigation and micro-sprinkler or spray stake irrigation. Drip irrigation systems are generally used in field-grown plants but are occasionally employed for production of large containers (Figure 32). Micro-sprinkler systems use small sprinklers placed on a stake. One or more stakes are commonly inserted into the substrate surface of large containers (Figure 33). Both systems are more efficient than overhead irrigation.

Figure 32. Drip irrigation is generally used for field production

Advantages:

Figure 33. For large containers, multiple emitters should be used

- Applies water directly to the substrate
    - ∞ Minimizes drift and evaporative losses
    - ∞ Reduces amount of water needed to irrigate an area
    - ∞ Can result in an 80 percent reduction in total irrigation volume compared to overhead irrigation
    - ∞ Little to no runoff
    - ∞ Fertigation is more efficient when applied by microirrigation compared to overhead irrigation
- Individual emitters can be shut off as plants sell within an irrigation zone (Figure 34)

Figure 34. As plants sell, individual emitters can be closed

- If containers partially tip over following high wind, they may still receive some irrigation
- Decreases foliar diseases as the plant canopy does not get wet during an irrigation event
- Decreases weed growth between containers compared to areas with overhead irrigation
    - ∞ Fewer weeds reduce the cost of pre and post emergence herbicides
- Pressure compensating emitters are available and improve distribution uniformity over standard emitters

Disadvantages:

- Because water is applied directly to the substrate surface, plant stress may be the first indicator of a problem with the irrigation system
- Drip lines are susceptible to rodent and other pest damage
- Worker and animal traffic can easily dislodge stakes
- Not as easy to maneuver in and harvest plants; may present a trip hazard for workers (Figure 35)

Figure 35. If not kept out of pathways, emitters can become a tripping hazard for workers

- Installation is more time-consuming per plant than overhead irrigation
    - Requires set up every time a crop is moved into or out of the area
- Individual emitters may be expensive, depending on the type
- Drip emitters are more susceptible to clogging than impact sprinklers
    - Filtration may be necessary to remove the source of clogging
- Maintenance is more time consuming as each emitter must be checked for problems
    - It is recommended that emitters be checked daily for clogs

Success Story

Pot-in-Pot: Building on Success

Hale and Hines Nursery

Hale and Hines Nursery was already using water carefully in pot-in-pot production by utilizing cyclic irrigation and monitoring leaching fractions. In 2010, Terry Hines partnered with John Lea-Cox and the team at the University of Maryland through the national SCRI-Managing Irrigation and Nutrition via Distributed Sensing project to continue to improve irrigation efficiency. Substrate moisture sensors were installed in 15-gallon containers of *Cornus florida* 'Cherokee Brave' and 30-gallon containers of *Acer rubrum* 'Autumn Blaze' trees. Some trees were irrigated using Terry's standard cyclic irrigation and other trees were irrigated based on the average reading of soil moisture sensors using a new sensor-based irrigation control capability that the SCRI-MINDS project developed. From March through November 2012, average daily water applied to dogwoods by the sensor-controlled irrigation was 0.58 gallon/tree less than the standard irrigation, a 63 percent reduction in water use and reduction in overall water use of 18,235 gallons per row. For red maple, the total reduction was 0.59 gallon/tree, the equivalent of a 34 percent reduction in water use for this species. No differences in tree caliper or quality were noted between the two irrigation treatments in either species over the year. Additionally, Terry didn't have to spend as much time as he had previously spent adjusting irrigation schedules, estimated at 4-8 hours per week. The cost of water was nearly entirely attributable to pumping water from a perennial stream, with electricity rates among the lowest nationwide.

Despite this inexpensive, high quality water ($55 per acre-foot), the payback period of the wireless sensor network was estimated to be just 2.7 years and was largely due to the reduction in irrigation management time. In a comparative analysis, the same irrigation savings applied in California (with a conservative $978 per acre-foot cost) would have realized a net annual savings of $138,408 with a payback period of less than 4 months for a large-scale sensor network. Terry has continued to use the sensors to determine the water requirements of other species he has in production and group species into zones based on need. As a result he has reduced overall water use in his pot-in-pot system by 25 percent, allowing continued expansion of production area without major water infrastructure improvements.

Success story provided by Terry Hines, Hale and Hines Nursery, McMinnville, TN and Bruk Belayneh and John Lea-Cox, University of Maryland.

For more information see: SCRI-MINDS project website at http://www.smart-farms.net/impacts and Belayneh, B.E. et al. 2013 – Benefits and costs of implementing sensor-controlled irrigation in a commercial pot-in-pot container nursery. HortTechnology 23:760-769.

6. SCHEDULING IRRIGATION

The goal of irrigation scheduling is to provide plants with the quantity of water they need when they need it. The physical properties of the substrate or soil along with container size determine how much of the applied water is retained (water holding capacity) and how much is available to the plant. The majority of water that reaches the soil/substrate surface is typically lost through evaporation while plants are small and/or the soil or substrate surface is exposed. As crops grow the portion of water that is taken up by plants rapidly increases to almost 100 percent of total water applied. For these reasons, *when* to irrigate and *how much* to apply is very important.

IRRIGATION TIMING

It is generally accepted in the nursery industry that plants should be irrigated in the morning. Morning irrigation conserves water because as the day progresses:

- Wind increases as the sun rises, causing overhead irrigation to drift from the desired location (Figure 36)
- Temperature and solar radiation increase, causing greater evaporation of droplets as overhead irrigation is applied and from the soil/substrate following application

Figure 36. Watering when it is windy redirects overhead irrigation

Also, irrigating pre-dawn can complete irrigation before workers arrive, permitting greater access to plants without irrigation interrupting production activities. Morning irrigation also minimizes the time that leaves are wet, reducing potential for disease infection.

However, research suggests that irrigating periodically throughout the day or throughout the afternoon with either microirrigation or overhead irrigation results in less plant stress and increased plant growth.

CYCLIC IRRIGATION

By dividing the daily irrigation volume into three or more separate events throughout the day, cyclic irrigation increases water retention in the container by about 38 percent, maintains the plant available water at higher, more consistent levels while reducing run-off and leaching and decreases overall water use by about 25 percent.

- Cyclic irrigation prevents large swings in container volumetric water content; as a result, container moisture is maintained at more desirable moisture levels throughout the day

- This approach prevents moisture levels from declining to levels at which little available water remains
- Maintaining a consistent substrate moisture level through cyclic irrigation can reduce substrate temperature, increase photosynthesis and plant growth and prevent substrate drying to the point that it becomes hydrophobic
- Maintaining a consistent substrate moisture level throughout the day also provides more of a buffer should a problem delay irrigation

USING LEACHING FRACTION

Leaching fraction is the amount of water that drains out of a container immediately after an irrigation event compared to the amount applied. This measurement is a quick and effective way to judge whether the length of the irrigation event is sufficient to replace the amount of water lost from the substrate. Large volumes of leachate and thus high leaching fractions indicate overirrigation while little to no leachate and low leaching fractions indicate underirrigation.

Advantages:

- Easy to calculate
- Uses inexpensive equipment
- Can give insight to both overhead and microirrigation

Disadvantages:

- While measuring leachate in small containers is relatively easy, as containers increase in size, they become heavier and more difficult to move

- Does not indicate when to irrigate, only whether the irrigation volume is appropriate to replace substrate depletion without excess losses
- Not compatible with field production

Method:

1. Before irrigating:
   - ∞ Place catch cans in the irrigation zone near plants from which drainage will be collected
   - ∞ Place several drainage cans of the same diameter as catch cans underneath plant containers (Figure 37)
     - -- Do not allow irrigation water to directly enter drainage containers
2. Initiate an irrigation event and allow plants to drain for an hour after the event is complete
3. Carefully pour the leachate from all drainage cans into a graduated cylinder or other clean container
4. Measure the drainage volume, then divide the volume by the number of drainage cans to get the average amount of leachate
5. Measure the catch can volume, then divide the volume by the number of catch cans to get the average application volume

Figure 37. Tight fitting drainage can to collect leachate

6. Divide the average amount of leachate by the average amount of water applied and multiply by 100 to get the leaching fraction
   - A leaching fraction of 10-20 percent is ideal
   - If leaching fraction is greater than 20 percent, irrigation operation time should be reduced
   - If leaching fraction is less than 10 percent, irrigation operation time should be increased

See Calculations for detailed instructions including a high accuracy weight-based option that accounts for capture factor and examples.

Leachate should be measured for multiple plant containers, which will help identify plants or portions of the block that are not typical. Some plant-to-plant variation is expected; however, if there is no leachate or excessive leachate in one or more of the containers (but not all), there may be a problem with distribution uniformity (see Irrigation System Efficiency).

EVAPOTRANSPIRATION (ET) MODELS

Evapotranspiration is the combined water loss from evaporation from the soil or substrate and transpiration from the plant. The goal of irrigating is to replace the water lost through evapotranspiration. There are several factors that influence evapotranspiration including:

Environmental

- Solar radiation
- Air temperature
- Humidity
- Wind speed and duration

Plant

- Plant variety
- Plant height
- Stage of growth
- Leaf area
- Leaf cuticle thickness
- Leaf density
- Trichome characteristics
- Stomatal response
- Plant container coverage

Soil/Substrate/Container

- Water salinity
- Soil salinity
- Water holding capacity
- Mulch thickness, if any
- Substrate/soil water potential
- Container color
- Plant/container spacing

If water lost through evapotranspiration can be determined and the application rate is known, the irrigation run time needed to replace the water lost can be calculated. Accurately calculating evapotranspiration is complex; however, a nursery-friendly estimation method can provide valuable information.

One way to determine evapotranspiration is to enter meteorological data from a weather station into the Penman-Monteith equation to generate reference evapotranspiration. This equation estimates water use for turf grass growing in soil under no water stress. After calculating reference evapotranspiration, the resulting value is typically multiplied by a crop coefficient that tailors the water use to a particular species' water use characteristics and the specific soil or substrate evaporation of the production system and crop. A plant species may have more than one crop coefficient based on developmental stage or management practices, such as pruning. Ideally, the crop coefficient would account for all of the characteristics listed above. Due to the number of necessary parameters and the complexity of the calculation, very few crop coefficients have been developed for nursery crops, and are generally not used by nurseries.

Nursery-friendly method for estimating evapotranspiration*

1. Select a few representative plants of a single species or cultivar and label them.
2. Determine the area of the top of the container.
3. Weigh plants early in the morning, about one hour after irrigation ends to allow drainage to occur.
4. Return plants to their original spots in the plot.
5. Re-weigh plants at the end of the day.
6. Subtract the weight at the end of the day from the morning weight; convert to the volume of water lost.
7. Container ET equals the number from step 6 divided by the area of the top of the container.
8. The resulting ET estimate can be used to determine how much irrigation is needed.

See Calculations for a more detailed method and an example

*Adapted from Million and Yeager 2012

SOIL AND SUBSTRATE MOISTURE SENSORS

Moisture sensors are tools that can be used to improve irrigation scheduling by measuring soil or substrate water content in real-time (Figure 38). Sensors are placed in the soil or container substrate where they send information to a data logger that stores the data (Figure 39). Many data loggers can also be programmed to recognize water content thresholds and control solenoid valves to trigger irrigation events.

