**On-site Evaluation of Irrigation Management Practices in Container Nurseries in Alabama and the Effect of Leaching Fraction-based Irrigation on Fertilizer Longevity.**

by

Claire Elizabeth Krofft

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 2, 2020

Keywords: Distribution uniformity, overhead irrigation

Approved by

Jeremy M. Pickens, Chair, Assistant Research and Extension Professor of Horticulture
Glenn B. Fain, Associate Professor of Horticulture
Jeff L. Sibley, Bohmann Endowed Professor of Horticulture

Abstract

Container production of ornamental plants is an important part of the green industry in Alabama. Container nursery growers rely on near daily irrigation and applications of fertilizers to produce marketable plants. Cultural practices lead to leaching of applied nutrients that could lead to eutrophication of surrounding watersheds, so efficient irrigation management is therefore an important part of reducing environmental harm as well as the loss of inputs from production systems**.** An on-site analysis of overhead irrigation systems was conducted at nine container nurseries in Alabama. Results of this study suggest that improving distribution uniformity (DU) is the most practical area to begin when improving irrigation practices in Alabama. The uniformity of plant size across all nurseries despite differing leaching fraction (LF) suggested that growers may be able to utilize lower volumes of irrigation to produce plants of salable size.

A study was conducted to determine the effects of LF and control-release fertilizer (CRF) rates on plant growth and fertilizer longevity in container nursery conditions. A target LF of 5%, 25% or 35%, and a CRF rate of 50, 70, or 90g per container were assigned irrigation plots arranged in a completely randomized design with three replications, a total of 27 plots. Each plot contained four 2.91gallon (11 L) black plastic containers planted with a dwarf Japanese holly (*Ilex crenata 'Compacta'*) liner. Plant growth index, percent fertilizer loss, and pour-throughs pH and electrical conductivity (EC) were recorded. LF and CRF rate had no effect on percent fertilizer loss and plant growth index and there were no interactions between LF and CRF rate. There were differences in pour-through pH among the LF treatments and differences in pour-through EC among the fertilizer rates, however, no significant trends for either. The results were likely inconclusive due to the containers overheating, as extreme heat stress on plant health

compromised size index data, and heating of the media may have influenced the rate of fertilizer release.

A study was then conducted to evaluate the effects of LF on the longevity of POLYON® CRF and leachate nutrient content in a greenhouse environment under six target LF treatments: 0.05, 0.15, 0.25, 0.35, 0.45, and 0.55. Results of this ten-week study indicate that reducing the LF did not influence the longevity of POLYON® CRF in a pine bark substrate, but that a lower LF may be useful in reducing nutrient runoff into the environment. The total amount of nutrients leached from the container was greater at higher LFs. The amount of dissolved nutrients left in the substrate decreased as the LF treatments increased, suggesting that at lower LFs, more nutrients may be available for plant uptake and that nursery producers could potentially reduce fertilizer rates when irrigating to lower target LFs.

# Acknowledgments

I would like to first acknowledge Dr. Adam Newby for his encouragement and advice during the pursuit of this degree, and for presenting me with this wonderful opportunity. Without him, this research would have never begun. I would also like to express the deepest gratitude to my advisor Dr. Jeremy Pickens, for his guidance, his expertise, and most importantly for his unwavering confidence in me. Without him, this thesis would have never been completed. I am a better scientist because of you. I want to thank my committee members, Dr. Glenn Fain and Dr. Jeff Sibley, as well as Dr. Raymond Kessler for their input in this research and their invaluable help in the creation of this thesis. A huge thanks to Kyle Owsley, John Olive, and everyone at the AU Ornamental Horticulture Research Station for their assistance in building and maintaining the experiments in Mobile; none of this would have been possible without their hard work. I will always be grateful to my fellow graduate students, especially Joshua Cook and Caroline Blanchard, for helping me make (and later destroy) 240 mesh bags, and for their moral support. You guys are my favorite podcast. Lastly, but most importantly, I am ever grateful to my parents for helping me achieve this success. Everything I am able to do is a result of your love and support. Thank you.

Table of Contents

Abstract ..... 2

Acknowledgments ..... 4

List of Tables ..... 7

List of Figures ..... 8

List of Abbreviations ..... 9

Chapter 1: Literature Review ..... 10

Literature Review ..... 10

Literature Cited ..... 29

Chapter 2: On-site analysis of irrigation management practices at container nurseries in Alabama ..... 37

Abstract ..... 37

Introduction ..... 38

Materials and Methods ..... 41

Results and Discussion ..... 43

Conclusion ..... 46

Literature Cited ..... 48

Tables and Figures ..... 51

Chapter 3: The effects of leaching fraction and fertilization rate on fertilizer longevity under simulated container nursery conditions ..... 56

Abstract ..... 56

Introduction ..... 57

Materials and Methods ..... 60
Results and Discussion ..... 62
Conclusion ..... 63
Literature Cited ..... 65
Tables and Figures ..... 68
Chapter 4: The effect of leaching fraction-based irrigation on fertilizer longevity and leachate nutrient content in a greenhouse environment ..... 70
Abstract ..... 70
Introduction ..... 71
Materials and Methods ..... 74
Results and Discussion ..... 78
Conclusion ..... 80
Literature Cited ..... 82
Tables and Figures ..... 86

List of Tables

Table 2.1. On-site irrigation data collected from nine container production nurseries in Alabama. ..... 51

Table 2.2. Distribution uniformity and leaching fraction of nine nurseries in Alabama. ..... 52

Table 2.3. Leaching fraction and pour-through data, sampled at nine nurseries after a typical irrigation cycle. ..... 53

Table 3.1. Impacts of fertilizer rate and target leaching fraction (LF) on plant growth and fertilizer loss..... 68

Table 3.2. Effects of fertilizer rate and target leaching fraction (LF) pour-through pH and electrical conductivity (µS/cm)..... 69

Table 4.1. Means comparison of N, P, and K in leachate over ten weeks and retained in pine bark substrate. ..... 86

Table 4.2. Means comparison of Ca, Mg, $SO_4$-S, and micronutrients in leachate over ten weeks and retained in pine bark substrate..... 87

Table 4.3. Comparison of leachate electrical conductivity (µS/cm) over ten weeks..... 88

Table 4.4. Comparison of leachate pH over ten weeks..... 89

Table 4.5. Means comparison of pH and electrical conductivity (µS/cm) of fertilizer remaining in mesh bags after ten weeks..... 90

Table 4.6. Means comparison of N, P, and K loss from fertilizer and remaining in fertilizer after ten weeks..... 91

List of Figures

Figure 1. Frequency of irrigation application from nine container nurseries in Alabama. ..... 54

Figure 2. Size index of sample dwarf yaupon hollies (*Ilex vomitoria* 'Nana') plants from eight container nurseries in Alabama ..... 55

Figure 3. Regression of average electrical conductivity of leachate over ten weeks. ..... 92

List of Abbreviations

| | |
|---|---|
| BD | Bulk density |
| BMP | Best management practice |
| CEC | Cation exchange capacity |
| CF | Capture factor |
| CRF | Controlled-release fertilizers |
| DU | Distribution uniformity |
| EC | Electrical conductivity |
| LF | Leaching fraction |
| SI | Size index |
| TMDL | Total maximum daily load |

# CHAPTER 1. LITERATURE REVIEW

## Water Consumption in Container Production

Global population and consumption of freshwater are expected to continue to rise in the future, making water resources more difficult and expensive to obtain (Beeson et al., 2004). Currently, agriculture is responsible for 70 to 80% of global water use (O'Neil and Dobrowolski, 2011). In Alabama in 2010, agriculture accounted for 3% of the state's total withdrawal of surface water, amounting to 287 million gallons a day (Atkins, 2017). By 2008, over half of the ornamental plants sold by nurseries in the United States were being produced in containers; in the southeastern region, the percentage is closer to 72% (Hodges et al., 2008). In container grown nursery production, root volumes are limited, and plants require daily inputs of irrigation for optimal plant growth (Lea-Cox et al., 2001). Nursery growers in Alabama are fortunate to have plentiful sources of water. However, nationwide even where water is abundant, drought, urban competition, salinity, runoff water quality, and legislation at state and county levels are increasing the pressure on nursery producers to manage water more effectively (Fernandez et al., 2009). Legislation and restrictions on water use and quality already exist in California, Florida, North Carolina, Oregon, and Texas and are expected to become even more strict in the coming years (Fernandez et. al., 2009; Fulcher et al., 2016). As the public has become increasingly concerned about water quality, legislation in many states has restricted nutrient applications and regulated the amounts of contaminants leaving a site (Beeson et al., 2004). Ornamental nurseries may be located near urban areas and might be pressured to yield their water resources for urban use in times of drought (Beeson et al., 2004). As freshwater quality and global resources decrease, efforts should be put forth by the nursery industry to conserve and protect water quality. (Moe and Rheingans, 2006). Increasing constraint upon water quantity and quality

available to nursery growers means that growers must find a way to use water more efficiently without compromising crop quality.

**Container Nursery Production in Alabama**

In the United States, and especially the state of Alabama, container nursery production is an important part of the green industry. In 2014, container nursery stock generated $91.9 million in sales in Alabama (USDA, 2014). In the United States, the value generated by the green industry is increasing. In 2017, total sales of container, nursery, and greenhouse crops, floriculture, and sod farms generated $16.2 billion, an increase from the $14.5 billion generated in 2012 (USDA, 2012; USDA, 2017). However, due to the nature of container production, container crops rely on frequent irrigation and regular application of pesticides and fertilizers to produce marketable plants and yield high economic returns. Container production has increased over the past 50 years because plants can be produced more efficiently than by in-field cultivation (Majsztrik et al., 2011). The large amount of irrigation water used by the container nursery industry is the result of cultural practices developed by growers in the 1970's, many of which remain relatively unchanged today (Biernbaum, 1992; Majsztrik et al., 2011).

**Cultural Practices**

*Substrates:* Soilless substrates are popular in the industry because they are light, relatively inexpensive, and have properties favorable to container production (Raviv and Lieth, 2008). Physical properties such as particle size, bulk density, and total porosity determine how substrates behave with water and solutes (Raviv and Lieth, 2008). The small particle size of native soils reduces porosity, leading to reduced gas exchange and poor drainage. Soilless substrates were developed to be porous enough to allow drainage while still maintaining adequate water holding capacity (Majsztrik et al., 2011). In the southeastern United States,

ground pine bark is the main component of nursery substrates, although substances such as peat, perlite, and sand can be added to modify the physical properties of the mix to grower's specifications. Pine bark substrate has a low bulk density and a high total porosity (Drzal et al., 1999), allowing drainage for container grown plants. Although the bulk density of pine bark is dependent on particle size and age and varies from batch to batch, screened aged pine bark at ½ and ¼ inch was reported to have a bulk density of 0.19 $g \cdot cm^3$ and a total porosity of 81 to 84% (Bilderback et al., 2005; Yeager et al., 1997). A low bulk density (BD), defined as dry weight per unit volume, is ideal in high-intensity production, where frequent irrigation could cause oxygen deficiency if containers did not properly drain (Raviv and Lieth, 2008). Low BD has the added benefits of making soilless substrates easier to mix, lighter to move, and allows more containers to be loaded into a shipping vehicle before the maximum weight load is reached.

The large particle size of pine bark influences other substrate physical and chemical properties (Richards et al., 1986). In pine bark substrate, particle size is correlated with the percentage of fine and medium sized particles, with cation exchange capacity (CEC) decreasing as particle size increases (Atland et al., 2014; Richards et al., 1986). CEC is a chemical property that describes the quantity of cations a substrate can hold and exchange within the substrate solution (Atland et al., 2014). A substrate's CEC is associated with its ability to hold on to mineral nutrients, with high CEC materials providing a more consistent supply of cations (Manning and Tripepi, 1995). The CEC of pine bark is considerably lower than field soil and can vary from 29.9 to 74.4 meq/L depending on specific particle size; an intermediary sized batch has a CEC of 47.2 meq/L (Atland et al., 2014). Because of the low CEC and subsequently low nutrient and water-holding capacity of pine bark substrate, container-produced plants require

nearly daily irrigation and frequent applications of fertilizers. Low CEC also allows nitrogen, phosphorus, and other substances to leach easily from the containers (Majsztrik et al., 2011).

*Fertilization:* Soilless substrates are nearly devoid of nutrients, so plants potted in substrates such as pine bark require supplemental fertilization for optimal plant growth and nutrition (Bilderback, 2002). In the container nursery industry, controlled-release fertilizers have become popular since customized blends have made application easy for species with different growth rates and nutritional requirements (Majsztrik et al., 2011). Controlled-release fertilizers (CRFs) are created by coating inorganic fertilizers with resins, sulfur, waxes, and other substances which reduce their immediate solubility in the environment (Cabrera, 1996) and form granules referred to as "prills". Examples of CRFs commonly used in the industry include Osmocote®, Nutricote®, and Polyon®. The release of nutrients from CRFs is generally determined by temperature, as well as coating thickness and watering practices (Andiru, 2010). At the required temperature, water penetrates the coating and dissolves the fertilizer within, creating an ion gradient between the fertilizer prill and the surrounding saturated substrate. The release of nutrient ions is driven by the ion-concentration gradient, allowing nutrients to be released through the coating to become available to plants (Adams et al., 2013). In an environment with a fluctuating water potential such as containers under irrigation, the mass flow of solution across the prill's coating could lead to a higher rate of nutrient release (Adams et al., 2013). Thus, excess irrigation leaches dissolved fertilizer out of the container, making it unavailable to the plant. Over-leaching will effectively "reset" the gradient, allowing more fertilizer to be released from the prills. Repeated excess irrigation may cause a constant flushing of nutrients, leading to faster exhaustion of the CRF (Adams et al., 2013).

CRFs are designed to release their nutrients into the surrounding substrate over an extended period, and different formulations and longevities from 3- to 4-month to 12- to 14-month are readily available (Andiru et al., 2013). Despite their longevity, CRFs are a significant financial input for growers. A single application of a CRF to plants in 3.7 L containers can cost over $ 7,500/ha (Bayer et al., 2014). Reducing the amount of CRFs necessary during production can decease production costs for growers. Growers often err on the side of excess, applying high rates of fertilization to counteract the perceived loss of nutrients from leaching due to irrigation (Biernbaum, 1992). Conversely, frequent irrigation is deemed necessary to prevent the possibility of soluble salt buildup and high electrical conductivity (Bilderback 2002). Despite being effective for producing container grown nursery crops, these cultural practices waste expensive resources and may contribute to environmental harm. Irrigation management is therefore an important part of nutrient management in container production and increasing efficiency can be a step toward reducing runoff and environmental degradation (Tyler et al., 1996; Lea-Cox et al., 2001, Fernandez et al., 2009).

*Herbicides:* Although growing substrate is relatively sterile and weed-free at the time of preparation, weed problems develop due to the dissemination of weed seeds by wind and water (Williams and Sanders 1984). Weeds compete with crops for the limited amount of water and resources in a container. Berchielli-Robertson et al. (1990) reported a 43% reduction in *Rhododendron* ×'Fashion' from one Eclipta (*Eclipta prostrata*) weed. Additionally, container grown ornamentals are marketed based on their aesthetic qualities, so consumers expect weed-free plants (Simpson et al., 2004). Growers have limited postemergence options in container production; preemergence herbicides and hand weeding are the primary form of weed control (Stewart, et al., 2017). In container nurseries in the southeastern U.S., frequent preemergence

herbicide applications up to every 8 to 10 weeks are required to adequately control weeds (Judge, 2001). Such frequent applications can incur significant costs to growers. In 2017, the estimated cost of a treating one hectare with a single application of granular herbicide was $690, not including the expense of labor (Stewart et al., 2017). Even with repeated applications, container ornamentals still require supplemental hand weeding to completely remove weeds. As labor for hand weeding becomes increasingly expensive and difficult to find (Simpson et al., 2004), many growers are looking for ways to increase the efficacy of herbicide treatments.

Unlike CRFs, preemergent herbicide is not often leached due to excess irrigation. Research has confirmed that many of the preemergence herbicides used in nursery crops are highly adsorptive to organic substrates (Stewart, et al., 2017). A previous study showed that although peat-based substrates retained herbicide better than bark-based substrates, 20 ppm of oxyfluorfen herbicide had a low risk of leaching out of a container and even a ten-fold increase in irrigation had limited effects on leaching rates (Horowitz and Elmore, 1991). When four pesticides were investigated for their movement in runoff water from a container nursery, results showed that isoxaben and thiophanate-methyl, moderately volatile compounds, were found in higher concentrations than trifluralin and chlorpyrifos, which had a greater affinity to adsorb to soil (Briggs et al., 1998) This suggests that the greatest source of water contamination from granular herbicide application is from nontarget losses (Gilliam et al., 1992). Nontarget loss refers to the amount of herbicide that falls between containers during application. Granular herbicides, commonly used in the container nursery industry, are often broadcast using a cyclone-type spreader. When applied to round containers, it is inevitable that a certain amount of herbicide will fall to the ground between containers (Gilliam et. al., 1992; Gilliam et al., 1990). This amount can be 20% or more of that applied (Horowitz and Elmore, 1991). Briggs et al.