Figure 38. Soil/substrate moisture sensor

Controlling irrigation timing with sensors can greatly reduce water use and water stress compared with traditional, timer-based irrigation because sensors provide an indirect measure of actual container water content. As a result, they account for variations in plant water requirements, rainfall events, atmospheric demand and leaching losses.

Sensor-based methods of scheduling irrigation include:

- Using sensors to determine daily water use and irrigating to replace that amount of water
  - Can reduce irrigation water volume up to 70 percent without reducing plant size and in some cases may increase plant size
  - Irrigates once daily, minimizing worker interruption

- Using sensors to trigger irrigation based on plant physiological thresholds
    - Threshold established based on the relationship between substrate moisture level and photosynthetic rate
        - Conserves water while maintaining plant growth and quality
        - Irrigates as needed throughout the day, thereby reducing water stress
- Using a sensor-based irrigation system to maintain a desirable substrate moisture level as dictated by experience
    - Used with success to grow several herbaceous and woody crops
        - Has been shown to eliminate gardenia plant death from root rot (previously 30 percent loss) and decrease production time by almost 70 percent
    - Conserves water while maintaining quality and growth
    - Irrigates as needed throughout the day

Figure 39. Moisture sensors are placed directly into the container to measure substrate moisture level

For more information on moisture sensors, see Munoz-Carpena (2012), Smajstrla and Harrison (2011) and Lea-Cox et al. (2013). For case studies at nurseries, please see the December 2013 special issue of HortTechnology on wireless sensor-based nursery irrigation.

USING DEFICIT IRRIGATION

Deficit irrigation is a method that replaces less water than what is used. While not common in nursery production, growers may practice deficit irrigation using sensors, scales or other tools to detect plant water needs.

Advantages:

- Reduced nutrient and pesticide leaching from substrate compared with plants that are more heavily watered
- Reduced foliar disease pressure compared with other irrigation methods (if foliage is wet fewer hours)
- Waiting to irrigate may allow time for a rain event to occur, saving the nursery energy and water
  - Rainfall is more effective at penetrating plant canopies than overhead irrigation
- Mild water stress encourages stomatal closure, reducing transpiration and enabling available water resources to be used more efficiently by the plant without affecting growth
- Water stress can lead to shorter internodes, creating a more compact plant without pruning
- May lead to an increase in flower production
- Can stretch the water supply during droughts or other shortages

Disadvantages:

- Plant growth may be hindered if the deficit is too great
- The amount of water stress a plant can withstand and still grow varies by species

- Some substrates can become hydrophobic when subjected to deficit irrigation regimes, and not retain as much water during subsequent irrigations
- Can lead to excessively dry areas if there is poor irrigation distribution uniformity (see Irrigation System Efficiency)

Success Story

Success with Water Sensitive Crops

Transplant Nursery, Inc.

Transplant Nursery, in collaboration with the University of Georgia, began trials on an automated irrigation system based on container substrate moisture level. Plants were produced with either the sensor-based automated irrigation or the nursery's conventional irrigation practices (hand operating irrigation valves based on weather and experience). The automated system used GS3 sensors connected to a data logger (NR5, Decagon Devices). Growers at Transplant Nursery determined the moisture level they were comfortable with and that was used as the set point to operate the automated irrigation. This set point was generally around 27-28 percent volumetric water content. Side-by-side comparisons were conducted with moisture sensitive species including *Pieris, Kalmia, Rhododendron*, and *Hydrangea quercifolia*. Plants were produced outdoors on a container pad with impact sprinklers. Crops were examined for overall growth, plant quality, water use and labor inputs. Results from this preliminary study are promising! Across these different species, the automated system did not cause a reduction in plant size or quality compared to the nursery's traditional irrigation practice. However, the automated system resulted in a reduction of water consumption by 48 percent over 2.5 months, roughly 56,990 gallons. Stay tuned for more results!

Success story supplied by Jeff Beasley, Transplant Nursery and William D. Wheeler, Matthew Chappell, Paul Thomas, Marc van Iersel and Jean Williams-Woodward, University of Georgia

For more information see: http://hortsci.ashspublications.org/content/suppl/2015/10/26/50.9.DC1/HS-Sept_2015-Conference_Supplement.pdf

Success Story

Leaching Less, Growing Better: Leachate-based Irrigation Scheduling Leads to Water Savings and Enhances Plant Appearance

Holden Nursery

Kim Holden, Holden Nursery, manages irrigation for his container-grown shrubs and perennials by manually operating valves. Kim had tried automated irrigation in the past but frequent failures led the switch back to manual irrigation control. In order to minimize management time devoted to irrigation and following customary practices in the area, Kim irrigates 2 hours every other day during the summer months. A team from the University of Tennessee set out to determine if significant water savings could be gained by adopting a leaching fraction-based automated irrigation system while maintaining the high plant growth and quality standards of Holden Nursery. Separate zones were used to compare the Holden Nursery standard irrigation with the automated system set to maintain a 15 percent leaching fraction. The resulting irrigation run times varied by day but were typically around 25 minutes for oakleaf hydrangea and 18 min for juniper (Blue Rug and Blue Pacific), less than half of the two hours every other day irrigation. Generally, the leachate-based irrigation kept the substrate moisture level higher and more consistent with less day-to-day variation. From August 17, 2015 to October 15, 2015, the two hour standard irrigation used 11,903 gallons while the leachate-based junipers used 4,375 gallons and the hydrangea used 5,715 in the relatively small test zones: over a 50 percent savings! Plants grown in the leachate-based irrigation were greener and had no reduction in growth compared to those irrigated with the 2 hour standard. The UT team will continue with the project for two more seasons, however Kim Holden is already convinced. He is making plans to automate a portion of his nursery and manually measure leachate in order to base irrigation on leaching fraction. Kim believes that the automated system will quickly pay for itself from reduced pumping costs associated with water savings, and the amount of time he will be able to devote to other activities will be a significant benefit. Who doesn’t want to grow better plants, save money, reduce waste and end up with more time for fishing on the weekends?

Success story provided by Kim Holden, Holden Nursery, and Quinn Cypher, Wesley Wright, Xiaocun Sun and Amy Fulcher, University of Tennessee, Knoxville, TN.

7. IRRIGATION SYSTEM EFFICIENCY

Starting out with an irrigation system designed by a qualified engineer is a great first step toward achieving uniform and efficient irrigation applications. The following section includes basic principles of irrigation design and how to test irrigation systems for efficiency. Factors that affect irrigation efficiency are also covered.

IRRIGATION DISTRIBUTION UNIFORMITY (DU)

If an irrigation system is properly designed, maintained and operated, all plants within a zone should receive nearly the same amount of water. If water distribution is not uniform, it could lead to:

- Lack of uniformity in plant growth (Figure 40)
- Increased pumping cost due to basing irrigation on the driest plants within a zone (see Scheduling coefficient)
- Overwatering plants that are in “wetter” areas of a zone

Figure 40. Poor distribution uniformity can lead to poor uniformity in plant growth

MEASURING DU

It is best to test DU when there are no plants in the plot, but if the plot already has plants in it, place catch cans just above the plant canopy (Figure 41).

Figure 41. Set capture containers in a grid pattern above the canopy

1. Place 24 buckets or other impermeable catch cans in a uniform grid pattern inside the zone.
2. Run a typical irrigation cycle.
3. Record the amount of water in each catch can and list from lowest to highest.
4. Calculate the average volume of water from all 24 catch cans.
5. Calculate the average of lower 25 percent catch cans.
6. Divide the average of lower 25 percent by the overall average (step 4) and multiply by 100 to produce percent uniformity.

A minimum of 24 catch cans is recommended, but 16 have been used successfully in nurseries. In general, more catch cans will better characterize the DU. Using a multiple of 4 is essential.

For microirrigation systems, place emitters directly into collection containers (Figure 42)

Figure 42. Place emitters directly into capture containers

See the Calculations for more details and an example

Distribution Uniformity	
>80%	*Desirable*
60-80%	*Opportunity for improvement, run time may be longer than necessary*
<60%	*Serious problem with design or hardware*

DU is affected by:

- **System design**
    - Consult an engineer to insure that the system is designed properly from the beginning
    - Design system to accommodate the flow rates of the sum of all emitters/nozzles that will be operated at one time
    - Ensure that proper sprinkler overlap is occurring
    - Use nozzles that create matched precipitation within a zone
    - Operate within the proper pressure range for the emitters/nozzles
        - Pipe diameter, length and slope affect pressure
    - Height of nozzles should be above plant canopy
    - Replace old parts with identical parts
    - Make sure all risers are perpendicular to the ground (Figure 43)
        - Stake with rebar if necessary
    - Ensure all nozzles are moving at the same speed (Figure 44)

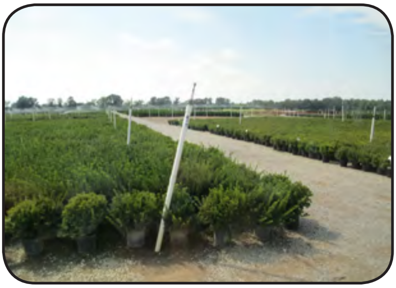

Figure 43. Crooked risers cause poor DU

Figure 44. If nozzles are not putting out the same amount of water, DU is reduced

- **Emitters/nozzles**
    - Ensure that all emitters/nozzles (and pipes) are free of debris
    - Use the proper emitters/nozzles for the current system and ensure that they are working properly (Figure 45)
    - If emitters/nozzles are worn out, replace them with identical emitters/nozzle (same manufacturer and model, not just same type of emitter/nozzle)

Figure 45. Ensure nozzles are working properly

- **Wind**
    - Wind can cause overhead irrigation water to be redirected from the plot
    - Consider adding a windbreak to minimize wind and improve irrigation uniformity (Figure 46)
    - Do not conduct DU test if wind speed is 5 mph or greater

- **Pressure**
  - Pressure is lost due to friction and is a function of flow rate, pipe diameter and distance
    - Bigger pipes cause less friction at a given flow rate, thus less water pressure is lost on the way to the emitter/nozzle
    - Valves, elbows, tees and any other similar changes in the pipe cause additional friction loss
    - Generally, the further the emitter/nozzle is from the water source, the larger the pipe needs to be
  - Pressure may need to be adjusted to increase uniformity
    - If pressure is too low, emitter/nozzle heads may need to be changed or the number of emitters/nozzles reduced
    - Consider irrigating fewer zones at the same time
    - If pressure is too high, pressure regulators and pressure reducers can help control and reduce pressure, respectively

Figure 46. Planting a windbreak will help lessen the effects of wind

> *A symptom of an improperly designed system is higher pressure at the first emitter/nozzle compared to the last, causing poor distribution uniformity. Pressure compensating emitters can help but proper design is necessary to prevent this problem.*

MATCHED PRECIPITATION RATE

In order to avoid watering roadways and other areas without plants, nozzles in the middle of a plot should be 360° nozzles, edges need 180° nozzles and corners need 90° nozzles. To maintain application rate uniformity, the flow rate of 180° and 90° degree sprinklers should be half and a quarter of the 360°, respectively (Figure 47). Selecting nozzles that will provide the same application rate (or precipitation rate) across a zone creates a matched precipitation rate. Using a 360° that applies 5 gallons per hour (gph) and a 90° that provides 5 gph will greatly decrease uniformity and will cause the area irrigated by the 90° to be more heavily irrigated while other areas will be underirrigated.

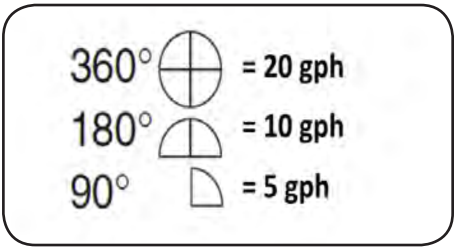

Figure 47. Selecting nozzles to provide matched precipitation
Adapted from Hunter Industries, http://www.hunterindustries.com/

MAXIMIZING EFFICIENCY WITH A SINGLE ROW OF SPRINKLERS

A single line of sprinklers will normally result in a lower DU than a grid or offset pattern, but is sometimes the only viable option in an overwintering house or narrow zone between overwintering houses. If full-circle (360°) nozzles are used in a single line, a general rule of thumb is the width of the production area watered by each line should be equal to or less than twice 40 percent of the nozzle output radius.

Following this general guideline will increase application uniformity by limiting the area in which plants are placed but it will also waste production space and water that falls in outlying areas. Sprinkler spacing within the line should be equal to the output radius or closer if located in a windy site.

Most irrigation companies have software that will calculate the DU based on riser spacing and sprinkler type, making it easy to select the ideal riser spacing for a given sprinkler and maximize use of irrigated space. For example, using a 2009 impact sprinkler (Senninger Irrigation, Inc.) in a 200 ft x 50 ft area spacing, a single line of sprinklers with a radius of 34 ft yields a DU of 55 percent (Figure 48). Doubling the number of sprinklers for a spacing of 17 feet apart yields a DU of 78 percent (Figure 49). This example does not hold true for all sprinkler types. The pattern of spray is very important in determining the best spacing for optimal DU.

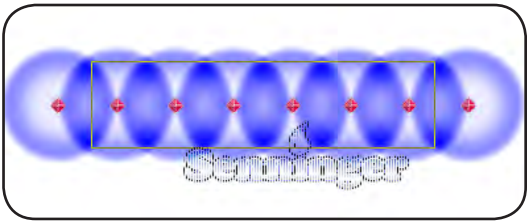

Figure 48. Sprinklers with a radius of 34 ft
Photo courtesy of Senninger Irrigation, Inc.

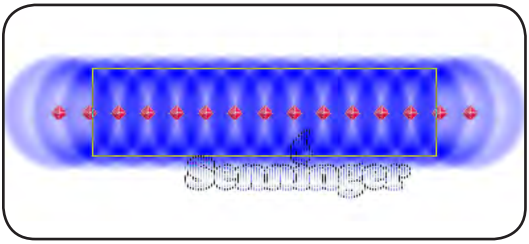

Figure 49. Sprinklers with a spacing of 17 ft
Photo courtesy of Senninger Irrigation, Inc.

APPLICATION RATE

It is important to know how much water an irrigation system applies during an irrigation event. If plants in a plot only require 0.5 inches of water a day (see Evapotranspiration Models to calculate this) but the irrigation system uniformly applies 2 inches of water, current irrigation duration or run time is too long. Also see scheduling coefficient.

It is easy to determine how much water an irrigation system applies to a plot while testing for distribution uniformity:

1. Place 24 straight-sided buckets or other straight-sided impermeable catch cans in a uniform grid pattern inside the irrigation zone.
    a. Catch cans that are too heavy to blow over work best
2. Operate irrigation for a typical irrigation cycle.
3. Measure the amount of water in each catch can using a ruler in inches and record.
4. Calculate the average of all 24 catch cans.
5. Divide the amount of time the irrigation ran (in minutes) by 60 minutes.
6. Divide the average of all 24 catch cans (step 4) by the number from step 5 to get inches applied per hour.

If too much water is being applied, decrease the amount of time the irrigation runs. If too little water is being applied, increase the amount of time irrigation runs.

Straight side catch cans must be used to determine application rate by measuring depth with a ruler (coffee cans are an option). See the Calculations for a technique that can be used regardless of container shape.

SCHEDULING COEFFICIENT

A scheduling coefficient (SC) can be used to adjust irrigation run time to the driest portion of the zone. It is the ratio of the average application rate for the whole zone compared to the contiguous area with the lowest application rate. See instructions on previous page for how to calculate the application rate. The lower the necessary scheduling coefficient, the better. The ideal scheduling coefficient is 1.0.

Example:

- If the average application rate is 0.8 inch per hour and the lowest application rate is 0.6 inches per hour, the SC is 1.3 (0.8 ÷ 0.6)
- If plants within the plot need 1 inch of water per day, the irrigation must be operated for 30 percent longer in order to ensure that plants in the driest portion of the plot receive an inch of water
    - 1 inch ÷ 0.8 in/hr × 1.3 × 60 min/hr = 97.5 minutes of run time

Success Story

Constructed Wetlands: Cleansing Water, Reducing Fertilizer Inputs

Monrovia

In the late 1990s, Monrovia installed its first constructed wetlands in Cairo, Georgia implementing an environmental stewardship program to proactively cleanse and limit the quantity of water leaving the nursery. Constructed wetlands are designed to replicate the ability of natural wetlands and operate as mini wastewater treatment plants. The system of plants, microbes and soils uses a range of processes to remove nutrients, and in some cases pesticides, from water. A team at Clemson University led by Dr. Sarah White began monitoring and evaluating the performance of the 1 million gallon per day wetland at Monrovia in 2000. Dr. White's team found that retaining leachate from containers in the wetlands for a 3-5 day period was very effective at removing nitrogen and phosphorus. The Clemson team evaluated performance on a monthly basis year round and conducted concentrated spring studies, coinciding with the heaviest fertilizer applications. Spring represented a "worst case scenario" for the wetlands by testing their capacity to clean water under the highest monthly inputs of nitrogen and phosphorus. During the spring, the constructed wetland system remediated essentially 100 percent of the nitrogen and phosphorus that drained out of plant containers and was channeled to the constructed wetlands. In an effort to minimize phosphorus loading, plant growth trials were conducted to determine the lowest levels of phosphorus that could be applied without a decrease in plant quality. The results of this work reduced the amount of phosphorus applied and associated fertilizer costs by approximately 50 percent! Recent studies by Dr. White's team found that these same constructed wetlands helped to remove most disease organisms, such as those causing root rot, from water before it is reused for irrigation or flows off-site. Related research continues through "Clean WateR3 - Reduce, Remediate, Recycle – Enhancing Alternative Water Resources Availability and Use to Increase Profitability in Specialty Crops", a Specialty Crop Research Initiative funded project - Cleanwater3.org.

Success story provided by Stewart Chandler, Monrovia and Sarah White, Clemson University

8. RECLAIMING WATER

Reclaiming water becomes increasingly important nationally and globally as the world's population continues to increase. An increasing population in surrounding states means Tennessee's border and along with it, our water supply, may continue to be a legal issue. Within Tennessee's borders, the demand for water is also increasing; between 2008 and 2013 the amount of water drawn from wells increased by 108 percent to support an increasing amount of acreage being irrigated in Tennessee. If a water shortage does occur in Tennessee, having a water recycling system already in place can supplement other water supplies, lessening the impact on crops in production.

Other benefits:

- Directing and capturing runoff will reduce the nursery's impact on adjoining waterways and other environmental systems by preventing pesticides, plant growth regulators and nutrients in irrigation water from leaving the nursery (Figure 50)
- Conveyance to, and containment ponds themselves, can be designed to filter water

Figure 50. Water carrying excess nutrients can enter natural waterways leading to eutrophication

Mitigating Risks

Because nurseries tend to apply several types of agrichemicals during a season, it is possible that fertilizers, pesticides and plant growth regulators may be reapplied to crops via reclaimed water, leading to a decline in plant appearance and/or health and possibly decreased growth and plant death. If leachate contains plant pathogens, the pathogens will be carried to collection ponds in runoff. Pathogens can be applied to crops in reclaimed irrigation water, causing an increase in pesticide use and decrease in plant health and quality and potentially decrease plant survival.

- Diverting runoff through wetlands or other vegetative areas before entering a collection structure allows biological processes to break down and filter water impurities (Figure 51)
- Using aerators in collection structures helps to speed up biological processes that break down water impurities
- Fresh water can be blended with reclaimed water before irrigation to dilute impurities
- Test water at regular intervals, preferably monthly, and treat as needed

Figure 51. Wetlands help to purify reclaimed water

Photo credit: Sarah A. White

COLLECTION STRUCTURES

- A containment structure should be designed to accommodate at least 90 percent of the daily irrigation applied as well as one half inch of water per acre to account for rain events*
- Containment structures can be lined with clay, concrete or a synthetic liner or depending on soil type, the existing soil can be compacted to prevent infiltration and drainage of water into the natural soil
- If groundwater seeps into the containment structure after it is dug, make the pond shallower or provide an impermeable barrier so the two water sources cannot mix to prevent groundwater contamination
- Install a way to discharge water from the containment structure in the event of heavy rainfall to prevent overflow into production areas

**Keep in mind this estimate only describes the size needed to capture daily water runoff and is not intended to be used as an estimate of pond size for a primary water source. Building a larger pond than this minimum will accommodate an increase in production and/or allow the containment pond to also serve as a water supply.*

WATER CONVEYANCE

Slope of the land

- When determining where to put retention ponds or other water-reclaiming structures, pay attention to where the water naturally flows after an irrigation cycle and/or heavy rainfall event
- Use the slopes and contours of the land to passively guide water from the nursery area to the collection structure (Figure 52)

Figure 52. Use the natural slope of the land to passively guide water to a containment structure

Water conveyance ditches

- If land is flat, conveyance ditches or channels must be constructed to direct the water flow (Figure 53)
- Consider the slope and the volume of water the ditch is expected to carry; improperly constructed water conveyance structures can cause erosion problems and decrease water quality
- Vegetation should be planted along ditches to prevent erosion and to serve as biofilters
- Water in open ditches is subject to evaporation, especially if water flow is slow, thereby decreasing the amount of water that reaches retention ponds; ditches shaded with vegetation have lower

Figure 53. If irrigation water pools, conveyance ditches may need to be constructed

evaporation rates than bare ditches

- Ditches should have breaks or obstacles, such as rocks or vegetation, to slow the water flow and encourage sediment suspended in the water to settle
  - ∞ However, water should always be moving as still water makes a great breeding ground for mosquitos
- Poorly designed conveyance ditches can cause safety issues for workers, equipment and vehicles
- Conveyance ditches may be an inefficient use of land as ditches have to be wide enough to hold and carry not only irrigation water runoff, but also storm water (Figure 54)

Figure 54. Conveyance ditches carry water to containment structures

Plant Selection

When choosing vegetation for a drainage ditch, it is important to consider plants that can tolerate fluctuating dry and wet periods, are easy to maintain and will not spread weed seeds to the nursery. Be wary of plants that spread quickly as these may clog waterways and require more maintenance.