(1998) stated that when spaced at a distance of around 50 cm, 10 L containers may only intercept 12.5% of a broadcast-applied granular formulation (Briggs et al., 1998). Frequent application of herbicides combined with inefficient irrigation systems when use of semi- or impermeable ground covers are used in production areas promotes the movement of pesticides in runoff water (Briggs et al. 1998). It is possible that by reducing irrigation volume, the amount of pesticides lost to runoff would decrease.

*Irrigation*: Container grown crops are grown in a finite amount of substrate, which limits access to water and nutrients (Beeson, 2007; Bilderback et al., 2013; Majsztrik et al., 2017). Plants quickly exhaust the limited water resources in the containers and require frequent irrigation. Beginning in the 1950's, plastic films and lines were developed, prompting the use of automated irrigation systems in the nursery industry (Biernbaum, 1992). Nursery growers mainly utilize either overhead irrigation or microirrigation, or a mix of the two. Most container nurseries producing #7 containers and smaller apply irrigation with overhead systems (Beeson et al., 2004; Bilderback, 2002). Overhead irrigation is the most common choice because it is relatively inexpensive to install and maintain and covers large areas (Bilderback, 2002). Other benefits are the versatility of overhead systems and the few labor-hours associated with moving plants under irrigation. The greatest downside is that overhead systems tend to have a low application efficiency, requiring a larger volume of water to irrigate the same number of plants compared to microirrigation (Majsztrik et al., 2011). Irrigation application efficiency is defined as the amount of applied water that falls in the root zone and is available for plant use (Mathers et al., 2005). Beeson and Knox (1991) reported that in an overhead irrigation system irrigating #1 containers, only 37% to 25% of applied irrigation (depending on species, sprinkler head type, and spacing) reached the container's substrate surface. The remainder of the water fell unused between pots or

was deflected off the plant canopy. Overhead sprinklers are less efficient if designed improperly, and the uniformity of a system may be impacted by environmental factors of wind and evaporation (Whitcomb, 1984).

Irrigation amount needed varies depending on plant material, container size, and substrate composition. The average daily irrigation applied at container nurseries in Alabama is around 15 mm (about 0.5 in) and ranges from 6 to 22 mm (0.2–0.8 in) (Fare et. al., 1992). Most growers irrigate continuously, applying water in a single application. Growers often err on the side of overwatering in the southeastern United States due to the availability of inexpensive, plentiful water sources, and irrigation is typically a small part of total operation costs (Majsztrik et al., 2011). Successful container nursery production is dependent on the interactions among cultural practices. Substrate properties, fertilization rate and type, and irrigation management are all closely linked. Irrigating more efficiently can not only conserve water but manage CRF more effectively.

**Impacts of Current Practices**

*Leaching and Runoff:* Irrigation systems at nurseries generate a large amount of water, much of which may not reach the container surface and leaves the production area as runoff. Of the water that does fall onto the substrate surface, some is not utilized by the plant and leaches from the container. The large amount of irrigation necessary to prevent containers from drying out and the low nutrient holding capacity of soilless substrate means that leaching of nutrients is a ready occurrence (Rathier and Frink, 1989 and Bilderback 2002). The leached nutrients are often in the form of dissolved $NO_3$-N (Rathier and Frink, 1989) and phosphorus. Over the decades, scientists have come to the realization that nitrogen and phosphorus are the primary nutrients contributing to the eutrophication and degradation of natural waters (Howarth and

Marino, 2006). Unutilized nitrates in runoff lead to contamination of surface and groundwater and have detrimental environmental effects such as excessive growth of algae and death of aquatic species (Howarth, 1988; Kabashima, 1993; Rauschkolb and Hornsby, 1994). Although the use of CRFs rather than soluble fertilizers have reduced nutrient loss, nurseries can still produce runoff that affects water quality. In 1990, container production bed runoff was sampled from nurseries across six states (Yeager et al., 1993). For nurseries using CRFs, $NO_3$ -N content in container bed runoff averaged 8 ppm, ranging from 0.5 to 33 ppm, a maximum exceeding the federal drinking water standard of 10 ppm. Runoff from production areas can carry other contaminants including sediment, fertilizer prills, pesticides, and phytopathogens, which are harmful to the aquatic environment (Majsztrik et al., 2017). Leaching of pesticides also means loss of expensive inputs from the production cycle, so improving irrigation practices to reduce runoff can reduce input costs for growers (Briggs et al., 1998).

*Restrictions on Water Use and Nutrient Load:* Public concern about the environmental impacts of nursery production has risen throughout the years (Warsaw et al., 2009). Due to concerns about water quality and runoff, legislation in states such as Maryland, Delaware, and California restrict nutrient application rate and regulate the concentration of contaminants leaving the site (Beeson et al., 2004). Provisions of the 1972 Clean Water Act section 303(d), require states to assess and submit a list of impaired waters every year for which total maximum daily load (TMDL) will be implemented (EPA, 1987). A TMDL defines the maximum amount of a contaminant allowed in a body of water while still meeting water quality standards (EPA, 1987). In eastern states, regulations have limited the TMDL of pollutants entering the environment for nonpoint and point sources (Majsztrik and Lea-Cox, 2013). Sources of pollution may be classified as either point-source or nonpoint source pollution; point-source

polluters are required to collect and treat wastewater and nonpoint source polluters are managed using best management practices (Fain et al., 2000). Container nursery production in the US is currently considered nonpoint source pollution, however if current trends continue, nursery growers may be reclassified as point-source polluters and will be required to follow strict point-source pollution standards (Hong and Moorman, 2005). If implemented, these standards would involve complete recapture and treatment of wastewater, creating a significant cost to growers. To avoid the added cost of implementing these standards, growers should employ nursery best management practices (BMPs) that maximize efficiency to reduce water use and loss of fertilizer from the production cycle.

Strict water regulations and voluntary conservation practices have led nursery producers to increase water conservation and consider other sources of irrigation, such as recycled runoff water. Capture, containment, and recycling of irrigation runoff has become a practice in many nurseries in the U.S. to provide adequate water supplies (Bilderback, 2002). However, collecting and reusing runoff water that is infected with pathogens risks the spread of disease and can cause crop damage (Hong and Moorman, 2005). The risk of infection of plant pathogens may discourage growers. Minimizing the amount of excess irrigation applied to crops is a preventative solution. With restrictions coming from both state and federal level, many container nurseries will have to modify their irrigation and nutrient management practices to remain compliant with regulation.

*Loss of herbicide efficacy:* Herbicide applications are expensive and with the cost of labor expected to rise, growers are looking to increase herbicide longevity in order to reduce costs (Simpson et al., 2004). Repeated overhead irrigation wets the surface of the soil, resulting in the ideal environment for weed seed germination (Wilen et al., 1999). Increasing irrigation

efficiency would likely reduce weed germination and growth simply by allowing the top layer of substrate to dry and reducing the amount of water available to weeds. In a container nursery setting, irrigating multiple times a day instead of in one single application decreased herbicide efficacy, with plants receiving three and six irrigation applications having 261% and 285% greater weed shoot dry weight respectively than plants receiving continuous irrigation (Fain et al., 2004). Some preemergence herbicides have shown increased rate of degradation in saturated soils compared with drier soils (Taylor-Lovell et al., 2002), although the bulk of this research is not focused on soilless substrates or herbicides that are commonly used in the ornamental nursery industry. The increased rate of degradation is likely caused by the biological processes of microbial populations in the substrate, which thrive in moist environments caused by frequent irrigation (Anderson 1984; Taylor-Lovell et al., 2002). Biological activity has been shown to be an important factor in the degradation of herbicides such as 2,4-D, trifluralin, diuron, chloramben, and chlorpropham (Weber, 1991). Irrigating only when necessary may preserve the longevity of herbicides and therefore reduce the need for more frequent and expensive applications.

*Decreased plant quality*: Ornamental crops are sold based on their aesthetic qualities, and any loss of plant health or appearance may result in reduced value. Excessive irrigation can cause waterlogging in plant substrates, decreasing plant access to oxygen and causing root suffocation and loss of vigor (Whitcomb, 1984). Waterlogging also spreads disease such as root rot, which impacts plant health and appearance and decreases the value of horticultural crops. Plant disease caused by inefficient irrigation combined with the intensive inputs needed to produce container ornamentals can lead to economic loss. Substrates used in the nursery are often very well-draining, so waterlogging is not a problem with most crops, but certain “problem crops” such as

*Gardenia jasminoides* are more susceptible to soil-borne pathogens (Chappell et al., 2013). Controlling soil moisture for these crops can reduce disease pressure and losses due to disease. In an anecdotal study at McCorkle nursery, in Dearing, GA in 2008, growers found that by monitoring soil moisture content in *Gardenia jasminoides*, they were able to reduce their losses due to soilborne pathogens. Previously close to 30%, loss was reduced to nearly zero when growers had better control over soil-moisture content (Chappell et al., 2013). In addition, they were able to shorten their production period and increase annual profit by $2.80 per square foot, a value which considers a reduced need for fungicides and the opportunity to begin growing other crops in this space (Chappell et al., 2013; Lichtenberg et al., 2013). This has implications for other disease-sensitive crops in which monitoring irrigation can increase profit for growers. By reducing the amount of irrigation, growers can not only prevent plant disease, but control leaching of nutrients and other chemicals, decreasing the cost of production.

**Irrigation Efficiency**

The initial design of an irrigation system has the greatest impact on its efficiency, followed by environmental factors like wind and evaporation (Whitcomb, 1984; Furuta, 1976). Many options exist for the arrangement and spacing of sprinklers, but the most efficient irrigation system is one that provides matched precipitation from head-to-head coverage (Bilderback et al., 2013). Once an overhead system is installed, regular maintenance and replacement of broken and worn out parts is required to maintain system uniformity (Bilderback et al., 2013). Failure to install the correct parts for the system specifications reduces overall system efficiency. The biggest limitation to the efficiency of overhead irrigation is distribution uniformity (Bilderback et al., 2013; Fare et al., 1994). Distribution uniformity (DU) is a measure of how uniformly water is applied to an irrigated area (Mathers et. al., 2005). The DU is

measured by placing a minimum of 16 catch cups or rain gauges in a grid pattern within an overhead irrigation area. The more cups, the more precise the measurements, but the number of cups should be a multiple of four (Mathers et al., 2005). The irrigation system should be run for an irrigation cycle, after which the volumes in the catch cups are collected and measured. The average of the lowest quartile of application volumes were divided by the overall average application volume and multiplied by 100.

$$DU = \frac{average\ application\ of\ lower\ quartile}{average\ overall\ application} \times 100$$

Poor DU within an overhead system can cause uneven application of irrigation, leading to areas that are overwatered and those that are underwatered. To compensate for a lack of uniformity, nursery growers often irrigate until the driest areas are sufficiently wetted, causing excess water to be applied in other areas (Biernbaum, 1992).

Spacing of containers and canopy effects of different crops are other factors associated with low efficiency (Fare et al., 1992). Different species have different canopy shapes, and leaf curvature can either capture or deflect overhead irrigation. In container production, where even closely spaced containers occupy a fraction of the production area, canopy irrigation capture has the potential to reduce the amount of irrigation which falls unused between containers (Million and Yeager, 2015a). Capture factor (CF) is the amount of water captured by a container with a plant in relation to the amount of water captured without it, and varies based on many factors including container size, plant species, plant size, spacing, and sprinkler type. (Million and Yeager, 2015a). Wide container spacing may be necessary to accommodate a growing plant, however wide spacing allows more overhead irrigation to fall unused between containers. The application efficiency of overhead irrigation is only around 80%, with this percentage decreasing as containers are spaced further apart (Furuta, 1976). Capture of irrigation is adequate when

plants are small and spaced pot-to-pot, but as plants grow and their canopies are pushed together, capture efficiency drops. This study suggests that application efficiency could be maximized if plants were potted in larger containers and spaced pot-to-pot for as long as possible (Beeson and Knox, 1991). Plants with more upright, spreading canopies had the highest CF values, and across all species CF values increased as plant size increased (Million and Yeager, 2015a). This suggests that grouping plants based on CF, or simply by canopy type and size, would allow growers to schedule irrigation more effectively.

**Best Management Practices**

Container nurseries can increase irrigation efficiency by implementing best management practices (BMPs), strategies intended to produce container ornamentals while mitigating environmental impact (Bilderback et al., 2013). BMPs are general guidelines growers can use to improve their irrigation and nutrient management practices. The Southern Nursery Association, working with universities and nursery and related industries, first published Best Management Practices: Guide for Producing Nursery Crops in 1997 (Yeager et al., 1997). The third edition, published in 2013, is referenced in these studies. The guide was funded partly by grants from the Environmental Protection Agency to create compliance with section 319 of the Federal Clean Water Act and the USDA's Risk Management Association (Bilderback et al., 2013). This section of legislature requires states to develop a nonpoint source pollution assessment and management plan (Fain et al., 2000). States and other entities receive federal grant money that supports specific nonpoint source projects (Environmental Protection Agency, 1987). Due to concerns about nursery runoff affecting Alabama's coastal waters, the Alabama Department of Environmental Management and the Alabama Nurserymen's Association developed set of BMPs which were expanded by the SNA into the current manual (Fain et al., 2000). BMPs are

purposefully unspecific to a growing system in order to make it easy for growers to incorporate into their existing management plans. Sometimes different BMPs can be used to achieve the same goal, allowing growers the option of choosing the best based on their needs (Lea-Cox et al. 2001). Implementing BMPs can reduce water use and leaching of contaminants from container nurseries and therefore decrease the cost of production, produce healthy, saleable plants, and mitigate environmental harm.

*Monitoring distribution uniformity and leaching fraction*: As mentioned above, poor DU can cause uneven application of irrigation and overwatering in certain areas and underwatering in others. Periodically checking DU can help growers monitor irrigation efficiency and recognize when systems are not functioning properly. The portion of water that leaches from a container divided by the irrigation applied is referred to as the leaching fraction (Niemiera, 1994). Monitoring leaching fraction (LF) can be used as a tool to help growers schedule irrigation more effectively. Million and Yeager (2015b), recommend monitoring LF every 2 to 4 weeks, or as plants are changed by pruning and spacing. LF should be around 15%, and when LF is above 20%, irrigation run time should be decreased (Bilderback et al, 2013). Saunders Brothers Nursery in Virginia found that by adjusting irrigation to meet a target leaching fraction, they could produce crops of the same quality while reducing fertilizer use by 30%, saving water, and increasing the length of time between herbicide applications (Saunders, 2014).

*Arrange plants according to water requirements:* Grouping container plants based on water needs and canopy structure can result in increased irrigation efficiency and reduced losses due to root pathogens, particularly in low water-use plant material (Bilderback et al., 2013). Although many factors determine the water use of container grown plants, species-specific crop coefficients can be used to determine when and how much to irrigate (Burger et al., 1987). Plants

with similar crop coefficients should be grouped together and irrigated at the same time. If grouping by water use is not possible, simply grouping based on container volume can help create a block of plants with more uniform water needs.

*Cyclic irrigation*: As mentioned above, most growers implement continuous irrigation. An alternative to continuous irrigation is cyclic irrigation. Cyclic irrigation involves dividing daily irrigation into multiple applications throughout the day (Bilderback et al., 2013). When daily irrigation is applied in two or three cycles, container leachate volume is reduced, resulting in less total leachate than continuous irrigation (Fare et al., 1994). Total effluent was reduced by 14% when irrigation was applied in three cycles compared to one continuous application (Fare et. al., 1992). In certain cases, cyclic irrigation can reduce runoff by 30% and nitrogen leaching by 41%, while still producing larger plants (Fare et al., 1994; Adkins et al., 2009). A study by Ruter (1998) reported that utilizing cyclic irrigation in pot-in-pot production reduced leachate volume by half and increased irrigation efficiency by 27%. These improvements in efficiency were made while increasing shoot dry weight by 40% compared to continuous irrigation (Ruter, 1998). Reduced leachate volume can help control the amount of nutrients leaving the production area as runoff, reducing the risk of environmental pollution. Applying irrigation in multiple applications continuously re-wets the substrate and can allow for more efficient plant water use. Warsaw and others demonstrated that as irrigation volumes were decreased, water use efficiency (increase in plant size/volume of water used) in container grown ornamentals increased (Warsaw et al., 2009). Reduced irrigation volume also decreased average runoff volumes and $NO^3$-N and $PO_4^{3-}$ -P losses compared with the control treatment of 19 mm per container per day, while producing the same size or larger plants. These results indicate that lower irrigation volumes

reduced nutrient loss, keeping greater concentrations of these nutrients in the substrate solution for plant use (Warsaw et al., 2009).

Although cyclic irrigation reduces leaching fraction, using cyclic irrigation can affect herbicide efficacy (Fain, 2004). In a study by Fain in 2004, plants under a micro-irrigation system with more frequent irrigation treatments had greater weed shoot dry weight than plants receiving only one application. However, despite the increase in weed infestation, the cyclic irrigation yielded larger plants than those under continuous irrigation, and container leachate volumes were reduced. Cyclic irrigation has been proven to decrease the total effluent volume and nutrient content exiting the container, but growers may be discouraged from implementing cyclic irrigation due to its effect on herbicide longevity.

*Collection structures and vegetative buffer zones*: Collection structures or containment reservoirs are intended to capture runoff and recycle or treat water before it leaves the property (Bilderback et al., 2013). Vegetated buffer zones and constructed wetlands can be used with or as an alternative to collection structures for producers not capturing and reusing water. In fact, the most effective BMP for protecting water quality in North Carolina was identified as the development of a 50 ft riparian buffer along any natural streams, rivers and estuaries (Bilderback, 2002). Buffers slow the flow of water and allow sediment to settle out, reducing pesticide and nutrient loads in runoff leaving production areas (Bilderback et al., 2013). Reduction of nitrogen and phosphate levels occurs as plants and microbes utilize excess nutrients in the buffer zone. A study by Vymazal (2007) reported that constructed wetlands removed of 40 and 50% of total nitrogen from inflow to outflow, and 40 to 60% of total phosphorus. Although not all nurseries have the space to implement a collection structure or buffer, they are a useful BMP to protect natural waters from the harmful effects caused by excess irrigation.

## Grower Education

There are many strategies for maximizing irrigation efficiency by implementing BMPs within the industry, however the level of knowledge about these strategies varies. A survey of nurseries and greenhouse growers across the United States in 2018 reported that that the level of knowledge and adoption of irrigation audits were low, despite widespread extension articles, bulletins, subsidized auditing services, and methods for self-audit (Warner et al., 2018). In a survey of nursery producers in Georgia in 2006, most of the BMPs assessed, including grouping by water requirements, runoff collection, and irrigation monitoring, were adopted by less than 50% of growers (Schoene et al., 2006). In this same study, it was noted that while only 35% of nurseries using overhead irrigation monitored irrigation uniformity, 69% of the nurseries using drip irrigation monitor irrigation uniformity (Schoene et al., 2006). This may be because growers using micro-irrigation are aware of the importance of uniformity and are therefore more mindful about monitoring it. Increasing awareness among growers about the importance of irrigation efficiency is an important step to improve practices. In a survey of Virginia container nursery growers in 2017, 81% of respondents reported learning about BMPs on their own (Mack et al., 2017). More outreach and grower connection could increase this number without relying on growers to learn about BMPs on their own. Focusing education efforts to increase the adoption of BMPs ensures that growers are aware of the importance and incentives of these practices.

## Conclusion

Irrigation is a significant part of container production due to its impact on plant health, fertilizer and herbicide longevity, and environmental safety. Increasing the efficiency of overhead systems would allow growers to produce container ornamentals of high quality while using less inputs and reducing their environmental footprint. A current assessment of irrigation

management practices in Alabama is necessary to provide information about practices and determine areas for improvement. As part of this research, on-site assessments of irrigation application, DU, and LF were conducted in nine container nurseries in Alabama. Irrigating for a target LF was examined as a possible way to increase the longevity of fertilizer and herbicide, while decreasing leachate volume and nutrient content from container production. The objective of the following research is to provide information about current irrigation management practices and to explore LF as a method of monitoring irrigation efficiency.

## Literature Cited:


Adams, C., J. Frantz, and B. Bugbee. 2013. Macro- and micronutrient release characteristics of three polymer-coated fertilizers: Theory and measurements. J. Plant Nutr. Soil Sci. 176: 76–88.

Adkins, C., G. Armel, M. Chappell, J.C. Chong, S. Frank, A. Fulcher, F. Hale, W. Klingeman, III, K. Ivors, A. LeBude, J. Neal, A. Senesac, S. White, A. Windham, and J. Williams-Woodward. 2009. Crop profile container and field-produced nursery crops in GA, KY, NC, SC, and TN. USDA: Southern Integrated Pest Management Center. <https://ipmdata.ipmcenters.org/source_report.cfm?sectionid=40&sourceid=664>. 5 December 2019.

Anderson, J. P. E. 1984. Herbicide degradation in soil: Influence of microbial biomass. Soil Bio. and Biochem. 16:483–489.

Andiru, G.A., C.C. Pasian, J.M. Frantz, and P. Jourdan. 2013. Longevity of controlled-release fertilizer influences the growth of bedding impatiens. HortTechnology 23:157–164.

Andiru, G. 2010. Effects of controlled-release fertilizer on nutrient leaching and garden performance of *Impatiens walleriana* (Hook F. 'Extreme Scarlet'). The Ohio State Univ. Columbus, OH. M.S. Thesis. 121 p.

Atkins, J.B., M.J. Harper, D.D. Johnston, and T.M. Littlepage. 2017. 2017 Surface water assessment report fact sheet. Ala. Dept. Economics Community Affairs.

Atland, J.E., J.C. Locke, and C.R. Krause. 2014. Influence of pine bark particle size and pH on cation exchange capacity. HortTechnology 24:1–6.

Bayer, A., K. Whitaker, M. Chappell, J. Ruter, and M.W. van Iersel. 2014. Effect of irrigation duration and fertilizer rate on plant growth, substrate solution EC and leaching volume. Acta Hortic. 1034:477–484.

Beeson R.C. 2007. Determining plant-available water of woody ornamentals in containers in situ during production. HortScience 42:1700–1704.

Beeson, R.C., M.A. Arnold, B.B. Bilderback, S. Chandler, H.M. Gramling, J.D. Lea-Cox, 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.

Beeson, R.C. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848–850.

Berchielli-Robertson, D.L., C. H. Gilliam and D.C. Fare. 1990. Competitive effects of weeds on the growth of container-grown plants. HortScience 25:77–79.

Biernbaum, J.A. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer. HortTechnology 2:127–312.

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.

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

Bilderback, T.E. 2002. Water management is key in reducing nutrient runoff from container nurseries. HortTechnology 12:541–544.

Briggs, J.A., M.B. Riley, and T. Whitwell. 1998. Quantification and remediation of pesticides in runoff water from containerized plant production. J. Environ. Qual. 27:814–820.

Burger, D.W., J.S. Hartin, D.R. Hodel, T.A. Lukaszewski, S.A. Tjosvold, and S.A. Wagner. 1987. Water use in California's ornamental nurseries. Cal. Ag. 41(9):7–8.

Cabrera R.I. 1996. Using slow- and controlled-release fertilizers in container nursery crops. Rutgers Coop. Research Ext. FS847.

Chappell, M., S.K. Dove., M.W. van Iersel, P.A. Thomas, and J. Ruter. 2013. Implementation of wireless sensor networks for irrigation control in three container nurseries. HortTechnology 23:747–753.

Drzal, M.S., W.C. Fonteno, and D.K. Cassel. 1999. Pore fraction analysis: A new tool for substrate testing. Acta Hortic. Proc. Int. Sym. Growing Media and Hydroponics. 481:43–54.

Environmental Protection Agency. 1987. Federal Water Pollution Control Act (Clean Water Act). 33 U.S.C. §1251.

Fain, G.B., C. H. Gilliam, K.M. Tilt, J.W. Olive, and B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18:142–144.

Fain, G.B., K.L. Paridon, and P.M. Hudson. 2004. The effect of cyclic irrigation and herbicide on plant and weed growth in production of *Magnolia grandiflora* 'Alta'. Proc. S. Nurs. Ass. Res. Conf. 49:37–39.

Fare, D.C., C.H. Gilliam, G.J. Keever, and J.W. Olive. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. HortScience 29:1514–1517.

Fare, D.C., C.H. Gilliam, and G.J. Keever. 1992. Monitoring irrigation at container nurseries. HortTechnology 2:75–78.

Fernandez, T., J.D. Lea-Cox, G. Zinati, C. Hong, R. Cabrera, D. Merhaut, J. Albano, M. van Iersel, T.H. Yeager, and D. Buhler. 2009. NCDC216: A multistate group for water management and quality for ornamental crop production and health. Proc. S. Nurs. Assn. Res. Conf. 54:35–38.

Fulcher, A., A.V LeBude, J.S. Owen, S.A. White, and R.C. Beeson. 2016. The next ten years: Strategic vision of water resources for nursery producers. HortTechnology 26:121–132.

Furuta, T. 1976. Environmental plant production and marketing. Cox Publishing, Arcadia, Calif. p. 94-156.

Gilliam, C.H., D.C. Fare, and A. Beasley. 1992. Nontarget herbicide losses from application of granular Ronstar to container nurseries. J. Environ. Hort. 10:175–176.

Gilliam, C.H., W.J. Foster, J.L Adrain, and R.L. Shumack. 1990. A survey of weed control costs and strategies in container production nurseries. J. Environ. Hort. 8:133–135.

Hodges, A.W., C.R. Hall, B.K. Behe, and J.H. Dennis. 2008. Regional analysis of production practices and technology use in the U.S. nursery industry. HortTechnology 43:1807–1812.

Hong, C.X., and G.W. Moorman. 2005. Plant pathogens in irrigation water: Challenges and opportunities. Crit. Rev. Plant Sci. 24:189–208.

Horowitz, M., and C.L. Elmore. 1991. Leaching of oxyfluorfen in container media. Weed Tech. 5:175–180.

Howarth, R.W. 1988. Nutrient limitation of net primary production in marine ecosystems. Ann. Rev. Ecol. 19:89–110.

Howarth, R.W. and R. Marino. 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems. Limnol. Oceanogr. 51(1, part 2), 364–376.

Judge, C.A. 2001. Predicting herbicide dissipation in container nursery crop production – a method for improving herbicide performance and reducing hand weeding. North Carolina State Univ., Raleigh, NC. M.S. Thesis. 75 p.

Kabashima, J.N. 1993. Innovative irrigation techniques in nursery production to reduce water usage. HortScience 28:291–293.

Lea-Cox, J.D., D.S. Ross, and K.M. Teffeau. 2001. A water and nutrient management planning process for container nursery and greenhouse production systems in Maryland. J. Environ. Hort. 19:230–236.

Lichtenberg, E., J. Majsztrik, and M. Saavoss. 2013. Profitability of sensor- based irrigation in greenhouse and nursery crops. HortTechnology 23:770–774.

Mack, R., J.S. Owen, A.X. Niemiera, and J. Latimer. 2017. Virginia nursery and greenhouse grower survey of best management practices. HortTechnology 27:386–392.

Majsztrik, J.C., R.T. Fernandez, P.R. Fisher, D.R. Hitchcock, J.D. Lea-Cox, J.S. Owen, L.R. Oki, and S.A. White. 2017. Water use and treatment in container-grown specialty crop production: a review. Water Air Soil Pollut. 228:151.

Majsztrik, J.C., and J.D. Lea-Cox. 2013. Water quality regulations in the Chesapeake Bay: Working to more precisely estimate nutrient loading rates and incentivize best management practices in the nursery and greenhouse industry. HortScience 48:1097–1102.

Majsztrik, J.C., A.G. Ristvey, and J.D. Lea-Cox. 2011. Water and nutrient management in the production of container-grown ornamentals. Hort. Rev. (Am. Soc. Hort. Sci.) 38:253–297.

Manning, L.K. and R.R. Tripepi. 1995. Suitability of composted bluegrass residues as an amendment in container media. HortScience 30:277–280.

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

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

Million, J. and T. Yeager. 2015b. Monitoring leaching fraction for irrigation scheduling in container nurseries. IFAS Ext. ENH1268.

Moe, C.L. and R.D. Rheingans. 2006. Global challenges in water, sanitation and health. J. Water Health 4:41–58.

Niemiera, A.X. (ed.). 1994. Fertilizers: Minimizing use and maximizing growth of container and field-grown plants. In: C.W. Heuser, Jr., and P.E. Heuser (eds.), Recycling and resource conservation. Pennsylvania Nurserym. Association Inc., Harrisburg, PA. p.105-115.

O'Neill, M.P. and J.P. Dobrowolski. 2011. Water and agriculture in a changing climate. HortScience 46:155–157.

Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and alberta spruce under different irrigation and N fertilization. J. Environ. Hort. 7:32–35.

Rauschkolb, R.S. and A.G. Hornsby. 1994. Nitrogen management in irrigated agriculture. Oxford Univ. Press, New York. 251 pp.

Raviv, M., and J.H. Lieth, Eds. 2008. Soilless culture: Theory and practice. Elsevier BV, New York.

Richards, D., M. Lane, and D.V. Beardsell. 1986. The influence of particle-size distribution in pinebark:sand:brown coal potting mixes on water supply, aeration and plant growth. Sci. Hort. 29(1–2):1–14.

Ruter, J. M. 1998. Pot-in-pot production and cyclic irrigation influence growth and irrigation efficiency of ‘Okame’ cherries. J. Environ. Hort. 16:159–162.

Saunders, T. 2014. An Irrigation Evolution. Comb. Proc. Intl. Plant Prop. Soc. 64:309–313.

Schoene, G., T. Yeager, and D. Haman. 2006. Survey of container nursery irrigation practices in West-Central Florida: An educational opportunity. HortTechnology 16:682–685.

Simpson, C.V., C.H. Gilliam, J.E. Atland, G.R. Wehtje, and J.L. Sibley. 2004. Diuron: Postemergence oxalis control in container-grown plants. J. Environ Hort. 22:45–49.

Stewart, C.J., S.C. Marble, B.J. Pearson, and P.C. Wilson. 2017. Impact of container nursery production practices on weed growth and herbicide performance. HortScience 52:1593–1600.

Taylor-Lovell, S., G.K Sims, and L.M. Wax. 2002. Effects of moisture, temperature, and biological activity on the degradation of isoxaflutole in soil. J. Agric. Food. Chem. 50:5626–5633.

Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. J. Environ. Hort. 14:199–204.

U.S. Department of Agriculture 2017. 2017 Census of agriculture. Table 2: Market value of agricultural products sold including landlord's share, food marketing practices, and value-added products: 2017 and 2012. Full report, Volume 1, p.10.

U.S. Department of Agriculture. 2014. 2014 Census of horticultural specialties. Table 17: Nursery stock sold: 2014. U.S. Dept. Ag., Washington, D.C.

U.S. Department of Agriculture. 2012. 2012 Census of agriculture. Ranking of market value of ag products sold, full report Vol. 1, Table 2. U.S. Dept. Ag., Washington D.C.

Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. Sci.Total. Environ. 380:48–65.

Warner, L.A., A.J. Lamm, P. Beattie, S.A. White, and P.R. Fisher. 2018. Identifying opportunities to promote water conservation practices among nursery and greenhouse growers. HortScience 53:958–962.

Warsaw, A.L., R.T. Fernandez, B. Cregg, and J.A. Andersen. 2009. Container-grown ornamental plant growth and water runoff nutrient content and volume under four irrigation treatments. HortScience 44:1573–1580.

Weber, J. B. 1991. Fate and behavior of herbicides in soils. Appl. Plant Sci. 5:28–40.

Whitcomb, C.E. 1984. Plant production in containers. Lacebark Pub. Stillwater, OK. p. 396–470

Wilen, C., U. Schuch, and C. Elmore. 1999. Mulches and subirrigation control weeds in container production. J. Environ. Hort. 17:174–180.

Williams, D. B. and J. Sanders. 1984. The origin and dissemination of weed seeds in container-grown nursery stock. South Nurserymen Assn. Res. Conf. Annu. Rep. 29:244–251.

Yeager, T., C. Gilliam, T.E. Bilderback, D. Fare, A. Niemiera, and K. Tilt. 1997. Best management practices, guide for producing container-grown plants. SNA. Atlanta, GA.

Yeager, T., R. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback, and R. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206–208.

# CHAPTER 2. ON-SITE ANALYSIS OF IRRIGATION MANAGEMENT PRACTICES AT CONTAINER NURSERIES IN ALABAMA


## Abstract

Auburn University and the Alabama Cooperative Extension System conducted an on-site analysis of irrigation management practices at nine container nurseries in Alabama July through October of 2018 and 2019. Average irrigation application, distribution uniformity (DU) and leaching fraction (LF) data were taken on blocks of dwarf yaupon holly (*Ilex vomitoria 'Nana'*) or a similar crop in 11 L (#3) containers under overhead irrigation. Pour-through pH, electrical conductivity (EC), and size index data were taken on sample plants. Daily irrigation time ranged from 20 to 120 minutes, with four out of nine nurseries irrigating for a duration of 30 minutes. Across all nurseries, irrigation application ranged from 0.43 to 2.24 cm (0.17 to 0.88 in) per day. Average irrigation application across all nurseries was 1.1 cm (0.4 in). DU ranged from 61% to 78% between nurseries, with all nine nurseries falling below the best management practice (BMP) recommendation of 80% or greater. LF ranged from 5.8% to 34.8% between nurseries, with only four out of nine nurseries falling within the BMP guideline of 15% or less. LF varied greatly within each nursery, likely due to poor DU. Results of this study suggest that the most practical area for improving irrigation practices in Alabama is to improve DU. The uniformity of plant size across all nurseries despite differing LF suggests that growers may be able to utilize lower volumes of irrigation to produce plants of salable size.