Underground pipes

- Pipes buried underground carry water from irrigation areas to retention ponds or drainage ditches
- Pipes used should be large enough in diameter to convey everyday runoff as well as allow for future expansion and heavy storm events

- Underground pipes reduce liability compared with open water ditches
- Underground pipes allow for more efficient use of land than open water ditches
- Underground pipes may be more expensive to install, maintain and repair than open ditches (Figure 55)

Figure 55. Drainage tiles lead to underground pipes that carry water to the containment structure

Success Story

Reducing Water Use Producing a Water Hog

McCorkle Nurseries, Inc.

Identifying ways to extend water supplies, especially during droughts, is an important aspect of nursery management. In 2008, McCorkle Nurseries in partnership with the University of Georgia, installed a Moisture Clik™ irrigation controller (Dynamax) trial on 4 of their 7 bays dedicated to producing *Hydrangea macrophylla* 'Mini Penny', a heavy water user and water sensitive crop. Moisture Click™ determines when to irrigate based on container substrate moisture content. This easy-to-use controller has a dial that is used to set the volumetric water content (VWC). For this project, the dial was set for 20 percent VWC, a fairly low moisture level. McCorkle Nurseries' water use went down 83 percent (133,000 gallons using their standard irrigation, compared to just 23,300 gallons with the Moisture Click™) from May 6 to July 23, 2008. Their traditional irrigation was timer-based, approximately 20 minutes per hour for 4 hours each morning at the beginning of the crop cycle, more as the plants grew. Moisture levels were more stable for the sensor-based system. The heavier irrigation provided by their standard irrigation practices led to greater fertilizer loss. For example, the fertilizer salt level in the nursery standard irrigation plot was 0.94 mS/cm, while that of the substrate moisture sensor-controlled plots was 1.51 mS/cm. Also, plants that typically required several plant growth regulator applications to increase plant quality no longer needed these applications when grown in plots using the Moisture Clik™. McCorkle Nurseries continues to use a substrate moisture sensor-based irrigation system.

Success story provided by McCorkle Nurseries and Marc van Iersel and Matthew Chappell, University of Georgia

For more information see: van Iersel, M., R.M. Seymour, M. Chappell, F. Watson, and S. Dove. 2009. Soil Moisture Sensor-Based Irrigation Reduces Water Use and Nutrient Leaching in a Commercial Nursery. Proceedings of the Southern Nursery Association Research Conference. vol. 54, pages 17-21. http://www.sna.org/Resources/Documents/09resprocsec01.pdf

9. DROUGHT PREPAREDNESS

Although it may seem like Tennessee has an abundance of water, it is important to realize that this is not always the case. The state has a drought plan. Shouldn't you, as a grower, have one too?

STATE PLAN

Tennessee experienced a major drought in 1987-88 and another one more recently in 2007. In the case of the 2007 drought, the state took several actions, including:

- Limited community water withdrawals that impacted sensitive aquatic habitats, such as rivers and lakes
- Increased the amount of water released from reservoirs to compensate for low flows
- Restricted the amount of water recreational fields, such as golf courses, may withdrawal
- Banned lawn watering in some communities
- Trucked or piped additional water to farm sites (the legal wording of this drought mitigation strategy implies food crops and livestock only)

For more information, refer to the State of Tennessee Drought Management Plan.

DEVELOPING A DROUGHT PREPAREDNESS PLAN…IT'S NOT ALWAYS AS EASY AS DIGGING A WELL!

During the 2007 drought, the number of wells drilled in Warren Country doubled compared to a typical year. What if drought conditions could not be solved simply by drilling a well? What if the state of Tennessee changes the permitting process, the increasing demand for wells causes delays to your well installation or digging a well becomes challenging because the water table has dropped? Having a plan for drought will provide a clear course of action during the chaos of water limitations. Key aspects of preparing for a drought should be addressed well in advance of water scarcity. In fact, making sure that water is being applied efficiently and in the amount crops need is the first priority. Wasting water due to poor delivery system infrastructure and poorly tailoring application amount to crop water use and soil/substrate water holding capacity will cause a nursery to exhaust its limited water supply much more quickly during a time of drought. This section addresses how to prepare in advance by conducting an irrigation audit and other preparations that can be made before a drought strikes.

Conduct an Informal Irrigation Audit

One of the best ways to evaluate your system efficiency is to conduct an irrigation audit. An irrigation audit can be conducted by a professional or you can conduct an informal irrigation audit. When conducting a self-audit, identify areas that need corrected in the short-term and prioritize those that need improvement in your long-term plan.

- Official irrigation audit standards can be found on the Irrigation Association website
- Schedule uninterrupted time to talk to employees who operate the irrigation system about their approach
  - Ask about opportunities to improve and areas of concern
- Schedule a leak identification period for one of the first really warm days of summer
  - As the irrigation runs, give a designated employee the task of flagging leaking pipes, risers and sprinklers
  - Consider making this a nursery-wide event; provide lunch or another perk that makes it a fun day for employees, and award prizes for identifying or fixing the most leaks
- Schedule “Raising Risers” days periodically during the growing season
  - Use those days to straighten and secure leaning sprinkler risers and identify and fix other problems
  - Make sure sprinkler heads in each zone are all of the same type/model and are functioning properly

Take Time to Talk with Employees!

With any large business, there can be a disconnect between what the nursery owner or general manager thinks is being done and what is done in day-to-day practice. By visiting with employees routinely, needs can be identified sooner and costly repairs and water shortages can be prevented.

- Test distribution uniformity (DU)
    - Set the goal of testing DU in each zone over the course of a season
    - Make changes as suggested in Irrigation System Efficiency
- When a bed is completely harvested and empty, take that opportunity to check DU and application rate
    - Check risers and emitters for leaks and wear before filling it with plants

Once water distribution problems are addressed, begin refining the amount of water plants receive. Refer to Cultural Practices That Can Reduce Water Use and Scheduling Irrigation for information on tailoring irrigation application volume to actual plant use. Applying water efficiently and only the amount that plants need are the first steps in being prepared for drought because they will greatly reduce the amount of water needed on a daily basis and allow your nursery to better cope with water scarcity.

DROUGHT PREPAREDNESS PLAN

A drought preparedness plan can include both immediate measures you plan to take to lessen the effect of drought and strategies you plan to act on when water becomes scarce.

Before a Drought Restricts Water Use

Consider the following changes when developing your drought preparedness plan:

- Change some of the plant species you grow to more drought tolerant species
- Consider if your customers have ample water and what plants they'll demand in the future
- Reconsider delivery method (for example, convert from traveling guns to drip lines for field production) and irrigation scheduling method
- Evaluate your production system; could you convert some container-grown crops to field production?
- Plant hedges as windbreaks
- Re-evaluate the height of sprinkler risers and make sure that they are not taller than necessary for the crop being grown
- Increase the capacity of retention ponds
- Purchase a water tank to collect rainwater
- Drill wells, if possible
- Install conservation devices such as a rain delay
- Install a few water meters each year until your whole farm is metered as a means of establishing how much

water you need in a typical season

- Consider purchasing land with greater water resources

When Water Becomes Restricted*

Consider the following when developing prioritizations for water use in your Drought Preparedness Plan:

- Communicate to your customers what you are experiencing and how you are handling it to sustain your business for the long run
- Let customers know the plant inventory you have available; offer attractive but competitive price discounts, and be sure to contact customers who are not in drought-stricken areas and thus will continue to buy, sell and/or install plants
- Identify plants that will be culled instead of watered
  - ∞ Cull loss leaders (plants sold below market cost to stimulate sales of other, profitable plants or products)
  - ∞ Cull pot bound and oversized plants that require more water
  - ∞ Cull or sell smaller sizes like #1 containers as they may be more difficult to amply irrigate during a drought
    - -- Smaller plants can be replaced faster than larger ones after the drought
- Irrigate
  - ∞ High margin plants
  - ∞ Crops that are unique to your nursery
  - ∞ Difficult to source/propagate plants
- Identify plants that can tolerate less frequent

irrigation including those under shade, evergreens with low water needs, and plants with waxy leaves

- Install shade fabric to the roof, and windward and sunny sides of houses
- Replace root pruning, biodegradable, and other porous containers with solid plastic pots
- Replace black plastic containers with lighter colored plastic containers

*Adapted from LeBude and Bilderback 2007

For Continued Water Conservation

- Visit nurseries in other areas and learn from their water-conserving practices
- Join the East Tennessee Nursery Association, Middle Tennessee Nursery Association, Tennessee Nursery and Landscape Association or your state's association(s) for frequent updates and news articles
- Complete the Tennessee Master Nursery Producer Program or your state's professional development program for in depth information on irrigation and other nursery production topics
- Join the International Plant Propagators' Society and other organizations that offer tours of innovative nurseries

CALCULATIONS

This section provides the methods to calculate capture factor (CF), distribution uniformity (DU), evapotranspiration (ET), irrigation delivery rate (IDR) and leaching fractions (LF). Examples of each calculation are given.

Important terminology:

Catch can = container used to catch irrigation water

Drainage can = container used to catch the leachate (drainage) from another container that has a plant growing in it

Plant container = a container with a plant growing in it

Nested container = a plant container nested in a drainage can

Important considerations:

Tests of overhead irrigation system efficiency should be done when the wind speed is less than 5 mph, such as early in the morning. However, the wind conditions during the normal run time should be taken into consideration to ensure that coverage is sufficient and that run time is adequate under typical conditions.

The more densely catch cans are spaced when doing application rate and tests of uniformity, the more accurate the results. However, it also becomes more time intensive the more cans there are to measure. Sources vary on the suggested density. In nurseries, a 5 ft by 5 ft spacing has been recommended, however, the irrigation association recommends 24 per zone or more, if there is a smaller sprinkler spacing. Ideally, the spacing of the catch cans would be no greater than 10 percent of the sprinkler throw radius.

CAPTURE FACTOR (CF)

1. Select and label representative container-grown plants within an irrigation zone. Measure the top diameter of the plant container (cm) and use that to calculate its area (area of a circle = πr^2).

Figure 56. Plant in drainage can and catch can of equal size

2. Nest several plant containers into other tight-fitting containers (drainage cans) to catch all leachate that drains from the plant containers (Figure 56). Weigh each set of nested containers to the nearest 0.01 kg and place them back into the irrigation zone (Figure 57).
3. Measure the diameter and calculate the top area of catch cans and place several within the irrigation zone being tested. Raise catch cans so their opening is at the same height as the top of the canopy of surrounding plants.
4. Run a typical irrigation event.
5. Reweigh each set of nested containers to the nearest 0.01 kg. To calculate the irrigation water that entered the plant containers, subtract the initial weight from the final weight and convert kg to cm^3 (multiply by 1000 because 1000 cm^3 = 1 kg). Then, divide the volume of irrigation water that entered the plant container (in cm^3) by the plant container's top area (step 1) to determine the depth of water that entered the plant container.
6. Measure the volume of irrigation water in the catch cans using a graduated cylinder in cm^3 (1 mL = 1 cm^3) and determine the average catch can volume (Figure 58). To calculate the depth of water applied by irrigation, divide the average volume of water collected in the catch cans by the top area of the catch cans.
7. The capture factor is the depth of water captured by the container-grown plant (step 5) divided by the irrigation depth applied (step 6).