**Index Words:** Best management practices, survey, ornamental production, leaching, distribution uniformity (DU), efficiency, water quality

**Project Partners:** Auburn University and the Alabama Cooperative Extension System worked to conduct on-site assessments of irrigation management practices in Alabama container

nurseries. This research was funded by the Alabama Specialty Crop Block Grant Program from November 1, 2017 to October 31, 2019.

**Significance to Industry**

Container nursery production relies heavily on near daily irrigation to produce quality plants, however high volumes of irrigation can lead to runoff and leaching of applied nutrients and other contaminants. One way to reduce the water use and the loss of nutrients by leaching is to irrigate more efficiently. Irrigation management is therefore an important part of reducing environmental harm and the loss of inputs from the production system**.** To begin improving irrigation management practices in Alabama, current practices must be assessed. The data collected from nurseries across the state indicate that an area where growers struggle to meet BMPs for irrigation is distribution uniformity (DU). Improving DU in overhead irrigation systems has the potential not only to reduce irrigation run time and volume of water but could also improve leaching fraction (LF) by distributing water more evenly. Decreasing LF would reduce leachate, sediment, and dissolved fertilizers lost from the production cycle and carried into the surrounding environment, increasing fertilizer savings for growers while reducing environmental impact.

**Introduction**

Water resource use is becoming increasingly important for container nursery growers across the United States. In the coming years, the amount of quality irrigation water available to nursery producers will likely decrease due to increased population demand, urbanization, and legislation (Beeson et al., 2004; Fernandez et al., 2009). A survey in Virginia asked greenhouse and nursery growers to list the top water management issues affecting their operation, and most responses included water availability or access, water quality, and water use or waste (Mack et

al., 2017). Due to concerns about the environmental impacts of water use, many states have implemented legislation that regulates the total maximum daily load of contaminants leaving the site (EPA, 1987; Beeson et al., 2004; Warsaw et al., 2009). In 2015, the Clean Water Rule was implemented under the Clean Water Act, which expanded the EPA's definition of "Waters of the United States" so that many previously excluded water bodies such as agricultural ponds and drainage ditches fell under EPA regulation (DOD, 2019; EPA, 2019). Under the new rule, all water leaving a nursery property was considered subject to EPA regulation. The 2015 rule was repealed in 2019, however this legislation should serve as an indication that in the future, similar regulations may be imposed which could impact the container nursery industry and burden growers with the costs associated with compliance (American Farm Bureau Federation, 2020). Thus, conservation through improved monitoring and application efficiency has been an industry concern for both growers and regulatory agencies (Beeson et al., 2004; Mack et al., 2017; Warsaw et al., 2009).

Overhead irrigation is the most common form of irrigation for container ornamentals in #7 containers and smaller (Beeson et al., 2004; Beeson and Knox, 1991; Bilderback, 2002). Overhead systems distribute water above and around crops using sprinkler head emitters in a broadcast pattern. These systems are flexible, can cover large areas, and are inexpensive compared to microirrigation or sub-irrigation, however they are less efficient if improperly installed, and the uniformity can be reduced by environmental factors of wind and evaporation (Beeson and Knox, 1991; Whitcomb, 1984). In an overhead irrigation system irrigating #1 containers, only 25% to 37% of applied irrigation reaches the plant surface; the majority falls unused between pots or is deflected by the plant canopy (Beeson and Knox, 1991). Non-target irrigation contributes to runoff and can carry fertilizer and other contaminants such as sediment,

pesticides, and phytopathogens into surrounding water resources (Majsztrik et al., 2017; Warsaw et al., 2009).

Ornamental container production in the southeastern region requires frequent irrigation due to limited container volume and the fast-draining nature of soilless substrates. Pine bark is the primary substrate used by the container nursery industry as it readily available, light weight, and has physical properties which are ideal for container production. Pine bark's porosity provides a high degree of air space for gas exchange and rapid drainage. High porosity substrates work well for container plant production, however excess irrigation may leach nutrients and other environmental contaminants from containers (Dzral et al., 1999; Warsaw et al., 2009). In the southeastern United States, water resources are plentiful, and irrigation is typically a small part of total operation costs (Majsztrik et al., 2011), so it is common for growers to rely on the porosity of soilless substrate and err on the side of overwatering. However, as growers become more aware of the negative effects of overwatering, they generally make an effort to conserve and protect water quality.

Needs assessment is the first step towards implementing research and extension programming to improve water use at container nurseries. A survey of irrigation practices at container nurseries in Alabama has not occurred in over 20 years (Fain et al., 2000), with no physical audit of irrigation efficiency since the late 80's (Fare et al., 1992). Surveys are important tools to collect large amounts of grower-reported data, but on-site assessments are necessary to quantify actual irrigation management practices in nurseries. The objective of this study was to measure the efficiency of current irrigation practices used in Alabama. Results obtained from this project will be used to help educate nursery growers about how to improve their resource use, efficiency, and crop quality through the implementation of BMPs.

## Materials and Methods

On-site irrigation data was collected to assess current irrigation practices at nine container production nurseries in Alabama. Data collection began in June of 2018 and continued through September 2018. Additional nurseries were visited in the summer of 2019 from July to October. Three nurseries were located in northern Alabama, three were located in central Alabama, and three were located in southern Alabama on the Gulf Coast. Nurseries were surveyed from the following counties: Limestone, Macon, Mobile, Montgomery, Morgan, and Shelby. Nurseries were assigned a letter (A-I) for comparison purposes but remain anonymous. At each nursery, application rate, distribution uniformity and leaching fraction were assessed on blocks of dwarf yaupon holly (*Ilex vomitoria* 'Nana') or a similar crop in 11 L (#3) containers under overhead irrigation. The pH and electrical conductivity (EC) of 8 to12 plants at each nursery were measured using the pour-through method, (Wright, 1986) and size index (SI) of the same plants was recorded.

Distribution uniformity (DU) is a measure of how uniformly water is applied to an irrigation area. To determine DU, 473.2 mL (16 oz) plastic collection cups were placed in a uniform grid pattern within an irrigation zone. Depending on the size of the block, 20 to 32 cups were used. Cups were weighed down to prevent tipping during an irrigation event. During this study, growers were asked to water as they typically would for the block of plants being assessed, in order to reflect a normal irrigation cycle. After an irrigation cycle, the volume of water collected in the cups was measured with a graduated cylinder. To calculate DU, the average of the lowest quartile of application volumes were divided by the overall average application volume and multiplied by 100.

$$DU = \frac{average\ application\ of\ lower\ quartile}{average\ overall\ application} \times 100$$

According to BMPs, DU values should be greater than 80%, with a percentage lower than 60% indicating a more thorough audit is required to determine design or hardware malfunctions in the system (Bilderback et al., 2013). The volume of water and cup diameter were used to calculate the total application in centimeters and inches and was averaged over the area assessed to obtain average irrigation application. Application rate was calculated by dividing the overall average application of irrigation by the application time (overall application average/run time in hours).

Leaching fraction (LF) is the proportion of applied water that leaches from a container, divided by the amount of irrigation applied (Niemiera, 1994). For microirrigation systems, LF is measured in two units: a container plant that has a catch pan to measure leachate, and an empty, holeless version of the same container placed directly next to the plant to measure applied water. In overhead irrigation, the amount of water the reaches the substrate surface is affected by the plant canopy, so this two-unit method may not give an accurate LF value (Million and Yeager, 2015). For this study, LF was analyzed as a single unit; the application and leachate volumes were measured gravimetrically on the same plant, so that capture efficiency of the canopy could be accounted for. To calculate the LF, 8 to 12 plants in containers were removed from the block and fitted tightly into a 9.46 L (10 qt) bucket with a diameter of 26 cm and height of 24 cm. A 15 cm section of 15.34 cm diameter (6 in) PVC pipe was used as a spacer between the bottom of the nursery container and the bottom of the bucket to allow space for leachate to collect. Plastic food wrap was then wrapped tightly around the top of the leachate collection bucket to create a water-tight seal between the nursery container and the bucket. The plant with the bucket, PVC spacer, and plastic skirt was then weighed to determine its pre-irrigation weight and placed back in its original location within the block. After running a typical irrigation cycle, samples were allowed

to drain for 30 minutes and weighed again. Any gain in weight was attributed to the addition of water. Total applied irrigation per plant was calculated by subtracting the pre-irrigation weight from the post-irrigation weight. The plants were then removed from the leachate collection buckets, and leachate was recovered and measured. To calculate the LF, the recovered leachate was divided by total applied irrigation and multiplied by 100.

$$LF = \frac{leacheate\ recovered}{total\ applied\ irrigation} \times 100$$

BMPs state that LF should be 15% or less to avoid excessive irrigation (Bilderback et al., 2013). If LF is over 20%, the manual recommends that irrigation run time should be reduced.

Size index (SI) data of the same plants used to measure LF was recorded as the average of the height, widest canopy width, and canopy width perpendicular to the widest width [(height + canopy widest width + width perpendicular) ÷ 3]. Media pH and electrical conductivity (EC) were measured on the same plants using the pour-through nutrient extraction method (Wright, 1986). Leachate pH and EC were measured using a HACH Pocket Pro+ Multi 2 Tester (Hach Co., Loveland, CO).

**Results and Discussion**

*Irrigation Rates*

Over the nine nurseries audited, irrigation cycle duration ranged from 20 to 120 minutes (Table 2.1). A run time of 30 minutes was the most frequent irrigation run time observed, with four out of nine nurseries irrigating for this length of time. Growers commonly assume their irrigation application rates are uniform and adequate, based on general “rules of thumb” associated with run time. However, this run time may not correlate with actual precipitation rates. In a 1992 survey of six Alabama growers indicated that they usually watered for one hour, applying what they thought to be 1 inch of water (Fare et al., 1992). When these same nurseries

were audited, the actual average irrigation applied was around 40% less than growers assumed (Fare et al., 1992).

Across all nurseries audited in this study, average irrigation application ranged from 0.43 to 2.24 cm (0.17 to 0.88 in) (Table 2.1) with an average irrigation application across all nurseries of 1.1 cm (0.4 in). This is consistent with research done by Fare and others (1992), reporting that growers in Alabama irrigated for an average of 1.5 cm (0.6 in), ranging from 0.8 to 3.3 cm (0.3 to 1.3 in). In a survey of 26 container nurseries in Georgia, growers reported that they applied around 1 acre-inch of water per irrigation event for #1 and #3 containers and about 0.5 acre-inch for #5 and larger containers (Garber et al., 2002). However, the study recognized that the information given was likely estimates reported by growers and that quantitative measurement would be necessary to document progress in irrigation management. This study by Garber et al. (2002) demonstrates the importance of monitoring irrigation systems for uniformity as well as the need for on-site analysis to determine actual irrigation management practices instead of reported values. Application rate ranged from 0.7 to 2.7 cm/hour (0.28 to 1.06 in/hour) between nurseries and averaged 1.4 cm/hour (0.56 in/hour) across all nurseries (Table 2.1). Application rate variances were likely due to differences in system designs, sprinkler heads, and irrigation run time.

In our study, across all nurseries visited, irrigation was most frequently applied in the range of 0.5 to 1 cm (0.2 to 0.4 in) (Figure 1), with 44% of the total observations falling within this range. Regional differences in irrigation practices showed that nurseries located in northern Alabama, nurseries A, B, and C, tended to apply no more than 1.3 cm (0.5 in) of irrigation. The central and southern nurseries (with the exception of nursery H) generally applied more

irrigation, in the range of 0.5 to >2.5 cm (0.2 to >1 in) (Table 2.1). These differences may have been due to cultural practices, seasonal changes, or water requirements of different crops.

One area of irrigation management that would benefit from improvement is distribution uniformity. The average DU for each nursery ranged from 61% to 78% (Table 2.2), meaning that all the nurseries visited fell below the BMP recommendation of 80% or greater. Average LF values ranged from 7.0% to 36.4% between nurseries (Table 2.2), with only 44% of nurseries having an average LF within the BMP guideline of 15% or less. Within each nursery, LF sample values ranged greatly within the same irrigation block. For example, at nursery G the LF of one container was 5%, while another container within the same irrigation block had a LF of 67%. The large range could be due to the low DU of irrigation systems. Growers may try to account for inadequate DU by irrigating longer so the dry spots receive ample water, erring on the side of overwatering the rest of the block. This practice can lead to high leaching in one area and very little in another. In nurseries A, B, C, and E, DU was above 70%, and LF values were relatively low. Nursery I had one of the best DU percentages, 78%, but LF was one of the highest recorded, 34.8%. The high leaching despite an acceptable DU was likely due to the time of irrigation. Grower I irrigated for two hours, and the resulting high LF indicates that irrigation run time should be reduced. Growers can use LF as a tool to generally adjust irrigation run time using the following equation (Million and Yeager, 2015).

$$New\ run\ time\ (\text{min}) = \frac{(100\% - Measured\ LF\ \%)}{(100\% - Desired\ LF\%)} \times Measured\ run\ time\ (\text{min})$$

Periodically monitoring the DU and LF of irrigation systems can help growers recognize inefficiencies so that changes can be made. Although an overall system or design overhaul may be expensive and labor-intensive, there are small improvements that can be made to current systems to increase efficiency.

*Plant Growth*

The SI of plants between nurseries were relatively uniform despite differing DU and LF (Figure 2). Across all nurseries, SI ranged from 21.7 to 49.7 with an average of 38.3 and a standard deviation of 4.9 (Nursery B was excluded from SI data because sampled plants were Boxwood species (*Buxus*) rather than dwarf yaupon hollies). This demonstrates that some growers were able to produce plants of a similar size with lower leaching fractions, which implies that reducing the loss of dissolved fertilizers through leaching both decreased the environmental impact of container nurseries and maximized the longevity of controlled release fertilizers (CRFs). Fertilizers are a costly input, so irrigating for a lower target LF may help growers reduce costs associated with CRF application.

Pour-through pH, EC, SI, and LF of sample plants were recorded for each nursery (Table 2.3). Correlations between pH, EC, SI and LF were calculated using Pearson's Correlation test in R (R Core Team, 2019), however there were no significant correlations consistent across more than two nurseries. No analysis between nurseries or regions was made due to different cultural practices, stages of production, and weather patterns.

**Conclusion**

The results of this assessment show that the most practical area to improve irrigation efficiency in Alabama container nurseries is the distribution uniformity of overhead irrigation systems. As a result of improving the DU of a system, water would be distributed more evenly and LF values would be more uniform. Additionally, the uniformity of plant SI across all nurseries, despite differing LF suggests that growers may be able to utilize lower volumes of irrigation to produce plants of salable size. Less leaching would not only reduce the

environmental impact of runoff from container nurseries, but may preserve the longevity of CRF, saving growers the expense of premature CRF reapplication.

**Literature Cited:**

American Farm Bureau Federation. 2020. Clean water act, WOTUS. Washington DC. <https://www.fb.org/issues/regulatory-reform/clean-water-act>. 2 January 2020.

Beeson, R.C., M.A. Arnold, B.B. Bilderback, S. Chandler, H.M. Gramling, J.D. Lea-Cox, 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.

Beeson, R.C. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848–850.

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. SNA, Acworth, GA.

Bilderback, T.E. 2002. Water management is key in reducing nutrient runoff from container nurseries. HortTechnology 12:541–544.

Department of Defense and Environmental Protection Agency. 2019. Definition of "Waters of the United States"—Recodification of Pre-Existing Rules. Fed. Reg. 84:56626–5667. (to be codified at 33 C.F.R. pt. 328 and 40 C.F.R. pt. 110, 112, 116, 117, 122, 230, 232, 300, 302, and 401). <https://www.epa.gov/sites/production/files/2019-09/documents/wotus_rin-2040-af74_final_frn_prepub2.pdf>. 20 December, 2019.

Drzal, M.S., W.C. Fonteno, and D.K. Cassel. 1999. Pore fraction analysis: A new tool for substrate testing. Acta Hortic. Proc. Int. Sym. Growing Media and Hydroponics 481:43–54.

Environmental Protection Agency. 1987. Federal Water Pollution Control Act (Clean Water Act). 33 U.S.C. §1251.

Fain, G.B., C. H. Gilliam, K.M. Tilt, J.W. Olive, and B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18:142–144.

Fare, D.C., C.H. Gilliam, and G.J. Keever. 1992. Monitoring irrigation at container nurseries. HortTechnology 2:75–78.

Fernandez, T., J.D. Lea-Cox, G. Zinati, C. Hong, R. Cabrera, D. Merhaut, J. Albano, M. van Iersel, T.H. Yeager, and D. Buhler. 2009. NCDC216: A multistate group for water management and quality for ornamental crop production and health. Proc. S. Nurs. Assoc. Res. Conf. 54:35–38.