Figure 57. Weigh the nested container before and after irrigation


Figure 58. Measure irrigation captured

Cature factor is only calculated for overhead irrigation. In microirrigation, it is assumed that the container is receiving 100 percent of the water applied.

Using a catch or drainage can of the same top diameter as the plant container will reduce the number of calculations. Simply line an empty production container with a plastic bag to create a catch or drainage can or ask your container manufacturer for containers without the drain holes punched in them. Place a spacer such as a short section of pvc pipe between the two containers to prevent the plant container from sitting in leachate and absorbing water. For nested containers, lining the drainage can with a bag works best for containers with holes on the bottom as side holes can be blocked from draining freely when the plant container is nested in it.

Example:

1. Select representative plants.
    a. Measure the diameter at the top of the plant container
        i. Diameter = 27.94 cm
    b. Calculate the top area of the plant container (area of a circle = πr^2)
        i. $r = 27.94 \text{ cm} \div 2 = 13.97 \text{ cm}$
        ii. $\pi r^2 = 3.14 * 13.97^2 = 613 \text{ cm}^2$
2. Nest several containers and weigh them prior to irrigating.
    a. Average weight before irrigation = 8.42 kg
3. Place several catch cans in the zone and run a typical irrigation cycle.
    a. Measure the diameter at the top of the catch can
        i. Diameter = 10 cm
    b. Calculate the top area of the catch can (area of a circle=πr^2)
        i. r (radius) = $10 \text{ cm} \div 2 = 5 \text{ cm}$
        ii. $\pi r^2 = 3.14 * 5^2 = 78.5 \text{ cm}^2$
4. Reweigh nested containers.
    a. Average weight after irrigation = 9.36 kg
    b. Calculate average weight difference and convert to cm^3 ($1000 \text{ cm}^3 = 1 \text{ kg}$)
        i. 9.36 kg – 8.42 kg = 0.94 kg
        ii. $0.94 \text{ kg} * 1000 \text{ cm}^3/\text{kg} = 940 \text{ cm}^3$
    c. Calculate the irrigation depth captured in the plant container (volume difference ÷ area of container top)
        i. $940 \text{ cm}^3 \div 613 \text{ cm}^2 = 1.53 \text{ cm}$
5. Record the average volume in the catch cans.
    a. Average volume of water in catch cans = 82 cm^3
    b. Calculate the irrigation depth applied
        i. $82 \text{ cm}^3 \div 78.5 \text{ cm}^2 = 1.04 \text{ cm}$
6. Calculate the capture factor.
    a. Irrigation captured (step 4) ÷ Irrigation applied (step 5)
        i. 1.53 cm ÷ 1.04 cm = 1.5
7. The capture factor is 1.5; therefore this plant is receiving 1.5 times as much irrigation water as an empty pot, or a plant with a capture factor of 1.

DISTRIBUTION UNIFORMITY (DU) OF THE LOWER QUARTER

1. Place 24 catch cans in a uniform grid pattern inside the irrigation zone. If plants are present in the irrigation zone being tested, raise catch cans so their opening is at the same height as the top of the canopy of surrounding plants. Catch cans that won't blow away work best.
2. Run a typical irrigation cycle.
3. Use a graduated cylinder or measuring cup to record the amount of water in each catch can.
4. Arrange the irrigation volumes from lowest to highest. Map the position of each catch.
5. Calculate the average water volume of all 24 catch cans.
6. Calculate average of lower 25 percent--lowest 6 catch cans (by volume).
7. Divide average of lower 25 percent (step 6) by overall average volume (step 5) and multiply by 100 to calculate percent uniformity.

Example:

1. Place 24 catch cans in irrigation zone.
2. Run irrigation cycle.
3. Record the volume of water (in cm^3) for each catch can using a graduated cylinder.
    a. 1 ml = 1 cm^3
4. Calculate the average volume of water in all 24 catch cans.
    a. Average volume of water = 82 cm^3
5. Calculate the average volume of water in the lower 25 percent of catch cans.
    a. Average volume of water in the lower 25 percent = 71 cm^3
6. DU equals the average volume in the lower 25 percent divided by the average volume of all catch cans.
    a. DU = 71 $cm^3 \div 82$ cm^3 = 0.87 = 87%

80 percent or higher is adequate, lower than 60 percent DU indicates serious problems with design or hardware and requires further investigation; 60-80 percent indicates there is a lot of opportunity for improvement and run time is probably longer than necessary to compensate for poor DU.

IRRIGATION DELIVERY RATE (IDR)

1. Record catch can diameter and place several within the irrigation zone, above plant canopies (Figure 59).
2. Calculate the area of the catch can (area of a circle = πr^2).
3. Operate irrigation for the normal amount of time; record the run time.
4. Collect the water from each catch can and get the average water captured per catch can.
5. Calculate the amount of irrigation water applied by dividing the average amount of water captured (step 4) by the area of the top of the catch can (step 2) and convert this number to inch/hour (60 minutes = 1 hour, 2.54 cm = 1 inch).

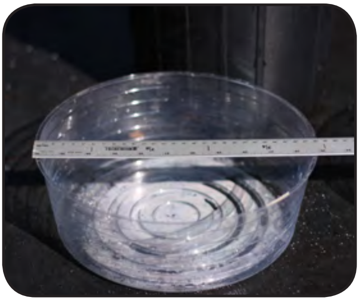

Figure 59. Measure catch can diameter

Example:

1. Place catch cans in irrigation zone.
    a. Measure the diameter of top of the catch can
        i. Diameter = 10 cm
    b. Calculate the area of the top of the catch can (area of a circle=πr^2)
        i. r = 10 cm ÷ 2 = 5 cm
        ii. $\pi r^2 = 3.14 * 5^2 = 78.5\ \text{cm}^2$
2. Run a typical irrigation event.
    a. Time irrigation ran = 30 minutes
3. Collect water from catch cans.
    a. Average water volume captured = 82 cm^3
4. Calculate the amount of water applied.
    a. Average water volume captured (step 3) ÷ area of the top of the catch can (step 1)
        i. $82\ \text{cm}^3 \div 78.5\ \text{cm}^2 = 1.04$ cm
    b. Convert irrigation time to hours (60 minutes = 1 hour)
        i. 30 mins ÷ 60 mins/hour = 0.5 hour
    c. Convert amount of water applied to inches (2.54 cm = 1 inch)
        i. 1.04 cm ÷ 2.54 cm/inch = 0.41 inch
    d. Determine how many inches of water are applied in an hour
        i. 0.41 inch ÷ 0.5 hour = 0.82 inch/hour

Using straight-sided containers allows depth of water to be measured with a ruler, rather than calculated, which will save time.

Irrigation delivery rate can be measured at the same time as distribution uniformity.

EVAPOTRANSPIRATION (ET)*

1. Select a few representative plants of a species and label them.
2. Determine the area of the top of the plant container in cm² (area of a circle = πr^2).
3. Irrigate plants with a typical cycle.
4. Weigh plants about 1 hour after irrigation ceases to allow drainage to occur; measure to the nearest 0.01 kg.
5. Return plants to their original spots in the zone.
6. Re-weigh plants just prior to irrigation the next day; measure to the nearest 0.01 kg.
7. Subtract the ending weight (step 6) from the beginning weight (step 4); convert this number to the volume of water loss using the conversion factor 1 kg = 1000 cm^3.
8. ET (step 7) divided by the area of the top of the plant container ($cm^3 \div cm^2 = cm$).
9. Convert to inches to determine the amount of water needed to replace the amount of water lost through ET (2.54 cm = 1 inch).

Ideally, steps 3 and 4, should occur before dawn so that the only weight loss during the one-hour period is due to drainage.

Example:

1. Select a few plants of the same species or cultivar and label them.
2. Diameter of the top of the plant container equals 11 inches; need to find the area of a circle (πr^2).
   a. Convert to cm
      i. 11 inches * 2.54 cm/inch = 27.9 cm
   b. Divide diameter by 2 to get the radius
      i. 27.9 cm ÷ 2 = 14.0 cm
   c. Find the area
      i. $\pi r^2 = 3.14 * 14.0\ cm^2 = 615\ cm^2$
3. Morning weight, 1 hour after irrigation ceases, equals 10.86 kg.
4. Place plants back in their previous locations within the plot.
5. Reweigh just prior to next irrigation event to get 9.34 kg.
6. Subtract final weight from initial weight.
      i. 10.86 kg – 9.34 kg = 1.52 kg
   a. Convert to cm^3 (1 kg = 1000 cm^3)
      ii. 1.52 kg * 1000 cm^3 = 1520 cm^3/ container
7. Find plant container ET.
   a. Weight difference divided by area of the plant container top
      i. 1520 cm^3 ÷ 615 cm^2 = 2.47 cm
8. Convert to inches (2.54 cm = 1 inch).
      i. ET = 2.47 cm ÷ 2.54 = 0.97 inch / container
9. Therefore 0.97 inches of water is needed to replace the water lost in a day.

*adapted from Million and Yeager 2002

DETERMINE HOW LONG TO IRRIGATE USING CF, DU, ET AND IDR*

In order to accurately determine how much water to apply within an irrigation zone you need to conduct all four of the above calculations.

Example:
From previous calculations:

CF = 1.5
DU = 87%
ET = 0.97 inch
IDR = 0.82 inch/hour

Irrigation required by plants:

- (ET ÷ CF) * (100% ÷ DU)
- (0.97 inch ÷ 1.5) * (100% ÷ 87%) = 0.65 inch * 1.15 = 0.75 inch

Duration of time that irrigation should be operated:

Dividing by DU helps insure that the areas with lower application rates receive sufficient water, however plants are still subjected to the lows and highs of uneven DU (unless DU is 100 percent).

- Irrigation requirement ÷ irrigation delivery rate * 60 min/hour
- 0.75 inch ÷ 0.82 inch/hour * 60 min/hour = 55 minutes

*Adapted from Million and Yeager 2002

LEACHING FRACTION BASED ON WATER VOLUME

1. Place catch cans in irrigation zone near plants from which leachate will be collected.
2. Nest several plant containers inside drainage cans within an irrigation zone. Make sure each drainage can fits snugly around the plant container so that irrigation water cannot enter the drainage can.
    a. 5-gallon buckets are often used for 3-gallon containers
    b. Use the same diameter containers in steps 1 and 2
3. Run a typical irrigation event.
4. Measure the volume of water applied to each catch can (do immediately after irrigation shuts off, while waiting for containers to drain in order to minimize errors due to evaporation).
5. Allow plants to drain for an hour.
6. Carefully pour the leachate (water that drained into the drainage can) into a graduated cylinder or measuring cup.
7. Measure the volume from each drainage can.
8. Divide the leachate volume by the volume of water applied and multiply by 100 to get the leaching fraction.
    a. If leaching fraction is greater than 10-20 percent, irrigation run time should be reduced
    b. If leaching fraction is less than 10-20 percent, irrigation run time should be increased

Leachate can be combined and measured at one time as can irrigation water. This will save time, but it will not allow you to identify plants that are atypical and, therefore, should be excluded from the calculation.

Example:

1. Place four or more catch cans in irrigation zone near plants from which leachate will be collected.
2. Nest four plant containers within drainage cans of same diameter.
3. Operate irrigation for the normal amount of time.
4. Measure and record the volume of water applied to each catch can in a graduated cylinder or measuring cup.
    a. Measured irrigation water = 100 ml, 105 ml, 107 ml and 112 ml
    b. Measure immediately to prevent errors due to evaporation
5. Allow plants to drain for 1 hour, then measure and record the volume of water leached from each drainage can.
    a. Measured leachate water = 40 ml, 41 ml, 42 ml and 49 ml

6. Divide volume of water leached by volume of water applied.
    a. 40/100 = 40%, 41/105 = 39%, 42/107 = 39% and 49/112 = 44%
    b. Average leachate is 40.5 percent, therefore irrigation can be reduced to meet the target 10-20 percent leachate

LEACHING FRACTION BASED ON WEIGHT OF WATER

The effect of capture factor can distort leaching fraction calculations. For example, if the water measured in the catch can is less than what the plant container actually received because branches channeled water from outside the plant container, the leaching fraction will be inflated. Weight can be used to calculate leaching fraction and will more accurately account for the amount of water applied to each plant container. This method has been reported as a faster method than measuring water in graduated cylinders. Containers of identical diameters must be used unless the diameter is mathematically accounted for as described in other calculations in this section.

1. Weigh the drainage can.
2. Nest the plant container inside the drainage can.
3. Weigh the nested containers.
4. Operate irrigation for the normal amount of time and allow plants to drain for one hour.
5. Weigh the nested containers.
6. Determine the amount of irrigation water applied by subtracting the pre-irrigation nested container weight from the post irrigation weight.
7. Remove the plant container and weigh the drainage can with leachate.
8. Subtract the weight of the empty drainage can (step 1) from the weight of the full drainage can (step 7) to get the weight of just the leachate.
9. Divide the leachate weight (step 8), by the weight of irrigation water (step 6), to get the leaching fraction.
10. The target leaching fraction is 10-20 percent.

Figure 60. A 5 gallon bucket can usually be used as a drainage can for #3 containers

GLOSSARY

Application efficiency: The amount of water stored in the root zone in relation to the amount of water applied. For container production, calculated as the average volume of water retained by a container after an irrigation event divided by the average volume of water applied to the container based on container top surface area. It is the inverse of the leaching fraction (See leaching fraction). For soils, the ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied.

Available water: The amount of water in the soil or substrate minus the amount of unavailable water. The most water is available at field/container capacity and the least amount of water is available as the permanent wilting point is approached. Available water is not the amount of water that can be absorbed by plants, as that is species specific.

Capture factor (CF): The plant canopy's capacity to direct overhead irrigation into or away from its container. Reflects the ability of the plant canopy to extend (or decrease) the effective collection area. Calculated as the ratio of water captured by the container with the plant compared to the amount captured by the same container without the plant. For CF, the denominator is the amount of water captured by a container, compare to interception efficiency where the denominator is based on the amount of water applied to the space allotted to each container+plant. A CF of >1 indicates more water enters the container than would enter the same container with no plant. A CF = 1 indicates the amount of water entering the container is not affected by the plant canopy. A CF of <1 indicates less water enters the container than would enter the same container with no plant. Capture factor can be used to adjust irrigation run time to ensure the intended amount of water is being applied.

Christiansen's uniformity coefficient (CUC): A measure of how evenly water is applied in an irrigation zone. The sum of the absolute value of the difference in the amount measured in each catch can and the average amount measured divided by the number of catch cans multiplied by the average amount of water measured. A CUC of 84 percent or greater is desirable. Also consider distribution uniformity (low quarter).

Container capacity (CC): The maximum amount of water held (maximum water holding capacity) in a substrate when completely saturated and after gravity has drained all free water; generally measured 1 hour after irrigation ceases. The maximum percent volume of the container occupied by water. The CC varies by substrate components and container height. For bark-base substrates, container capacity usually ranges from 60-70 percent. See water holding capacity.

Cyclic irrigation: Applying the total daily irrigation volume in several smaller applications generally 30 minutes to 2 hours apart instead of one large daily application.

Daily water use: The loss of water from evapotranspiration within approximately a 24 hour period, typically measured by weighing plants 1 hour after irrigation ceases, when at container capacity, and again 24 hours after irrigation was initiated. Measured while plants are under a normal irrigation schedule with no rainfall. Water use is calculated in units of water per day by subtracting final measurement from the initial measurement.

Data logger: An electronic device that records data from internal or external sensors.

Distribution uniformity (DU) (low quarter): A measure of how evenly water is applied to an irrigation zone based on the driest 25 percent of that zone. Calculated by dividing the average application of the driest 25 percent of a zone by the overall average application volume for that zone and multiplying by 100 to get a percentage. DU of approximately 80 percent or better is desirable. Also see Christiansen's uniformity coefficient.

Evaporation: The conversion of liquid water into water vapor resulting in water loss from the soil/substrate surface.

Evapotranspiration: The combination of water evaporated from the substrate/soil and used in transpiration by the plant.

Field capacity: The amount of water a field soil can hold from irrigation or rain following 2-3 days of drainage under normal conditions, assuming a uniform soil profile and no evaporation.

Groundwater supply: Water that is stored beneath the earth's surface; refers to water stored in aquifers as well as moisture in the soil.

Interception efficiency (IE): Reflects the amount of water captured by a container compared to the amount of water applied to the space allotted to each container+plant. Calculated as the volume of water entering each container divided by the amount applied to the space each plant/container is allotted, then multiply by 100 to get a percentage. The IE is a function of plant spacing and container size. Interception efficiency increases the closer the plant spacing is; containers spaced can tight in a triangular pattern have the highest IE. The fewer the plants occupying a zone, the more space is allocated to each, decreasing IE. Capture factor influences IE; plants with a higher CF may have a higher IE at a given container spacing because their branches can intercept water that would otherwise fall between containers.

Irrigation: A controlled process where water is applied to a soil or substrate for plant use.

Irrigation application efficiency: See application efficiency.

Irrigation controller: A device that is programmed to turn an irrigation system on and off according to the irrigation schedule.

Irrigation efficiency: In everyday terms, this refers to applying the minimum amount of water to achieve the greatest results. In technical terms, can refer to 1) irrigation system performance, 2) uniformity of application, or 3) crop response to irrigation (See water use efficiency).

Irrigation scheduling: When to irrigate, how much to apply and for what duration.

Leachate: Water that may contain nutrients, pesticides and plant growth regulators draining from a container (or to soil below the root zone) during and following irrigation; container effluent.

Leaching: Drainage of water that may contain nutrients, pesticides and plant growth regulators from a container (or below the root zone in soil) during and following irrigation.

Leaching fraction (LF): The ratio of water leached to water applied from an irrigation application. Calculated as the volume (or weight) of leachate divided by the volume (or weight) of irrigation applied and multiplied by 100 to get a percentage. A LF of 10-20 percent is desirable. It is the inverse of application efficiency (See application efficiency).

Matched precipitation: A zone in which the application (precipitation) rate provided by all sprinklers is the same. A 90° sprinkler would apply water at ¼ the rate of a 360° sprinkler, and a 180° degree sprinkler would apply water at half the rate of a 360° sprinkler so that the entire zone receives the same amount of water.

Microirrigation: Localized irrigation that provides water directly to a small area of soil or substrate as opposed to overhead irrigation.

Permanent wilting point: The highest water content of a soil or substrate at which plants wilt and fail to recover when irrigated.

Plant available water: See available water.

Real-time: Measurements provided or made available to the end-user instantaneously as opposed to at the end of a day or another time period.

Root zone: The portion of soil or substrate occupied by roots from which roots absorb water and nutrients.

Runoff: Precipitation or irrigation water that discharges from the production area rather than infiltrating and being retained by the substrate or soil. Water that originates at one place, such as a nursery, but ends up at another place, such as a stream. Runoff that does not permeate the soil is known as surface runoff; when it permeates the soil it is called groundwater runoff.

Scheduling coefficient: A multiplier that reflects the application uniformity of a zone. Irrigation run time is increased by the scheduling coefficient to ensure the driest portion of the zone receives the intended amount of water. When using a scheduling coefficient, other areas of the zone will receive more than the intended application volume.

Stomata: Regulated openings, mostly located on the undersides of leaves, which control gas exchange. In general, CO_2 enters the plant and O_2 and water vapor are released.

Substrate solution/soil solution: The combination of water and dissolved substances (solutes) held within the substrate or soil between irrigation events. Chemical and biological activity occur in the soil/substrate solution.

Transpiration: Evaporation of water primarily through plant leaves via openings called stomata. Transpiration cools the plant and aids in solute transport from the substrate or soil solution to aboveground portions of the plant. Nearly all water taken up by a plant is used for transpiration, leaving only a fraction that is actually used for growth and other metabolic functions.

Unavailable water: The portion of water that cannot be removed from the soil or substrate by plants. The water that is inaccessible to plants either as a result of being adsorbed to the surface of solid particles or bound tightly in micropores. It is the water remaining in the soil or substrate when a plant reaches permanent wilting point. It can also be calculated as field or container capacity minus available water.

Volumetric water content (VWC): Volumetric water content is the volume of liquid per volume of soil or substrate; the volume of water retained in the pore or void space in a known volume of substrate or soil.

Water holding capacity: The amount of water that can be held by a unit volume or weight of soil or substrate (see field capacity and container capacity).

Water potential: A measure of how tightly water is bound to soil or substrate. Measured water potential is a negative number (unless free water is present) and is often expressed in bars or megapascals (MPa). Water will move from a less negative water potential to a more negative water potential.

Water quality trading: A joint EPA-USDA program that allows one entity to purchase the environmental equivalent (or better) pollution reductions from another entity who can achieve these reductions at a lower cost. The end result is water quality goals are met but at a lower cost.

Water trading: The act of a water owner selling his water rights/access to another person or business.

Water use efficiency (WUE): Describes irrigation effectiveness in terms of crop growth. Water use efficiency assesses biomass gained during a production period or season in which irrigation was applied. Calculated as the difference between beginning and ending growth index (or dry weight) divided by amount of irrigation applied plus precipitation.

IRRIGATION pH CHECKLIST

AN IMPORTANT LINK BETWEEN YOUR IRRIGATION WATER AND PLANT HEALTH

- ☐ pH measures the concentration of hydrogen ions in a solution on a scale of 0 to 14 – less than 7.0 is acidic and greater than 7.0 is basic.
- ☐ pH determines the availability of many plant nutrients.
- ☐ An incorrect soil pH will limit plant growth and can cause nutrient deficiencies.
- ☐ pH can determine flower color in some plants like *Hydrangea macrophylla*.
- ☐ The pH of your water can alter the efficacy of some pesticides spray solutions.
- ☐ Both high and low water pH can damage spray equipment and parts.
- ☐ pH can influence how certain water treatments work, such as chlorine.
- ☐ Irrigation water that has a pH of 5.4 to 7.0 is ideal for most nursery and landscape plants.
- ☐ Container substrate that has a pH of 5.2 to 6.3 is ideal for most nursery crops.
- ☐ To lower the pH of the substrate solution, consider reducing lime in substrate, using acidifying forms of nitrogen, or injecting acid into irrigation water for more severe cases.
- ☐ Alkalinity indicates how difficult it will be to change the pH. Check it too!
- ☐ Test irrigation water at least once a year and monitor container leachate for EC and pH every 1-2 weeks during the growing season.