Garber, M. P., J. M. Ruter, J. T. Midcap, and K. Bondari. 2002. Survey of container nursery irrigation practices in Georgia. HortTechnology 12:727–731.

Mack, R., J.S. Owen, A.X. Niemiera, and J. Latimer. 2017. Virginia nursery and greenhouse grower survey of best management practices. HortTechnology 27:386–392.

Majsztrik, J.C., A.G. Ristvey, and J.D. Lea-Cox. 2011. Water and nutrient management in the production of container-grown ornamentals. Hort. Rev. (Am. Soc. Hort. Sci.). 38:253–297.

Majsztrik, J.C., R.T. Fernandez, P.R. Fisher, D.R. Hitchcock, J.D. Lea-Cox, J.S. Owen, L.R. Oki, and S.A. White. 2017. Water use and treatment in container-grown specialty crop production: a review. Water. Air. Soil. Pollut. 228:151.

Million, J., and T. Yeager. 2015. Monitoring leaching fraction for irrigation scheduling in container nurseries. IFAS Ext. ENH1268.

Niemiera, A.X. (ed.). 1994. Fertilizers: Minimizing use and maximizing growth of container and field-grown plants. In: C.W. Heuser, Jr., and P.E. Heuser (eds.), Recycling and resource conservation. Pennsylvania Nurserym. Assoc. Inc., Harrisburg, PA.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>. 27 December, 2019.

Warsaw, A.L., R.T. Fernandez, B. Cregg, and J.A. Andersen. 2009. Container-grown ornamental plant growth and water runoff nutrient content and volume under four irrigation treatments HortScience 44:1573–1580.

Whitcomb, C.E. 1984. Plant production in containers. Lacebark Pub. Stillwater, OK. p. 396–470

Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227–229.

Table 2.1. On-site irrigation data collected from nine container production nurseries in Alabama.

| Nursery | Irrigation duration (hour) | Average irrigation applied (in[z]) | Irrigation range (in) | Irrigation rate[y] (in/hr) |
|---|---|---|---|---|
| A | 0.5 | 0.26 | 0.15–0.44 | 0.52 |
| B | 0.2 | 0.17 | 0.11–0.21 | 0.85 |
| C | 0.5 | 0.25 | 0.14–0.40 | 0.51 |
| D | 0.5 | 0.53 | 0.22–0.95 | 1.06 |
| E | 1 | 0.48 | 0.33–1.05 | 0.48 |
| F | 1.5 | 0.48 | 0.24–1.07 | 0.32 |
| G | 2 | 0.56 | 0.3–1.05 | 0.28 |
| H | 0.5 | 0.30 | 0.12-0.67 | 0.60 |
| I | 2 | 0.88 | 0.53–1.29 | 0.44 |

[z]Calculated from cup dimensions and volume of irrigation collected, inches irrigation = [irrigation volume (mL) ÷ area of cup mouth ($cm^2$)] ÷ 2.54.

[y]Irrigation rate was calculated in number of inches per hour, and reflects the average application (in) that would occur if all nursuries irrigated for one hour. Irrigation rate = average irrigation ÷ irrigation duration.

Table 2.2. Distribution uniformity and leaching fraction of nine nurseries in Alabama.

| Nursery | Distribution uniformity[z] | Average leaching fraction[y] | Leaching fraction range |
|---|---|---|---|
| A | 78% | 8.6% | 4.3%–8.3% |
| B | 74% | 7.6% | 1.2%–15.8% |
| C | 72% | 17.2% | 3.9%–41.2% |
| D | 67% | 7.4% | 1.8%–15.5% |
| E | 74% | 17.5% | 1.7%–35.2% |
| F | 61% | 7.0% | 0.9%–34.7% |
| G | 66% | 36.4% | 5.0%–67.2% |
| H | 65% | 24.7% | 0%–51.6% |
| I | 78% | 34.8% | 16.9%–50.7% |

[z]Distribution uniformity = (average application of lower quartile)/ (average overall application) × 100.

[y]Leaching fraction = (leachate recovered/total applied irrigation) × 100.

Table 2.3. Leaching fraction and pour-through data, sampled at nine nurseries after a typical irrigation cycle.

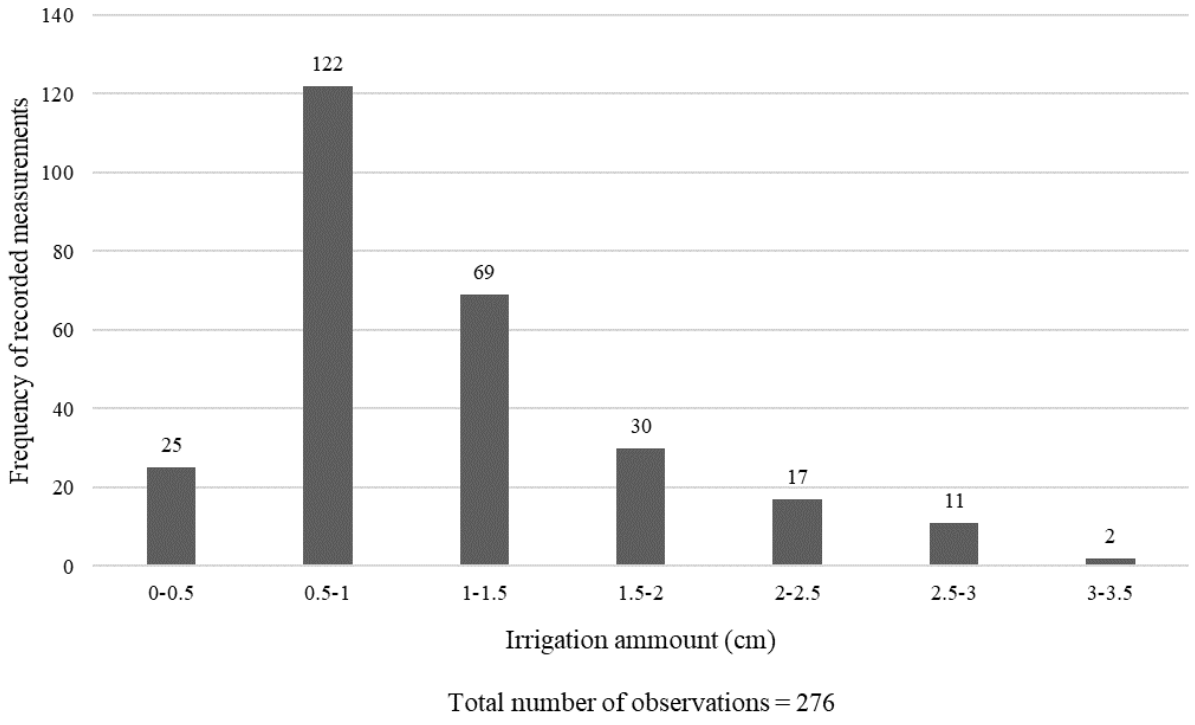
| Nursery | Average leaching fraction[z] | Average pH | Average electrical conductivity (µS/cm)[y] | Average Size index[z] |
|---|---|---|---|---|
| A | 8.6% | 7.21 | 261.56 | 34.16 |
| B | 7.6% | 6.2 | 892.83 | 24.28 |
| C | 17.2% | 4.77 | 845.6 | 43.61 |
| D | 7.4% | 5.55 | 326.77 | 42.13 |
| E | 17.5% | 5.31 | 1017.83 | 41.77 |
| F | 7.0% | 6.67 | 406.83 | 33.76 |
| G | 36.4% | 4.59 | 1565.2 | 41.55 |
| H | 24.7% | 6.5 | 410.4 | 37.07 |
| I | 34.8% | 6.33 | 575.63 | 37.39 |

[z]Leaching fraction = (leachate recovered/total applied irrigation) × 100.

[y]µS/cm = Microsiemens per cm, 1 µS/cm = 0.001 S/m.

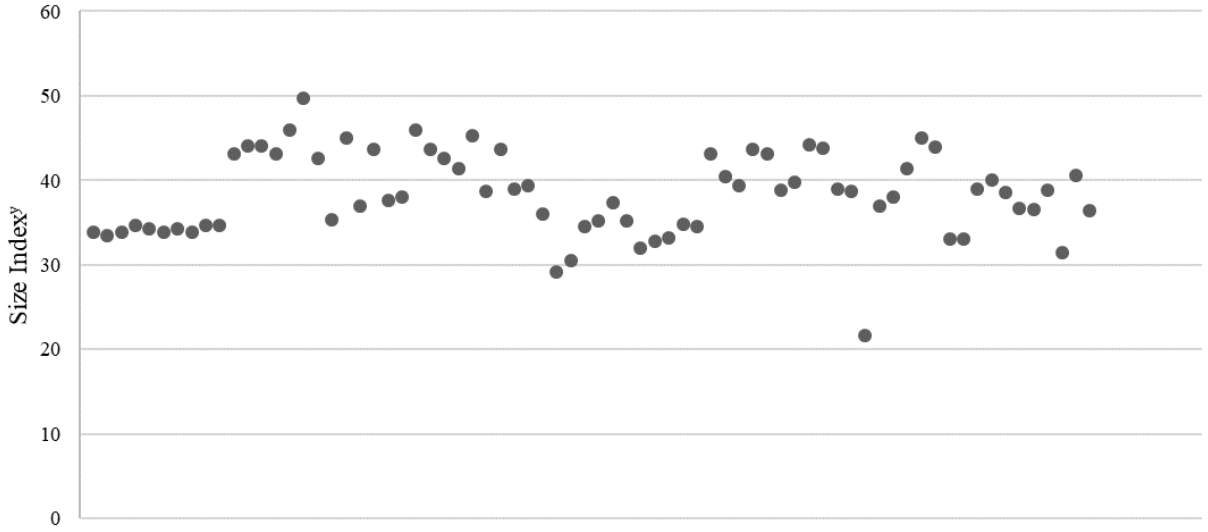
[z]Size index = [(height + canopy widest width + width perpendicular) ÷ 3].

Figure 1. Frequency of irrigation application from nine container nurseries in Alabama.




Total number of observations = 276

Figure 2. Size index of sample dwarf yaupon hollies (*Ilex vomitoria 'Nana'*) plants from eight[z] container nurseries in Alabama




[z]Nursery B was excluded because sampled plants were Boxwood species (Buxus) rather than dwarf yaupon hollies

[y]Size Index = [(height + canopy widest width + width perpendicular) ÷ 3]

# CHAPTER 3: THE EFFECTS OF LEACHING FRACTION AND FERTILIZATION RATE ON FERTILIZER LONGEVITY UNDER SIMULATED CONTAINER NURSERY CONDITIONS


## Abstract

This study was conducted at the Ornamental Horticulture Research Station in Mobile, Alabama to determine the effects of leaching fraction (LF) and control-release fertilizer (CRF) rates on the growth of ornamental plants and fertilizer longevity in container nursery conditions. Each plot was assigned a leaching fraction (LF) of 5%, 25% or 35%, and a fertilizer rate of 50, 70, or 90g (1.76, 2.47, and 3.17 oz). Three replications of each treatment, a total of 27 irrigation plots, were arranged in a completely randomized design on a crushed stone pad. Four 11 L (2.91 gal) black plastic containers filled with 100% pine park substrate amended with dolomitic lime and planted with dwarf Japanese holly (*Ilex crenata 'Compacta'*) liners were placed in the center of each irrigation plot. The assigned rates of 18-6-8 total Florikan® CRF with Nutricote® were encased in mesh bags and sub dressed beneath the soil surface to allow for prill recovery at the end of the study after 24 weeks. Main effects of LF and fertilizer rate on percent fertilizer loss and plant growth index were not significant ($P>0.05$) and there were no significant interactions between LF and fertilizer rate. There were differences ($P<0.05$) in pour-through pH among the LF treatments and significant differences in pour-through electrical conductivity (EC) among the fertilizer rates, however, no significant trends for either. The results may have been inconclusive due to the containers overheating. Effects of extreme heat stress on plant health and survival compromised size index data and made it impossible to draw conclusions about the effects of CRF or LF on plant size index. The heating of the media may have also influenced the rate of fertilizer release, since the release of CRF is very temperature dependent. This experiment used

cultural practices typical of container producers in the southeastern region of the U.S., however the wide spacing and small number of containers may have been contributing factors for overheating.

**Index Words:** Overhead irrigation, Ornamentals, CRFs, Nutrients

**Significance to the Industry**

Despite lasting for many months, CRFs are a significant cost for growers (Bayer et al., 2015). Maintaining the longevity of fertilizers could reduce the cost associated with production. Irrigation and fertilization practices are interrelated, and repeated over-irrigation causes constant leaching of nutrients, potentially leading to faster exhaustion of CRF (Adams et al., 2013). Managing irrigation more effectively has the potential to reduce the environmental impact of container nurseries and decrease the cost of production by maximizing plant nutrient use efficiency while minimizing losses due to leaching.

**Introduction**

Over the past 50 years, the use of containers in nursery production has increased because plants can be produced more efficiently than by in-field cultivation (Majsztrik et al., 2011). By 2008, over half of the ornamental plants sold by nurseries in the United States were being produced in containers; in the Southeast region, this percentage was closer to 72% (Hodges et al., 2008). Currently, container nurseries utilize large volumes of irrigation and high rates of fertilization, often erring on the side of over-applying, to ensure maximum plant growth (Biernbaum, 1992). Although effective for producing container ornamentals, these management practices lead to large volumes of nutrient-laden runoff leaving production areas (Tyler et al., 1996). Many nurseries now use controlled-release fertilizers (CRFs) rather than soluble

fertilizers due to concerns about nutrient runoff and because they are easy to use and customize. (Majsztrik et al., 2011; Yeager et al., 1993).

CRFs are designed to release nutrients into the surrounding substrate over a controlled time period and formulations lasting from three months to a year are readily available (Andiru et al., 2013). The dissolution and release of nutrients from CFRs is determined by temperature, coating type and thickness, and watering practices (Andiru, 2010; Adams et al., 2013). The movement of nutrient ions from CRFs is driven by the ion-concentration gradient: as water penetrates the fertilizer prill coating and dissolves the fertilizer within, an ion gradient allows nutrients to move from the prill to the substrate (Adams et al., 2013). As dissolved nutrients in the substrate are removed by plant uptake or leaching, more nutrients are released from the prill to maintain the gradient. Repeated over-irrigation may cause constant leaching of nutrients from the container, effectively "resetting" the ion gradient and leading to faster exhaustion of CRFs (Adams et al., 2013). Controlling the amount of irrigation to limit leaching may allow growers to protect the longevity of CRFs and prevent the need to reapply fertilizer sooner than necessary. Irrigation management is a critical part of nutrient management in container production and maximizing efficiency can be a step toward reducing production costs and environmental impacts (Tyler et al., 1996; Lea-Cox et al., 2001, Fernandez et al., 2009).

Leaching fraction (LF) can be used to quantify the amount of irrigation that leaches after an irrigation event and is defined as the proportion of water that leaches from a container divided by the amount applied (Niemiera, 1994).

$$\% \, LF = \frac{leacheate \; recovered}{total \; applied \; irrigation} \times 100$$

The LF of container-grown plants has a significant influence on fertilizer concentration in the substrate solution as well as the amount of nitrogen leached from the container (Niemiera and

Leda, 1993). In pine bark columns, the total amount of N leached from a column with a LF of 40% was 61% greater than that of a column with a LF of 20%. A lower LF also increased the concentration of nutrients in the substrate solution, creating a larger pool of nutrients available for plant uptake (Niemiera and Leda, 1993). Therefore, irrigating to maintain a suitable LF or using a LF-based system has implications to reduce nutrient runoff and increase fertilizer available to plants. An anecdotal study at Saunders Brothers Nursery in Piney River, VA reported that focusing on LF-based irrigation, water usage could be reduced by 89 million gallons simply by targeting a 15% LF for their outdoor container production (Saunders, 2014). As a result, not only did Saunders Brothers produce a higher quality of plants in the same amount of time, they were able to reduce fertilizer rates by 30%.

Previous studies have investigated the effects of fertilizer rates and irrigation volume under microirrigation systems. Compared to a high LF of 40 to 60%, a low LF of 0 to 20% decreased the volume of effluent by 63% and decreased nitrate and phosphorus contents in effluent (Tyler et al., 1996). These gains in efficiency were offset by a 10% loss in total plant growth. Other studies have reported similar reductions in plant growth but suggest that plants might still be at saleable size. In a study conducted at the University of Georgia, shorter irrigation durations consistently produced less leachate, while higher fertilizer rates typically resulted in lower leachate volumes, likely due to increased plant growth (Bayer et. al., 2014). Regardless of irrigation duration, plants grown at the 50% fertilization rate and above were considered “salable”. These results show potential for using shorter irrigation durations and lower fertilization rates to produce high quality plants with minimal leaching. In a similar study, *Gardenia jasminoides* grown in pine bark substrate in a container nursery setting were treated with one of three fertilizer rates of 100%, 50% and 25% of the recommended bag rate and four

irrigation volumes ranging from 66 to 165 mL per irrigation event (Bayer et al., 2015). Results showed that fertilizer rate had a greater effect on plant growth than irrigation volume, and up to a 50% reduced fertilization rate combined with more efficient irrigation produced plants of salable size with less leaching (Bayer et al., 2015). These findings demonstrate the effect of fertilizer rate and LF on plant size, runoff content, and water usage, however a study evaluating these factors on fertilizer longevity are necessary.