Acid loving plants: These plants prefer a pH of 5.0 or less

Franklinia – *Franklinia alatamaha* | Carolina silverbell – *Halesia carolina* Mountain laurel – *Kalmia latifolia* | Sweetbay magnolia – *Magnolia virginiana* | Sourwood – *Oxydendrum arboreum* | Japanese pieris – *Pieris japonica* |Azalea and Rhododendron – *Rhododendron* spp. Blueberry – *Vaccinium* spp.

Resources

1.&2. INTRODUCTION AND WATER SOURCES

All Tennessee code (Tenn. Code) information can be found at:
http://www.lexisnexis.com/hottopics/tncode/.

EPA/USDA water trading initiative:
http://water.epa.gov/type/watersheds/trading/upload/2008_09_12_watershed_trading_mou061013.pdf.

Well requirements for installers, builders, and owners:
http://www.lexisnexis.com/hottopics/tncode/ (title 69, chapter 10).

Beeson, Jr., R.C., M.A. Arnold, T.E. Bilderback, B. Bolusky, S. Chandler, H.M. Gramling, J.D. LeaCox, J.R. Harris, P.J. Klinger, H.M. Mathers, J.M. Ruter, and T.H. Yeager. 2004. Strategic vision of container nursery irrigation in the next ten years. J. Environ. Hort. 22:113-115.

Ferner, M. 2013. These 11 cities may completely run out of water sooner than you think. The Huffington Post. December 4, 2013. Accessed on 16 Dec. 2014. http://www.huffingtonpost.com/2013/12/04/water-shortage_n_4378418.html.

Food and Agricultural Organization of the United Nations (FAO). 2007. Coping with water scarcity. Accessed on 26 Feb. 2013. http://www.fao.org/nr/water/docs/escarcity.pdf.

Harding R. 1991. The saline groundwater of the Sow Valley, and of the Upper Trent Valley near Weston. M.S. Thesis, University of Birmingham.

Hodgson, S. 2006. Modern water rights, theory and practice. Food and Agriculture Organization of the United Nations Legislative Study 92. ISSN 1014-6679. Development Law Service Legal Office, Rome, Italy.

Jones, H.G and F. Tardieu. 1998. Modelling (sic) water relations of horticultural crops: a review. Sciencia Hort. 74:21-46.

Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace, and M.A. Maupin. 2009. Estimated use of water in the United States in 2005. U.S. Geological Survey, Reston, VA. Circular 1344:52.

Kulac, S., P. Nzokou, D. Guney, B.M. Cregg, and I. Turna. 2012. Growth and physiological response of Fraser fir [Abies fraseri (Pursh) Poir.] seedlings to water stress: Seasonal and diurnal variations in photosynthetic pigments and carbohydrate concentration. HortScience 47(10):1512-1519.

Schaible, G.D. and M.P. Aillery. 2012. Water conservation in irrigated agriculture: trends and challenges in the face of emerging demands. United States Department of Agriculture, Economic Research Service. Washington, DC.

United States Department of Agriculture (USDA). 2013. 2013 Farm and ranch irrigation survey, Table 4. Census of Agriculture. Washington, DC. Accessed on 8 January 2015. http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris13_1_004_004.pdf.

3. WATER TESTING

Argo, W.R. and P.R. Fisher. 2002. Understanding pH management for container-grown crops. Meister Publishing Company. Willoughby, OH.

Bailey, D., T. Bilderback, and D. Bir. 1999. Water considerations for container production of plants. Raleigh: North Carolina State University, NC Cooperative Extension Service. Horticulture Information Leaflet 557. http://content.ces.ncsu.edu/water-considerations-for-container-production-of-plants.pdf.

Bui, E. 2013. Possible role of soil alkalinity in plant breeding for salt-tolerance. Biol. Lett. 9(5):20130566.

Costello, L.R., E.J. Perry, N.P. Matheny, J.M. Henry, and P.M. Geisel. 2003. Abiotic disorders of landscape plants: a diagnostic guide. UCANR Publications. publication 3420.

Devitt, D.A., R.L. Morris, M. Baghzouz, and M. Lockett. 2005. Water quality changes in golf course irrigation ponds transitioning to reuse water. HortScience 40:2151-2156.

Duncan, R.R., R.N. Carrow, and M.T. Huck. 2009. Turfgrass and landscape irrigation water quality: Assessment and management. CRC Press. Taylor & Francis Group. Boca Raton, FL.

Hillel, D. 2000. Salinity Management for Sustainable Irrigation: Integrating Science, Environment, and Economics. The International Bank for Reconstruction and Development/The World Bank. http://dx.doi.org/10.1596/0-8213-4773-X.

Kerkhoff, K.L. and D. Melchior. 2006. How to: Test irrigation water quality. Grounds Maintenance 41(7).

Obreza, T., E. Hanlon, and M. Zekri. 2008. Dealing with iron and other micro-irrigation plugging problems. IFAS. SL 265. http://edis.ifas.ufl.edu/pdffiles/SS/SS48700.pdf.

Park, D.M., S.A. White, L.B. McCarthy, and N. Menchyk. 2014. Interpreting Irrigation Water Quality Reports. Clemson University Cooperative Extension. CU-14-700.

Park, D.M., S.A. White, and N. Menchyk. 2014. Assessing irrigation water quality for pH, salts, and alkalinity. J. Ext. 52(6) Article 6TOT8. http://www.joe.org/joe/2014december/tt8.php.

Parke, J. and P. Fisher. 2012. Treating Irrigation Water. The Digger. http://c.ymcdn.com/sites/www.oan.org/resource/resmgr/imported/digger/Digger_201202_pp41-45_web.pdf.

Spectrum Analytic, Inc. 2013. Guide to Interpreting Irrigation Water Analysis. http://www.spectrumanalytic.com/support/library/pdf/guide_to_interpreting_irrigation_water_analysis.pdf.

UMass Extension. 2014. Water Quality for Crop Production. University of Massachusetts Extension. http://ag.umass.edu/greenhouse-floriculture/greenhouse-best-management-practices-bmp-manual/water-quality-for-crop.

Wilson, P.C. 2010. Water Quality Notes: Alkalinity and Hardness. IFAS. SL 322. http://edis.ifas.ufl.edu/pdffiles/SS/SS54000.pdf.

Yeager, T. H. 1999. Collecting water samples at container nurseries. IFAS. ENH128.

Zinati, G. and X. Shuai. 2005. Management of Iron in Irrigation Water. Rutgers Cooperative Research and Extension Factsheet FS516. https://njaes.rutgers.edu/pubs/fs516/.

4. CULTURAL PRACTICES THAT CAN REDUCE WATER USE

Beeson Jr., R.C. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26(7):848-850.

Beeson, Jr., R.C. and T.H. Yeager. 2003. Plant canopy affects sprinkler application efficiency of container-grown ornamentals. HortScience 38:1373–1377.

Bilderback, T.E. and M.R. Lorscheider. 2007. Best Management Practices: Overhead Irrigation. Green Industry Knowledge Center for Water and Nutrient Management Learning Modules. http://www.waternut.org/moodle/course/view.php?id=18.

Bilderback, T.E., S.L. Warren, J.S. Owen, and J.P. Albano. 2005. Healthy substrates need physicals too! HortTechnology 15(4):747-751.

Bilderback, T., C. Boyer, M. Chappell, G. Fain, D. Fare, C. Gilliam, B.E. Jackson, J. Lea-Cox, A.V. LeBude, A. Niemiera, J. Owen, J. Ruter, K. Tilt, S. Warren, S. White, T. Whitwell, R. Wright, and T. Yeager. 2013. Best management practices: Guide for producing nursery crops. 3rd ed. SNA, Acworth, GA.

Boyer, J.S., S.C. Wong, and G.D. Farquhar. 1997. CO_2 and water vapor exchange across leaf cuticle (epidermis) at various water potentials. Plant Physiol. 114(1):185-191.

Day, S.D., J.R. Harris, and S.B. Dickinson. 2008. Basic Overview of Soils and Substrates. Green Industry Knowledge Center for Water and Nutrient Management Learning Modules. http://www.waternut.org/moodle/course/view.php?id=11.

Furuta, T. 1974. Environmental plant production and marketing. 1st ed. Cox Publishing, Arcadia, Calif. p. 94-156.

Mathers, H.M., T.H. Yeager, and L.T. Case. 2005. Improving irrigation water use in container nurseries. HortTechnology 15(1):8-12.

Million, J.B. and T.H. Yeager. 2015. Capture of sprinkler irrigation water by container-grown ornamental plants. HortScience 50(3):442-446.

Owen, J., A. LeBude, M. Chappell and T. Hoskins. 2015. Advanced irrigation management for container-grown ornamental crop production. Virginia Polytechnic and State University Ext. Pub. in press.

Still, D.W. and F.T. Davies, Jr. 1993. Water use, water use efficiency and growth analysis of selected woody ornamental species under a nonlimiting water regime. Scientia Hort. 53:213-223.

Wang, X., R.T. Fernandez, B.M. Cregg, R. Auras, A. Fulcher, D.R. Cochran, G. Niu,

Y. Sun, G. Bi, S. Nambuthiri, and R.L. Geneve. 2015. Multi-state evaluation of plant growth and water use in plastic and alternative nursery containers. HortTechnology 25(1):42-49.

Warsaw, A.L., R.T. Fernandez, and B.M. Cregg. 2009. Water conservation, growth, and water use efficiency of container grown woody ornamentals irrigated based on daily water use. HortScience 44(5):1308-1318.

Zinati, G. 2005. Irrigation Management Options for Containerized-Grown Nursery Crops. Rutgers Coop. Res. and Ext. http://njaes.rutgers.edu/pubs/publication.asp?pid=E302.

5. IRRIGATION DELIVERY SYSTEMS

Beeson, Jr. R. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26(7):848-850.

Bilderback, T., C. Boyer, M. Chappell, G. Fain, D. Fare, C. Gilliam, B.E. Jackson, J. Lea-Cox, A.V. LeBude, A. Niemiera, J. Owen, J. Ruter, K. Tilt, S. Warren, S. White, T. Whitwell, R. Wright, and T. Yeager. 2013. Best management practices: Guide for producing nursery crops. 3rd ed. Southern Nursery Association, Acworth, GA.

Mathers, H.M., T.H. Yeager, and L.T. Case. 2005. Improving irrigation water use in container nurseries. HortTechnology 15(1):8-12.

Ross, D.R. 1994. Reducing water use under nursery and landscape conditions, p 21-35. In: C. Heuser and P. Heuser (eds.). Recycling and resource conservation a reference guide for nursery and landscape industries. Pennsylvania Nurseryman's Association, Inc., Harrisburg, Pennsylvania.

Weatherspoon, D.M. and C.C. Harrell. 1980. Evaluation of drip irrigation for container production of woody landscape plants. HortScience 15:488-489.

6. SCHEDULING IRRIGATION

Bauerle, B. 2008. Plant Water Use and Modeling. Green Industry Knowledge Center http://www.waternut.org/moodle/course/view.php?id=27.

Beeson, R.C., Jr. 2008. Irrigation Scheduling. Green Industry Knowledge Center http://www.waternut.org/moodle/course/view.php?id=17.

Beeson, R.C., Jr. and T.H. Yeager. 2003. Plant canopy affects sprinkler application efficiency of container-grown ornamentals. HortScience 38:1373-1377.

Bilderback, T., C. Boyer, M. Chappell, G. Fain, D. Fare, C. Gilliam, B.E. Jackson, J. Lea-Cox, A.V. LeBude, A. Niemiera, J. Owen, J. Ruter, K. Tilt, S. Warren, S. White, T. Whitwell, R. Wright, and T. Yeager. 2013. Best management practices: Guide for producing nursery crops. 3rd ed. Southern Nursery Association, Acworth, GA. 2013. Best management practices: Guide for producing nursery crops, 3rd edition. Southern Nursery Association, Acworth, GA.

Biology Online.org. Plant Metabolism. http://www.biology-online.org/11/9_plant_metabolism.htm.

Brown, D.R., D.J. Eakes, B.K Behe, and C.H. Gilliam. 1992. Moisture stress: an alternative method of height control to B-nine (daminozide). J. Environ. Hort. 10:232-232.

Food and Agriculture Organization of the United Nations (FAO). 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, Rome.

Lampinen, B.D., K.A. Shackel, S.M. Southwick, B. Olson, J.T. Yeager, and D. Goldhamer. 1995. Sensitivity of yield and fruit quality of French prune to water deprivation at different fruit growth stages. J. Amer. Soc. Hort. Sci. 120(2):139-147.

Lea-Cox, J.D., W.L. Bauerle, M.W. van Iersel, G.F. Kantor, T.L. Bauerle, E. Lichtenberg, D.M. King, and L. Crawford. 2013. Advancing wireless sensor networks for irrigation management of ornamental crops: An overview. HortTechnology 23:717-724.

Majsztrik, J.C., E.W. Price, and D.M. King. 2013. Environmental benefits of wireless sensor-based irrigation networks: case-study projections and potential adoption rates. HortTechnology 23:783-793.

Mathers, H.M., T.H. Yeager, and L.T. Case. 2005. Improving irrigation water use in container nurseries. HortTechnology 15(1):8-12.

Million, J. and T. Yeager. 2012. Measuring the Irrigation Requirement of Container-grown Nursery Plants. IFAS. http://edis.ifas.ufl.edu/ep458.

Munoz-Carpena, R. 2012. Field devices for monitoring soil water content. IFAS. p. 16.

Raven, J.A. and D. Edwards. 2000. Roots: Evolutionary origins and biogeochemical significance. J. Expt. Botany. 52 (S1):381-401.

Shackel, K.A., B. Lampinen, S. Southwick, W. Olson, S. Sibbett, W. Krueger, J. Yeager, and D. Goldhamer. 2000. Deficit irrigation in prunes: maintaining productivity with less water. HortScience 35(6):1063-1066.

Smajstrla, A.G. and D.S. Harrison. 2011. Tensiometers for soil moisture measurement and irrigation scheduling. IFAS. CIR487.

Sneed, R. 1996. Pumps, pipes and consultations. Amer. Nurseryman. June:45-46.

Vince, Ö. and M. Zoltán. 2011. Plant Physiology. Debreceni Egyetem, Nyugat-Magyarországi Egyetem, Pannon Egyetem. http://www.tankonyvtar.hu/en/tartalom/tamop425/0010_1A_Book_angol_01_novenyelettan/ch02.html#id467606.

Warren, S. and T. Bilderback. 2002. Timing of low-pressure irrigation affects plant growth and water utilization efficiency. J. Environ. Hort. 20(3):184-188.

Warsaw, A.L., R.T. Fernandez, and B.M. Cregg. 2009. Water conservation, growth, and water use efficiency of container-grown woody ornamentals irrigated based on daily water use. HortScience 44(5):1308-1318.

Williamson, C.S., S.L. Warren, and T.E. Bilderback. 2004. Timing of overhead irrigation affects growth and substrate temperature of container-grown plants. Southern Nursery Assoc. Res. Conf. 49:77-80.

7. IRRIGATION SYSTEM EFFICIENCY

Center for Irrigation Technology, Fresno State University. Space Pro Software https://www.fresnostate.edu/jcast/cit/software/.

Haman, D.Z., A.G. Smajstrla, and D.J. Pitts. 2003. Uniformity of sprinkler and microirrigation systems for nurseries. Univ. Fla. Ext. Bul. 96-10. http://ufdc.ufl.edu/IR00004509/00001.

Hunter Industries Incorporated. 2010. The Handbook of Technical Irrigation Information: A complete reference source for the professional. www.hunterindustries.com/sites/default/files/tech_handbook_of_technical_irrigation_information.pdf.

Million, J.B. and T.H. Yeager. 2013. Factors affecting the irrigation requirement of container-grown ornamentals. Acta Hort. 1014:335-340.

Rain Bird Corporation. http://www.rainbird.com/.

Senninger Irrigation, Inc. http://www.senninger.com/.

Sneed, R. 1996. Pumps, pipes and consultations. Amer. Nurseryman. June: 45-46.

8. RECLAIMING WATER

Bailey, D., T. Bilderback, and D. Bir. 1999. Water considerations for container production of plants. NC Cooperative Extension Service. Horticulture Information Leaflet 557.

USDA. 2008. 2008 Farm and Ranch Irrigation Survey, Table 11. United States Department of Agriculture. Census of Agriculture. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/fris08_1_11.pdf.

USDA. 2013. 2013 Farm and Ranch Irrigation Survey, Table 4. United States Department of Agriculture. Census of Agriculture. http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris13_1_004_004.pdf.

Yeager, T.H., 2008. Capture and Recycling of Irrigation Water. Green Industry Knowledge Center for Water and Nutrient Management Learning Modules. http://www.waternut.org/moodle/course/view.php?id=21.

Yeager, T.H., C.H. Gilliam, T.E. Bilderback, D.C. Fare, A.X. Niemiera, and K.M. Tilt. 1997. Best management practices guide for producing container-grown plants. Southern Nursery Assn., Atlanta, Ga.

9. DROUGHT PREPAREDNESS

Drought Monitor http://droughtmonitor.unl.edu/.

Irrigation Association https://www.irrigation.org/default.aspx.

Irrigation Association Audit Standards https://www.irrigation.org/defaultcontent.aspx?id=842&terms=audit.

LeBude, A.V. and T.E. Bilderback. 2007. Managing Drought on Nursery Crops. N.C. State University. DRO-18. http://content.ces.ncsu.edu/managing-drought-on-nursery-crops-1/.

Map of current US drought conditions
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif.

Anonymous. 2010. Drought Management Plan. Tennessee Department of Environment and Conservation, State of Tennessee, Nashville, TN. http://www.tn.gov/assets/entities/environment/attachments/droughtmgtplan.pdf.

CALCULATIONS

Anonymous. 2009. Certified Landscape Irrigation Auditor/ Golf Irrigation Recommended Audit Guidelines. Irrigation Association. Fairfax, Va. https://www.irrigation.org/uploadedFiles/Certification/CLIA-CGIA_Audit-Guidelines.pdf.

Irrigation Association. https://www.irrigation.org/default.aspx.

Million, J. and T. Yeager. 2012. Measuring the Irrigation Requirement of Container-grown Nursery Plants. IFAS. http://edis.ifas.ufl.edu/ep458.

Owen, J., A. LeBude, M. Chappell and T. Hoskins. 2015. Advanced irrigation management for container-grown ornamental crop production. Virginia Polytechnic and State University Ext. Pub. in press.

Regan, R. 1987. Irrigation Practices: Measuring Sprinkler System Application Uniformity. Ornamentals Northwest Archives. 11(1):10-12. http://horticulture.oregonstate.edu/system/files/onn110110.pdf.

Stanley, J. 2012. Using Leaching Fractions to Maximize Irrigation Efficiency. Proceedings of the International Plant Propagators' Society. p. 331-334.

Vinchesi, B., M. Igo, and J. Gilbert. 2007. How Catch Cup Quantity Affects Audit Results. Proc. Int. Irrig. Show. Dec. 9-11, San Diego, CA.

GLOSSARY

Anonymous. Irrigation Glossary. Irrigation Association. Fairfax, VA. https://www.irrigation.org/default.aspx.

Beeson Jr., R.C. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26(7):848-850.

Bilderback, T.E. Container Nursery Irrigation Efficiency, Interception Efficiency and Leaching Fraction Practices. http://www.nurserycropscience.info.

Bilderback, T.E., S.L. Warren, J.S. Owen, Jr., and J.P. Albano. 2005. Healthy substrates need physicals too! HortTechnology. 15(4) 747-751.

Bilskie, J. 2001. Soil water status: content and potential. Campbell Scientific, Inc. Logan, UT. http://ftp.campbellsci.com/pub/outgoing/apnotes/soilh20c.pdf.

Christiansen, J.E. 1942. Irrigation by sprinkling. California Agricultural Experiment Station Bulletin 670. University of California, Berkley, CA.

Dane, J.H. and G.C. Topp. 2002. Methods of soil analysis, Part 4: Physical methods. Soil Science Society of America, Inc. Madison, WI. 1692 pp.

Fulcher, A. and T. Fernandez. 2013. Sustainable Nursery Irrigation Management

Series: Part II. University of Tennessee Extension Publication. https://utextension.tennessee.edu/publications/Documents/W279.pdf.

Jones, H.G and F. Tardieu. 1998. Modelling (sic) water relations of horticultural crops: A review. Sciencia Hort. 74:21-46.

Knox, G.W. 1989. Water use and average growth index of five species of container-grown woody landscape plants. J. Environ. Hort. 7:136–139.

Regan, R. 1987. Irrigation Practices: Measuring Sprinkler System Application Uniformity. Ornamentals Northwest Archives. 11(1):10-12. http://horticulture.oregonstate.edu/system/files/onn110110.pdf.

Ross, D. S. 2008. Irrigation System Audits. Water and Nutrient Management Learning Modules. http://www.waternut.org/moodle/course/view.php?id=26.

Million, J. and T. Yeager. 2015. Measuring the Irrigation Requirements of Container-Grown Nursery Plants. IFAS. ENH-1197. https://edis.ifas.ufl.edu/pdffiles/EP/EP45800.pdf.

Owen, J. and H. Stoven. 2010. Irrigation Strategies to Conserve Water in Container Nurseries. Climate Friendly Nurseries. http://www.climatefriendlynurseries.org/resources/irrigation_efficiency.pdf.

Owen, J.S., A. LeBude, M. Chappell, and T. Hoskins. 2015. Advanced irrigation management for container-grown ornamental crop production. Virginia Cooperative Extension Publication Ext. Pub. in press.

Richter, B. 2014. Chasing water: A guide for moving from scarcity to sustainability. Island Press, Washington, DC. 2014.

Yeager, T.H. 2003. Implementation guide for container-grown plant interim measure. IFAS. ENH-895. http://ufdcimages.uflib.ufl.edu/IR/00/00/17/52/00001/EP15200.pdf.

NOTES

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