The objective of this research is to study the effects of fertilizer rates and irrigation rates on plant growth and CRF longevity in a simulated container nursery setting under overhead irrigation. The results from this study will give further insight into the relationship between LF, CRF rates, and plant growth and may be used to optimize fertilizer life and reduce runoff from container nurseries.

**Materials and Methods**

This study took place at the Ornamental Horticulture Research Station in Mobile, Alabama (USDA Cold Hardiness Zone 8b). Twenty-seven square irrigation plots 2.4 by 2.4 m (8 ft by 8 ft) were constructed on a crushed stone pad. Irrigation plots were separated by a 1.22 m (4 ft) space to prevent overspray. Irrigation was applied using four head-to-head spaced Hunter MP800SR rotator sprinklers on 60.9 cm (2 ft) high risers. The angle of application was set to a 90º arc with a radius of 2.4 m (8 feet).

On May 1, 2019, 108 dwarf Japanese holly (*Ilex crenata* 'Compacta') liners were potted into 11 L (2.91 gal) black plastic containers. The substrate used was 100% pine bark substrate amended with dolomitic limestone at a rate of 3.56 kg/$m^3$ (6 lbs/$yd^{3)}$. Japanese holly was chosen as the plant material because it is a nearly ubiquitous crop in Alabama container nurseries and the small, tight canopy was unlikely to interfere with the spray pattern of the overhead irrigation.

Once potted, liners were pruned to a uniform height of 10 cm (3.9 in) and thoroughly watered in. Four containers with liners were placed in the center of each irrigation plot, spaced 45.7 cm (18 in) from one another. Each plot was assigned one of three irrigation rates to obtain a daily LF goal of 5%, 20%, or 35%. Each plot was assigned a low, medium, and high CRF rate of 50g, 70g, and 90g (1.76, 2.47, and 3.17 oz) respectively. The fertilizer used was 18-6-8 total Florikan® CRF with Nutricote® 12-month release at 25°C (77°F). The fertilizer prills were encased in mesh bags to allow for prill recovery at the end of the study. The bags were constructed using Phiefer vinyl-coated charcoal fiberglass standard insect screening that was heat sealed around the edges (Phiefer Inc., Tuscaloosa, AL). This material was chosen because of the large mesh spaces, based on research by Wilson and others (2009) where mesh bags for fertilizer with larger openings provided better contact between CRF and the substrate, resulting in a better estimate for nutrient release. In order to prevent the plant roots from becoming too entangled in the bags and to ensure even nutrition, the fertilizer treatments were split into two equal amounts and encased in separate bags. Sato and Morgan (2008) reported a better nitrogen (N) recovery rate by applying CRF to the subsurface rather than the surface of substrates, likely due to the reduction of N lost to volatilization In our study, bags were placed in each pot, one on either side of the liner, approximately 2.5 cm (1 in) under the surface of the substrate to minimize N loss from volatilization and protect the bags from weathering.

The experimental design was a 3 by 3 factorial with three irrigation treatments and three fertilizer treatments. Each treatment was replicated three times for a total of 27 replications arranged in a completely randomized design. Each of the nine treatments was controlled with a solenoid valve. Irrigation applications were programmed with an Orbit battery operated controller with an inline solenoid valve (Orbit Irrigation Products LLC., North Salt Lake, UT),

and manually started. Liners were irrigated for the same duration regardless of treatment for the first two weeks of the study until the root systems were established. Leaching fraction of one plant per replication was measured periodically and daily irrigation time adjusted according to the target daily leaching fraction. The equation used was as the following (Million and Yeager, 2015):

$$New\ run\ time\ (min) = \frac{(100\% - Actual\ LF\%)}{(100\% - Desired\ LF\%)} \times Current\ run\ time(min)$$

Plant size index (SI) was measured monthly by averaging the height, widest canopy width, and canopy width perpendicular to the widest width [(height + canopy widest width + width perpendicular) ÷ 3]. Growth index of plants was calculated by subtracting the initial SI from the final SI. At the conclusion of the study, the mesh bags were recovered and removed from the containers. The fertilizer prills were left to air-dry in the bags for 24 days before processing to let absorbed water evaporate. The prills were then manually removed from the bag, separated from remaining soil, and weighed. Fertilizer loss in mass was calculated. Any loss in mass was attributed to nutrient release into the substrate, leaching, uptake by plants, or volatilization. Percent fertilizer loss was calculated as [Fertilizer applied(g) - fertilizer recovered(g)] ÷ fertilizer applied(g). Data was analyzed in SAS® University Edition by SAS (SAS Institute Inc., Cary, NC) using the procglimmix procedure and Tukey's test for means comparison.

**Results and Discussions**

Main effects of LF and fertilizer rate on percent fertilizer loss and plant growth index were not significant ($P>0.05$) and there were no significant interactions (Table 3.1). There were

differences ($P<0.05$) in pour-through pH among the LF treatments and significant differences in pour-through EC among the fertilizer rates, however, no significant trends were shown for either (Table 3.2). The results of this study may have been impacted by environmental complications. The plants were arranged in the irrigation plots at a wide spacing to minimize the canopy effects from neighboring plants, similar to conditions in a typical nursery setting in southern Alabama, however the plant canopies could not grow enough to shade the container walls. The black plastic nursery containers absorbed heat from the sun and created supraoptimal root zone temperatures (data not available) resulting in poor root growth across treatments that likely influenced plant size. High rootzone temperatures may have also compromised the rate of fertilizer release, since the release of CRF is very temperature dependent.

**Conclusion**

This study aimed to answer the question of whether CRF rates and LF, or the interaction between the two, impacted the overall size of ornamental container plants as well as the longevity of CRF. If ornamentals could be grown using a lower fertilization rate when LF was kept to a minimum, the cost of production and environmental impact of nurseries could be reduced by maximizing the efficiency of CRFs through irrigation management. The results were inconclusive due to the containers overheating, compromising plant size index and possibly causing the CRF to release at a faster rate. Despite its problems, this study did highlight the importance of container spacing on the cooling effects of containers in a nursery.

To study the effect of CRF rate and LF independently, this experiment was designed as a three by three factorial. Each irrigation block was treated as an experimental unit, so that as plant water need increased at different rates due to variation in fertilizer treatments, irrigation to obtain

the desired LF could be modified accordingly. In order to get the necessary minimum of three replications of each treatment, the construction of 27 individual irrigation plots was necessary.

Future experiments might consider a different experimental design, such as a split plot design, with the main plot as LF and the subplot of CRF rates. Although this would not account for the differences in plant water requirements due to varying plant growth rate, this would allow containers to be spaced closer together, hopefully creating a shading effect and minimizing the risk of the containers overheating. As a precaution, it may also be necessary to choose a low growing yet heat tolerant crop such as a Juniper (*Juniperus)* species.

## Literature Cited:


Adams, C., J. Frantz, and B. Bugbee. 2013. Macro- and micronutrient release characteristics of three polymer-coated fertilizers: Theory and measurements. J. Plant Nutr. Soil Sci. 176: 76-88.

Andiru, G.A., C.C. Pasian, J.M. Frantz, and P. Jourdan. 2013. Longevity of controlled-release fertilizer influences the growth of bedding impatiens. HortTechnology 23:157–164.

Andiru, G. 2010. Effects of controlled-release fertilizer on nutrient leaching and garden performance of *Impatiens walleriana* (Hook F. 'Extreme Scarlet'). The Ohio State Univ. Columbus, OH. M.S. Thesis. 121 p.

Bayer, A., J. Ruter, and M.W. van Iersel. 2015. Optimizing irrigation and fertilization of *Gardenia jasminoides* for good growth and minimal leaching. HortScience 50:994–1001.

Bayer, A., K. Whitaker, M. Chappell, J. Ruter, and M.W. van Iersel. 2014. Effect of irrigation duration and fertilizer rate on plant growth, substrate solution EC and leaching volume. Acta Hortic. 1034:477–484.

Biernbaum, J.A. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer. HortTechnology 2:127–312.

Fernandez, T., J.D. Lea-Cox, G. Zinati, C. Hong, R. Cabrera, D. Merhaut, J. Albano, M. van Iersel, T.H. Yeager, and D. Buhler. 2009. NCDC216: A multistate group for water management and quality for ornamental crop production and health. Proc. S. Nursery. Assn. Res. Conf. 54:35–38.

Hodges, A.W., C.R. Hall, B.K. Behe, and J.H. Dennis. 2008. Regional analysis of production practices and technology use in the U.S. nursery industry. HortTechnology 43:1807–1812.

Lea-Cox, J.D., D.S. Ross, and K.M. Teffeau. 2001. A water and nutrient management planning process for container nursery and greenhouse production systems in Maryland. J. Environ. Hort. 19:230–236.

Majsztrik, J.C., A.G. Ristvey, and J.D. Lea-Cox. 2011. Water and nutrient management in the production of container-grown ornamentals. Hort. Rev. (Am. Soc. Hort. Sci.) 38:253–297.

Million, J. and T. Yeager. 2015. Monitoring leaching fraction for irrigation scheduling in container nurseries. IFAS Ext. ENH1268.

Niemiera, A.X. (ed.). 1994. Fertilizers: Minimizing use and maximizing growth of container and field-grown plants. In: C.W. Heuser, Jr., and P.E. Heuser (eds.), Recycling and resource conservation. Pennsylvania Nurserym. Assn. Inc., Harrisburg, PA. p.105-115.

Niemiera, A.X. and C.E. Leda. 1993. Nitrogen leaching from Osmocote-fertilized pine bark at leaching fractions of 0 to 0.4. J. Environ. Hort. 11:75–77.

SAS Institute Inc. 2019. SAS® University Edition. Cary, NC: SAS Institute Inc.

Sato, S. and K.T. Morgan. 2008. Nitrogen recovery and transformation from a surface or sub-surface application of controlled-release fertilizer on a sandy soil. J. Plant Nutr. 31:2214–2231.

Saunders, T. 2014. An irrigation evolution. Comb. Proc. Intl. Plant Prop. Soc. 64:309–313.

Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. J. Environ. Hort. 14:199–204.

Wilson, M.L., C.J. Rosen, and J.F. Moncrief. 2009. A comparison of techniques for determining nitrogen release from polymer-coated urea in the field. HortScience 44:492–494.

Yeager, T., R. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback, and R. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11:206–208.

Table 3.1 Impacts of fertilizer rate and target leaching fraction (LF) on plant growth and fertilizer loss[z]

| **Fertilizer Rate** | Growth Index[y] | Percent fertilizer loss[x] | **Target LF** | Growth Index | Percent fertilizer loss |
|---|---|---|---|---|---|
| **50g** | 25.29 ns | 26 ns | **0.05** | 24.79 ns | 26 ns |
| **70g** | 28.83 | 27 | **0.20** | 27.47 | 25 |
| **90g** | 27 | 26 | **0.35** | 28.87 | 26 |

[z]Main effects were not significant (ns) at (P>0.05) using Tukey's test of means comparison, SAS® University Edition (SAS Institute Inc., Cary, NC).

[y]Growth Index = Initial size index (SI) [(height + canopy widest width + width perpendicular) ÷ 3]-Final SI.

[x]Percent fertilizer loss = [Fertilizer applied(g) - fertilizer recovered(g)] ÷ fertilizer applied(g).

Table 3.2. Effects[z] of fertilizer rate and target leaching fraction (LF) on pour-through pH and electrical conductivity (µS/cm)[y].

| **Fertilizer Rate** | pH | EC |
|---|---|---|
| 50g | 6.98 ns[x] | 1000.25 b |
| 70g | 7.02 | 996.58 b |
| 90g | 6.83 | 1292.22 a |
| **Target LF** | | |
| 0.05 | 6.95 ab[w] | 1196.14 ns |
| 0.20 | 7.09 a | 1057.56 |
| 0.35 | 6.79 b | 1035.36 |

[z]Main effects were not significant (ns) at (P>0.05) using the procglimmix procedure and Tukey's test of means comparison, SAS® University Edition (SAS Institute Inc., Cary, NC).

[y]µS/cm = Microsiemens per cm, 1 µS/cm = 0.001 S/m.

[x]Simple effects means comparison between fertilizer rate (lowercase letters in columns) using the procglimmix procedure and Tukey's test of means comparison, SAS® University Edition (SAS Institute Inc., Cary, NC)

[w]Simple effects means comparison between target LF (lowercase letters in columns) using the procglimmix procedure and Tukey's test of means comparison, SAS® University Edition (SAS Institute Inc., Cary, NC)

# CHAPTER 4: THE EFFECT OF LEACHING FRACTION-BASED IRRIGATION ON FERTILIZER LONGEVITY AND LEACHATE NUTRIENT CONTENT IN A GREENHOUSE ENVIRONMENT


## Abstract

An experiment was conducted to evaluate the effects of leaching fraction (LF) on the longevity of controlled release fertilizer (CRF) and leachate nutrient content. The effect of LF-based irrigation was evaluated under six target LFs of 5%, 15%, 25%, 35%, 45%, and 55%. Trade gallon (2.72 L or 0.71 gal) nursery pots were filled with 100% pine bark substrate amended with dolomitic lime at a rate of 2.97 kg/m$^3$ (5lbs/yd$^{3)}$ and Harrell's 16-6-13 POLYON® applied at rate of 6g (0.21 oz) per container. Fertilizer was encased in vinyl-coated fiberglass mesh bags and subdressed 2.5 cm (1 in) under the substrate surface for recovery at the end of the 10-week study. The total amount of nutrients leached from the container was greater at higher LFs, with twice as much inorganic nitrogen leached at a LF of 55% than a 15% LF. The amount of dissolved nutrients left in the substrate decreased as the LF treatments increased. There was 29.6% more inorganic nitrogen and 37.7% more phosphorus left in the substrate irrigated with a 15% LF as compared to a 55% LF. This suggests that at lower LFs, more dissolved nutrients may be available for plant uptake. No differences were seen in the amount of nutrients lost from the CRF or remaining in the prills. Results indicate that reducing the LF did not influence the longevity of POLYON® CRF in a pine bark substrate, but that a lower LF may be useful in reducing nutrient runoff into the environment. Targeting a lower LF also resulted in a larger pool of plant-available nutrients, allowing nursery producers to potentially reduce fertilizer rates.

**Index Words:** Nitrogen, CRFs, Substrate, Container production, Effluent, Runoff

## Significance to the Industry

Water issues are an increasing concern for the container nursery industry. Growers rely on frequent irrigation and applications of controlled release Fertilizer (CRF) to produce saleable plants (Biernbaum, 1992). These practices contribute to increased runoff of nitrogen and phosphorus and may lead to a faster release of CRF (Adams et al., 2013, Kochba et al., 1990; Rathier and Frink, 1989). In previous studies and in nursery applications, irrigating based on a 15 to 20% target LF or monitoring substrate moisture has shown potential to reduce the loss of nutrients through leaching and preserve CRF longevity (Chappell et al., 2013; Kochba et al., 1990; Stanley, 2012). Despite this evidence, results of this study indicate that LF did not influence the longevity of POLYON® CRF in a pine bark substrate, but that lower LFs did reduce the amount of nutrients in leachate and increased the amount of dissolved nutrients held in the substrate. This has implications to reduce the environmental footprint of the container nursery industry and may allow growers to save on input costs by reducing initial applications of CRF.

## Introduction

In the coming years, water resources available to nursery producers will likely decrease due to an increasing global demand for freshwater (Beeson et al., 2004). Even in areas such as the southeastern United States where water resources are abundant; drought, salinity, and legislation restricting water use and runoff are increasing pressure on nursery producers to implement efficient and sustainable irrigation management practices (Fernandez et al., 2009). Container-grown plants are limited to a finite amount of porous substrate and therefore require

daily irrigation and frequent applications of fertilizers to maintain optimal plant growth (Biernbaum, 1992; Majsztrik et al., 2017; Bilderback et al., 2013). Most container nurseries apply irrigation with overhead systems (Beeson et al., 2004; Bilderback, 2002). Controlled release fertilizers (CRFs) are regularly used in the container nursery industry because of their longevity and ease of application (Andiru et al, 2013).

Over-irrigation of container-grown ornamentals is common due to poor overhead irrigation system uniformity (Fare et al., 1992) and in some cases, grower preference to err on the side of over-application rather than under-application (Biernbaum, 1992). Excess irrigation leaches dissolved fertilizer out containers, carrying $NO_3$-N (Rathier and Frink, 1989) and phosphorus from controlled-release fertilizer (CRF). Unutilized nitrates can lead to contamination of local water resources and have detrimental environmental effects such as eutrophication and death of aquatic species (Howarth, 1988; Kabashima, 1993; Rauschkolb and Hornsby, 1994). Due to concerns about environmental harm, legislation at the federal and state level has restricted nutrient applications and regulated the amounts of contaminants leaving a site (Beeson et al., 2004; EPA, 1987). In addition to environmental effects, over-irrigation can lead to decreased herbicide efficacy (Fain et al., 2004), the spread of plant disease (Whitcomb, 1984), and may necessitate additional fertilizer applications during the production cycle (Bayer et al., 2015). Despite their longevity, each application of CRF is a significant expense. Improving irrigation practices to minimize the loss of fertilizer can reduce input costs for growers (Bayer et al., 2014; Briggs et al., 1998).

In many situations, growers choose how to irrigate based on their experience with visual cues such a media color, texture, feeling the heaviness of the pots, or by plant appearance such as

wilting. Measuring leaching fraction (LF) is a tool that has been developed to monitor irrigation efficiency under a wide range of production methods (Million and Yeager, 2020). LF is the amount of water that leaches from a container divided by the total amount of irrigation applied.

$$\% \, LF = \frac{leacheate \; recovered}{total \; applied \; irrigation} \times 100$$

Previous studies have demonstrated the effects of a reduced LF under microirrigation systems. Owen et al. (2008) found that lowering the target LF from 0.2 to 0.1 reduced effluent volume by 64% without influencing plant dry weight. The same reduction in target LF also reduced dissolved reactive P concentration in effluent by 64% (Owen et al., 2008). This corresponds well with research done by Tyler et al. (1996) where a low LF of 0 to 20% decreased the volume of container effluent by 63% compared to a LF of 40 to 60%, and decreased nitrate and phosphorus contents in effluent (Tyler et al., 1996). Prehn et al. (2010) reported that plants irrigated with a target LF of 20% had equivalent growth compared to those that were irrigated with an on-demand irrigation system, suggesting that plants of similar size could be produced even with a significantly reduced LF. On-demand irrigation, although efficient, would be very difficult for growers to maintain without real-time substrate moisture monitoring equipment (Prehn et al., 2010), however a LF-based irrigation systems have been successfully implemented in the industry. Saunders Brothers Nursery in Piney River, VA, applied LF-based irrigation to their outdoor container production by targeting a 10 to 20% LF; they were able to reduce the total volume of water during the growing season 43% as compared to the previous three years (Stanley, 2012). The following year, Saunders Brothers Nursery was able to reduce costs by cutting fertilizer rates by 30% for the next year of production. McCorkle Nursery (Dearing, GA) implemented a soil moisture monitoring system and was able to reduce

water use by 83%, eliminate Gardenia death due to pathogens, and shorten production time by 6 months (Chappell et al., 2013). These improvements in soil moisture management led to an increase annual profit by $2.80 per square foot a value which includes a reduced need for fungicides and the opportunity to begin growing other crops in this space (Chappell et al., 2013; Lichtenberg et al., 2013).

Nutrients are released from CRFs when water penetrates the prill coating and dissolves the fertilizer, creating an ion gradient between the prill and the surrounding substrate (Andiru, 2010). Nutrient release by diffusion is driven by the ion gradient, which allows nutrients to diffuse across the polymer coating and become available for plant uptake (Adams et al., 2013; Andiru, 2010)**.** When determining the effects of substrate moisture on CRF release rates, there are conflicting reports in the literature. Kochba et al. (1990) reported that coated $KNO_3$ release was essentially equal if the moisture content of the soil was greater than 50% of field capacity. Du et al. (2006) demonstrated that rates of release for CRF were generally around 5 to 20% slower in a column of sand at field capacity compared to saturated sand or free water. This phenomenon was attributed to a buildup of nutrients in the substrate, which caused a reduction in the ion gradient responsible for the driving force of the CRF release (Du et. al, 2006). A study by Adams et al. (2013) reported that although there were no differences between CRF release in a moist solid substrate and pure water, the mass flow of water across the prill surface in fluctuating water potential environments may lead to faster exhaustion of the CRF (Adams et al., 2013). The objective of this study was twofold: to determine if LF influenced the longevity of CRF and how different LFs affect leachate nutrient content in a pine bark substrate.

**Materials and Methods**

This study began on August 9, 2019 and was conducted in a greenhouse at Paterson Greenhouse Complex, Auburn University in Auburn, Alabama (USDA Cold Hardiness Zone 8a). Trade gallon (2.72 L) black plastic nursery containers were filled with 1,200 g of 100% pine bark amended with 336 g (rate of 2.97 kg/$m^3$ or 5 lbs/$yd^3$) of dolomitic lime to simulate a typical nursery mix. At time of potting, the mix had a moisture content of 37.7%. Harrell's 16-6-13 POLYON® controlled release fertilizer (Harrell's LLC, Lakeland, FL) was applied at a rate of 6 g to every container. Fertilizer was weighed, encased in 11 cm by 11 cm (4.3 in) mesh bags made from vinyl-coated charcoal fiberglass mesh that were heat sealed around the edges (Phiefer Inc., Tuscaloosa, AL). Mesh bags were applied 2.5 cm (1 in) below the media surface. Material for mesh bags was chosen based on results by Wilson and others (2009) that found that larger openings provide better contact with the substrate, giving a more accurate measure of release.

SOAX® liquid wetting agent (Smithers Oasis, Kent, OH) at 1200 ppm was applied to the containers in order to help with surface wetting and minimize the effects of channeling in the pine bark media. Containers were thoroughly watered in and drained for one hour. Containers were then weighed, left for two days, and weighed again to determine water loss due to evaporation. Initial irrigation volumes were calculated using the water loss and target leaching fraction for each container:

$$Irrigation\ volume\ (mL) = water\ loss\ (mL) + (water\ loss\ (mL) \times LF)$$

After the initial irrigation calculation, adjustments to irrigation volume were determined using the actual leaching fraction obtained from each irrigation. The equation used was adapted from Owen et al. (2016):

$$\pm Irrigation\ volume\ (mL) = applied\ irrigation\ (mL) \times (target\ LF - actual\ LF)$$

Data collection began on August 12, 2019 and took place over a period of 10 weeks. Containers were irrigated to obtain six different target leaching fractions: 5%, 15%, 25%, 35%, 45%, and 55%. Each container represented an experimental unit; there were four reps of each irrigation treatment, a total of 24 containers arranged in a completely randomized design. Containers were irrigated by hand three times a week with a syringe. Water was distributed slowly and evenly over the surface of the container. During irrigation events, each fallow container was fitted into a 2.5 L (0.66 gal) leachate collection bucket. The containers fit snugly into the collection buckets, leaving an adequate space between the container and bucket for leachate to collect. After irrigating, containers drained for 30 minutes. After this time, leachate volume was measured with a graduated cylinder and recorded for each container. Leachate volume was used to calculate LF. Leachate pH and EC was then measured using a HACH Pocket Pro+ Multi 2 Tester (Hach Co., Loveland, CO).

A 15 mL aliquot of each leachate sample was placed in a sealed collection tube and refrigerated. Throughout the week, the three individual samples collected from each replication were combined, a total of one pooled 45 mL sample per container, per week. Samples were kept in refrigeration at 3°C (37.4°F) during the collection week after which the samples were frozen. After 5 weeks and 10 weeks, samples were thawed and sent to Quality Analytical Laboratories in Panama City, FL for a complete soilless media analysis. Water samples were analyzed for $NO_3$-N and $NH_4$-N (fertilizer did not contain urea) with a Lachat Quikchem® 8500 series flow injection analysis system (Hach Co., Loveland, CO). Total phosphorus, potassium, $SO_4$-S, calcium, magnesium and micronutrients (Fe, Mn, B, Cu, Zn, Mo, Na, Al, and Cl) were analyzed

using a Thermo Scientific™ iCAP™ 7400 ICP-OES analyzer (Thermo Fisher Scientific™, Waltham, MA).

At the end of the study, mesh bags were retrieved and the prills were removed to determine nutrients remaining in the fertilizer bags. Bags were separated from the substrate and allowed to air-dry for 14 days. The prills from each recovered bag were weighed and then 100 prills were separated and weighed again. These 100 prills were ground using a mortar and pestle and mixed with 1 L of deionized (DI) water. The prill solution was stirred with a stir rod for 5 minutes before a 45 mL aliquot of the extractant was taken and sampled for pH and EC using a HACH Pocket Pro+ Multi 2 Tester. The samples were frozen until analyzed.

Initial fertilizer application was determined from an average of four analyses of 6g of unused CRF. Fertilizer recovered from the mesh bags after the completion of the study were recorded as remaining fertilizer. Fertilizer loss was calculated as:

$$Fertilizer\ loss = Initial\ fertilizer - Remaining\ fertilizer$$

Total fertilizer leached (mg) was determined by multiplying the concentration of nutrients in the weekly leachate samples by weekly leachate volume and totaled over the ten weeks. Fertilizer remaining in the substrate or lost to volatilization was calculated by subtracting fertilizer loss from the total fertilizer leached.

$$Fertilizer\ in\ substrate\ or\ volatized = Fertilizer\ loss - Fertilizer\ leached$$

Data was analyzed in JMP® and SAS University Edition by SAS (SAS Institute Inc., Cary, NC) using a Tukey's HSD test for means comparison.

## Results and Discussion

*LF and leachate nutrient content:* The total amount of CRF leached from the containers over ten weeks was significantly greater at higher leaching fractions, with twice as much $NO_3$-N and $NH_4$-N nitrogen leached and over twice as much P leached at a LF of 0.55 than 0.15 LF (Table 4.1). In this study, irrigating to a 0.15 LF instead of a 0.25 LF was found to reduce leachate volume by 18.9% and $NO_3$-N and P in leachate by 11.8% and 11.1% respectively. While not as dramatic as findings by Owens et al. (2008) in a microirrigated system, where decreasing the target LF from 0.2 to 0.1 reduced leachate volume by 64% and dissolved P in leachate by 64%, both agree with previous research by Tyler et al. (1996), that the amount of N and P in effluent can be reduced by decreasing the target LF. In our study, containers with a 55% target LF lost an average of 0.27 g of nitrogen to leaching over the course of ten weeks. When extrapolated for one acre of container production area filled with trade gallon containers spaced at 6 inches, (allowing 35% of the area for walkways and roads) the 55% LF would have leached over 14 pounds (6.35 kg) of nitrogen per acre over 10 weeks. Results from this study indicate that irrigating to a lower LF can reduce the amount of $NO_3$-N and P, the major nutrients responsible for eutrophication, in runoff from container nurseries. The amount of dissolved nutrients left in the substrate decreased as the LF treatments increased (Table 4.1). There was 29.6% more inorganic nitrogen and 37.7% more phosphorus left in the substrate irrigated with a 0.15 LF as compared to a 0.55 LF, likely due to flushing of dissolved nutrients out of containers at the higher leaching fractions (Table 4.1). Although there were some discrepancies in the micronutrients, possibly due to the addition of mineral nutrients from substrate breakdown and in the addition of dolomitic lime to the substrate, there were trends observed with $SO_4$-S, Ca, Mg, Fe, Mn, B, Cu, Zn, Mo, Na, Al, and Cl (Table 4.2). In general, more of these nutrients were lost

from the containers in leachate when containers were irrigated to a higher LF, and at a lower LF more nutrients were retained in the substrate (Table 4.2). This suggests that at lower leaching fractions, a larger pool of plant available nutrients may be available for uptake, potentially allowing growers to reduce the application rate of CRF. In weeks 5 through 10, target LF treatment had a significant effect on leachate EC, at the higher target LFs leachate EC was lower (Table 4.3). Although irrigating to a lower target LF may reduce the amount of nutrients leached, a grower that is monitoring the leachate for EC may see higher numbers associated with lower LF, due to the high concentration of salts in a small volume of leachate (Figure 3). Leachate EC increased as the weeks progressed, due to the control-release mechanism releasing fertilizer over time (Table 4.3). Leachate pH decreased linearly over the course of ten weeks, but there were no consistent trends of LF treatment on the pH of the leachate. (Table 4.4).

*LF and fertilizer longevity:* There was a significant quadratic trend in the pH of the fertilizer remaining in the mesh bags between treatments; pH increased as target LF increased from 0.05 to 0.35 and then decreased as target LF increased to 0.55 (Table 4.5). A similar quadratic trend between EC of the fertilizer remaining in the mesh bags between treatments, with fertilizer EC decreasing as target LF increased from 0.05 to 0.25 and then increasing as target LF increased toward 0.55. (Table 4.5). The fertilizer used in the study was a scheduled three-month longevity, and this study occurred over the course of ten weeks, however, it is possible that the fertilizer was completely exhausted within the first five or six weeks of the study. In future studies, reducing the length of the experiment may reveal more obvious differences in fertilizer EC between LF treatments. Despite a slightly higher EC in treatments with lower LF, no significant differences were seen in the amount of nutrients lost from the CRF or found remaining in the prills (Table 4.6), again potentially due to the extended time period of this

study. A shorter duration of six weeks may have shown differences in the amount of nutrients lost and nutrients remaining in the CRF prills. The results of this study indicate that reducing the LF did not influence the longevity of POLYON® CRF in a pine bark substrate over ten weeks, but that a lower LF may be useful in reducing nutrient runoff into the environment. This shows potential for growers to use a reduced LF to reduce total loading of nutrients in runoff, a benefit in areas with strict water-quality requirements or where environmental quality is a concern. Targeting a lower LF also results in a larger pool of plant-available nutrients, allowing nursery producers to save on input costs by potentially reducing CRF rate.

**Conclusion**

Irrigating to different target leaching fractions had no significant effect on the longevity of Harrell's 16-6-13 POLYON® in pine bark substrate over ten weeks. The results of this study suggest that there are benefits to targeting a lower LF, including a reduction in the amount of nutrients leached and a greater concentration of dissolved nutrients in the substrate. Lower LF were shown to reduce the total amount of N and P leached, which has implications to reduce the environmental impact of container nursery production. Limiting nutrient leaching may also help growers stay compliant with any current or future federal and state standards regarding water quality and daily nutrient loads. Lower LF treatments were also associated with larger amounts of dissolved nutrients in the substrate. Although this study did not contain any plants, higher concentrations of nutrients available for plant uptake may influence growth rate or plant size. By targeting a lower LF, growers may be able to reduce their application rates of CRFs while still producing salable plants. It is important to note that this was the conclusion of this particular study, and that CRF with a different prill coating and release mechanism may respond

differently. Further research is necessary to explore the effects of LF on CRF with different release mechanisms as well as the impact of LF on plant growth and salability.

## Literature Cited:


Adams, C., J. Frantz, and B. Bugbee. 2013. Macro- and micronutrient release characteristics of three polymer-coated fertilizers: Theory and measurements. J. Plant Nutr. Soil Sci. 176: 76–88.

Andiru, G.A., C.C. Pasian, J.M. Frantz, and P. Jourdan. 2013. Longevity of controlled-release fertilizer influences the growth of bedding impatiens. HortTechnology 23:157–164.

Andiru, G. 2010. Effects of controlled-release fertilizer on nutrient leaching and garden performance of *Impatiens walleriana* (Hook F. 'Extreme Scarlet'). The Ohio State Univ. Columbus, OH. M.S. Thesis. 121 p.

Bayer, A., J. Ruter, and M.W. van Iersel. 2015. Optimizing irrigation and fertilization of *Gardenia jasminoides* for good growth and minimal leaching. HortScience 50:994–1001.

Bayer, A., K. Whitaker, M. Chappell, J. Ruter, and M.W. van Iersel. 2014. Effect of irrigation duration and fertilizer rate on plant growth, substrate solution EC and leaching volume. Acta Hortic.1034:477–484.

Beeson, R.C., M.A. Arnold, B.B. Bilderback, S. Chandler, H.M. Gramling, J.D. Lea-Cox, 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.

Biernbaum, J.A. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer. HortTechnology 2:127–312.

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.

Bilderback, T.E. 2002. Water management is key in reducing nutrient runoff from container nurseries. HortTechnology 12:541–544.

Briggs, J.A., M.B. Riley, and T. Whitwell. 1998. Quantification and remediation of pesticides in runoff water from containerized plant production. J. Environ. Qual. 27:814–820.

Chappell, M., S.K. Dove., M.W. van Iersel, P.A. Thomas, and J. Ruter. 2013. Implementation of wireless sensor networks for irrigation control in three container nurseries. HortTechnology 23:747–753.

Du, C.W., J.M. Zhou, and A. Shaviv. 2006. Release characteristics of nutrients from polymer-coated compound controlled release fertilizers. J. Poly. Environ. 14:223–230.

Environmental Protection Agency. 1987. Federal Water Pollution Control Act (Clean Water Act). 33 U.S.C. §1251.

Fain, G.B., K.L. Paridon, and P.M. Hudson. 2004. The effect of cyclic irrigation and herbicide on plant and weed growth in production of *Magnolia grandiflora* 'Alta'. S. Nurs. Assn. Res. Conf. 49:37–39.

Fare, D.C., C.H. Gilliam, and G.J. Keever. 1992. Monitoring irrigation at container nurseries. HortTechnology 2:75–78.

Fernandez, T., J.D. Lea-Cox, G. Zinati, C. Hong, R. Cabrera, D. Merhaut, J. Albano, M. van Iersel, T.H. Yeager, and D. Buhler. 2009. NCDC216: A multistate group for water management and quality for ornamental crop production and health. Proc. S. Nursery. Assn. Res. Conf. 54:35–38.

Howarth, R.W. 1988. Nutrient limitation of net primary production in marine ecosystems. Ann. Rev. Ecol. 19:89–110.

Kabashima, J.N. 1993. Innovative irrigation techniques in nursery production to reduce water usage. HortScience 28:291–293.

Kochba, M., S. Gambash, and Y. Avnimelech. 1990. Studies on slow release fertilizers: I. Effects of temperature, soil moisture, and water vapor pressure. Soil Sci. 149:339–343.

Lichtenberg, E., J. Majsztrik, and M. Saavoss. 2013. Profitability of sensor- based irrigation in greenhouse and nursery crops. HortTechnology 23:770–774.

Majsztrik, J.C., R.T. Fernandez, P.R. Fisher, D.R. Hitchcock, J.D. Lea-Cox, J.S. Owen, L.R. Oki, and S.A. White. 2017. Water use and treatment in container-grown specialty crop production: a review. Water Air Soil Pollut. 228:151–178.

Million, J.B. and T.H. Yeager. 2020. Periodic versus real-time adjustment of a leaching fraction-based microirrigation schedule for container-grown plants. HortScience 55:83–88.

Owen, J.S., S.L.Warren, T.E. Bilderback, and J.P. Albano. 2008. Phosphorus rate, leaching fraction, and substrate influence on influent quantity, effluent nutrient content, and response of a containerized woody ornamental crop. HortScience 43:906–912.

Owen, J.S., A.V. LeBude, M. Chappell, and T. Hoskins. 2016. Advanced irrigation management for container-grown ornamental crop production. Va. Tech. Coop. Ext. Serv. Bul. HORT-218P.

Prehn, A.E., J.S. Owen, Jr., S.L.Warren, T.E. Bilderback, and J.P. Albano. 2010. Comparison of water management in container-grown nursery crops using leaching fraction or weight-based on demand irrigation control. J. Environ. Hort. 28:117–123.

Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and alberta spruce under different irrigation and N fertilization. J. Environ. Hort. 7:32–35.

Rauschkolb, R.S. and A.G. Hornsby. 1994. Nitrogen management in irrigated agriculture. Oxford Univ. Press, New York. 251 pp.

SAS Institute Inc. 2019. SAS® University Edition. Cary, NC: SAS Institute Inc.

Stanley, J. 2012. Using leaching fractions to maximize irrigation efficiency. Proc. Intl. Plant Propagators Soc. 62:331–334.

Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. J. Environ. Hort. 14:199–204.

Whitcomb, C.E. 1984. Plant production in containers. Lacebark Pub. Stillwater, OK. p. 396–470

Wilson, M.L., C.J. Rosen, and J.F. Moncrief. 2009. A comparison of techniques for determining nitrogen release from polymer-coated urea in the field. HortScience 44:492–494.

Table 4.1. Means comparison[z] of N, P, and K in leachate over ten weeks and retained in pine bark substrate.

| Nitrogen | LF | Leached from Pot (mg) | Left in Pot (mg) |
|---|---|---|---|
| | 0.05 | 102 c | 583 a |
| | 0.15 | 135 bc | 547 ab |
| | 0.25 | 153 bc | 534 ab |
| | 0.35 | 213 ab | 472 bc |
| | 0.45 | 205 ab | 476 bc |
| | 0.55 | 270 a | 422 c |
| Significance[y] | | L*** | Q*** |
| **Phosphorus** | | | |
| | 0.05 | 12 b | 89 a |
| | 0.15 | 16 b | 84 ab |
| | 0.25 | 18 b | 82 ab |
| | 0.35 | 27 ab | 73 bc |
| | 0.45 | 23 b | 76 ab |
| | 0.55 | 39 a | 61 c |
| Significance | | L*** | Q*** |
| **Potassium** | | | |
| | 0.05 | 193 d | 386 a |
| | 0.15 | 215 d | 375 a |
| | 0.25 | 241 cd | 353 ab |
| | 0.35 | 305 bc | 284 bc |
| | 0.45 | 347 b | 240 c |
| | 0.55 | 460 a | 136 d |
| Significance | | Q*** | Q*** |

[z] Tukey's HSD test for means comparison (lowercase letters in columns by nutrient) using JMP® by SAS (SAS Institute Inc., Cary, NC).
[y] Significant quadratic (Q) or linear (L) trends using regression models at P<0.001(***).

Table 4.2. Means comparison[z] of Ca, Mg, $SO_4$-S, and micronutrients in leachate[y] over ten weeks and retained in pine bark substrate.

| | Leached from Pot (mg) | | | | | |
|---|---|---|---|---|---|---|
| LF | 0.05 | 0.15 | 0.25 | 0.35 | 0.45 | 0.55 |
| Calcium | 92.27 d[x] | 120.71 d | 135.29 cd | 178.96 cd | 189.81 b | 260.49 a |
| Magnesium | 43.85 d | 55.11 d | 61.76 cd | 79.84 bc | 85.59 b | 117.42 a |
| $SO_4$-Sulfur | 66.01 c | 79.22 c | 88.86 cd | 119.46 b | 127.39 b | 188.06 a |
| Iron | 0.53 bc | 0.44 c | 0.70 bc | 0.97 b | 0.93 b | 1.51 a |
| Manganese | 0.15 b | 0.12 b | 0.17 b | 0.22 b | 0.21 b | 0.41 a |
| Boron | 0.02 ab | 0.01 b | 0.01 b | 0.04 a | 0.03 ab | 0.04 a |
| Copper | 0.14 bc | 0.11 c | 0.17 bc | 0.30 ab | 0.22 bc | 0.41 a |
| Zinc | 1.13 bc | 0.88 c | 1.23 bc | 1.80 ab | 1.84 ab | 2.33 ab |
| Molybdenum | 0.00 ab | 0.00 a | 0.00 a | 0.00 a | 0.00 a | 0.00 a |
| Sodium | 18.20 e | 22.27 de | 25.76 d | 35.56 c | 44.78 b | 66.66 a |
| Aluminium | 0.12 d | 0.13 d | 0.17 cd | 0.21 cd | 0.21 ab | 0.21 ab |
| Silicon | 5.70 c | 6.72 c | 7.64 bc | 9.71 b | 12.90 a | 14.72 a |

| | Left in Pot (mg) | | | | | |
|---|---|---|---|---|---|---|
| LF | 0.05 | 0.15 | 0.25 | 0.35 | 0.45 | 0.55 |
| Calcium | -92.27 a | -120.73 a | -136.31 ab | -179.91 bc | -190.42 c | -260.07 d |
| Magnesium | -58.87 a | -70.47 a | -80.04 ab | -98.13 bc | -104.61 b | -134.57 a |
| $SO_4$-Sulfur | 109.82 a | 95.65 a | 78.73 ab | 47.90 bc | 37.18 c | -16.18 d |
| Iron | 6.87 a | 6.90 a | 6.63 ab | 6.32 b | 6.35 b | 5.75 c |
| Manganese | 3.48 a | 3.43 ab | 3.24 bc | 3.16 cd | 3.19 c | 2.95 d |
| Boron | -0.02 ab | -0.01 a | -0.01 ab | -0.04 b | -0.03 ab | -0.04 b |
| Copper | 3.49 a | 3.50 a | 3.45 a | 3.32 ab | 3.39 ab | 3.24 b |
| Zinc | 2.43 ab | 2.67 a | 2.31 ab | 1.78 bc | 1.75 bc | 1.29 c |
| Molybdenum | 0.11 a | 0.12 a | 0.08 a | 0.05 AB | 0.09 a | 0.12 a |
| Sodium | -6.08 a | -9.97 ab | -13.61 bc | -22.92 cd | -31.80 d | -53.45 e |
| Aluminium | -0.03 ab | -0.05 ab | -0.10 bc | -0.15 cd | -0.18 d | -0.26 e |
| Silicon | -5.70 a | -6.72 a | -7.64 ab | -9.71 b | -12.90 c | -14.72 c |

[z] Tukey's test for means comparison using SAS® University Edition (SAS Institute Inc., Cary, NC).

[y] Discrepancies in leached Ca and Mg likely due to the addition of dolomitic lime to the substrate.

[x] Means comparison between LF (lowercase letters in rows by nutrient) using the procglimmix procedure and Tukey's test of means comparison, SAS® University Edition (SAS Institute Inc., Cary, NC).

Table 4.3. Comparison[z] of leachate electrical conductivity (µS/cm)[y] over ten weeks.

| | Target LF | | | | | | |
|---|---|---|---|---|---|---|---|
| Weeks | 0.05 | 0.15 | 0.25 | 0.35 | 0.45 | 0.55 | Significance[x] |
| 1 | 582.6 | 370.1 | 437.1 | 507.9 | 337.1 | 480.3 | ns |
| 2 | 619.0 | 667.0 | 634.1 | 583.0 | 608.5 | 516.0 | ns |
| 3 | 669.3 | 780.8 | 668.3 | 736.0 | 618.1 | 669.8 | ns |
| 4 | 757.2 | 991.9 | 936.7 | 1000.8 | 906.0 | 1053.6 | ns |
| 5 | 1505.6 | 1438.3 | 1331.4 | 1269.0 | 926.7 | 939.6 | L** |
| 6 | 1481.0 | 1519.0 | 1562.3 | 1048.0 | 905.0 | 792.3 | L*** |
| 7 | 1333.3 | 1602.3 | 1415.5 | 1334.8 | 938.5 | 739.3 | Q* |
| 8 | 1648.5 | 1562.0 | 1541.0 | 1544.8 | 1195.5 | 1093.8 | L*** |
| 9 | 2023.0 | 1806.8 | 1698.3 | 1460.0 | 1247.3 | 1037.0 | L*** |
| 10 | 2084.0 | 1823.3 | 1822.8 | 1642.5 | 1277.5 | 917.5 | Q* |
| Significance | L*** | Q* | L*** | L*** | L*** | Q* | |

[z]Analyzed using procglimmix procedure in SAS® University Edition (SAS Institute Inc., Cary,

[y]µS/cm = Microsiemens per cm, 1 µS/cm = 0.001 S/m.

[x]Significant or nonsignificant (ns) quadratic (Q) or linear (L) trends using regression models at P<0.001(***), P<0.01(**), and P<0.05(*).

Table 4.4. Comparison[z] of leachate pH over ten weeks.

| | Target LF | | | | | | |
|---|---|---|---|---|---|---|---|
| Weeks | 0.05 | 0.15 | 0.25 | 0.35 | 0.45 | 0.55 | Significance[y] |
| 1 | 6.55 | 6.82 | 6.66 | 6.62 | 6.70 | 6.47 | Q* |
| 2 | 6.87 | 6.97 | 6.94 | 6.90 | 6.90 | 6.94 | ns |
| 3 | 6.70 | 6.82 | 6.80 | 6.69 | 6.80 | 6.77 | ns |
| 4 | 6.72 | 6.77 | 6.76 | 6.66 | 6.71 | 6.55 | ns |
| 5 | 6.39 | 6.41 | 6.42 | 6.36 | 6.55 | 6.47 | ns |
| 6 | 6.21 | 5.85 | 5.80 | 5.97 | 6.08 | 6.17 | Q*** |
| 7 | 5.71 | 5.67 | 5.68 | 5.73 | 5.88 | 6.06 | Q* |
| 8 | 6.31 | 5.90 | 5.83 | 5.81 | 5.98 | 6.06 | Q*** |
| 9 | 5.68 | 5.40 | 5.39 | 5.35 | 5.67 | 5.82 | Q*** |
| 10 | 5.70 | 5.41 | 5.30 | 5.33 | 5.51 | 5.73 | Q*** |
| Significance | L*** | L*** | L*** | L*** | L*** | L*** | |

[z] Analyzed using procglimmix procedure in SAS® University Edition (SAS Institute Inc., Cary, NC).

[y] Significant or nonsignificant (ns) quadratic (Q) or linear (L) trends using regression models at $P<0.001$(***) and $P<0.05$(*).

Table 4.5. Means comparison[z] of pH and electrical conductivity (µS/cm) of fertilizer remaining in mesh bags after ten weeks.

| LF | pH | EC (µS/cm)[y] |
|---|---|---|
| 0.05 | 6.0 b | 805.0 a |
| 0.15 | 6.3 ab | 715.0 ab |
| 0.25 | 6.4 a | 620.0 b |
| 0.35 | 6.4 a | 645.0 b |
| 0.45 | 6.4 a | 652.5 b |
| 0.55 | 6.4 ab | 622.5 b |
| Sign.[x] | Q** | Q** |

[z] Tukey's test for means comparison (lowercase letters in columns) using SAS® University Edition (SAS Institute Inc., Cary, NC).

[y] µS/cm = Microsiemens per cm, 1 µS/cm = 0.001 S/m.

[x] Significance (Sign.) quadratic (Q) trends using regression models at P<0.01(**).

Table 4.6. Means comparison[z] of N, P, and K loss from fertilizer and remaining in fertilizer after ten weeks.

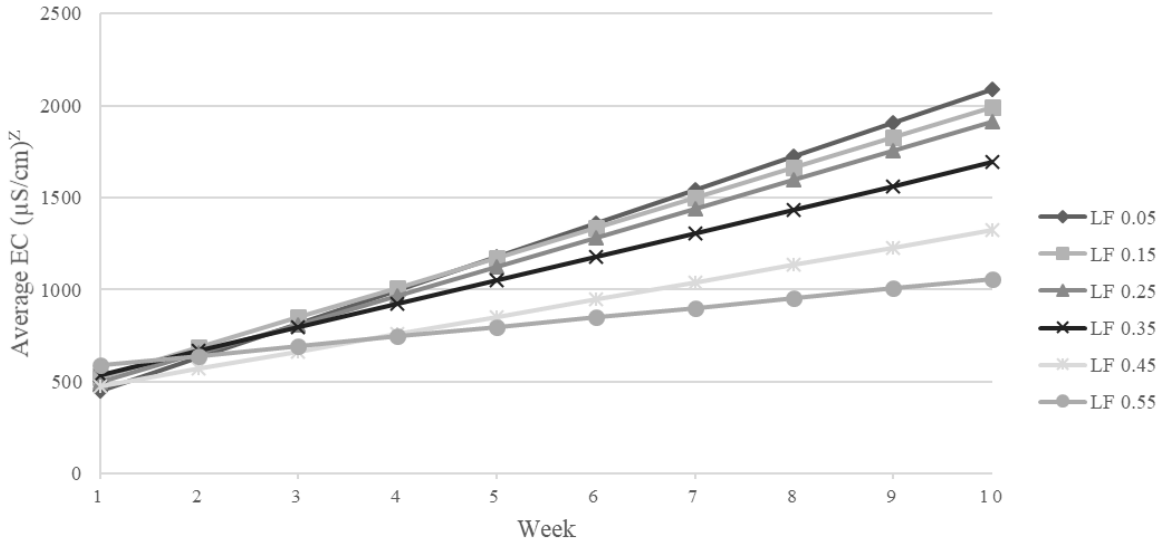
| Nitrogen | LF | Fertilizer Loss (mg)[y] | Remaining in Fertilizer (mg) |
|---|---|---|---|
| | 0.05 | 685.2 ns[x] | 119.2 ns |
| | 0.15 | 682.1 | 122.3 |
| | 0.25 | 687.5 | 116.9 |
| | 0.35 | 684.5 | 119.9 |
| | 0.45 | 681.7 | 122.7 |
| | 0.55 | 691.6 | 112.8 |
| Phosphorus | | | |
| | 0.05 | 101.8 ns | 31.2 ns |
| | 0.15 | 99.9 | 33.1 |
| | 0.25 | 100.5 | 32.5 |
| | 0.35 | 99.9 | 33.1 |
| | 0.45 | 99.7 | 33.3 |
| | 0.55 | 100.8 | 32.2 |
| Potassium | | | |
| | 0.05 | 578.6 ns | 170.4 ns |
| | 0.15 | 590.8 | 158.2 |
| | 0.25 | 593.8 | 155.2 |
| | 0.35 | 589.1 | 159.9 |
| | 0.45 | 586.3 | 162.7 |
| | 0.55 | 595.3 | 153.7 |

[z] Tukey's HSD test for means comparison using JMP® by SAS (SAS Institute Inc., Cary, NC).

[y] Loss from fertilizer = Initial fertilizer in satchel - remaining fertilizer in satchel.

[x] Means comparison between LF (lowercase letters in columns by nutrient) using Tukey's HSD test for means comparison using JMP® by SAS (SAS Institute Inc., Cary, NC).

Figure 3. Regression of average electrical conductivity of leachate over ten weeks.




[z]µS/cm = Microsiemens per cm, 1 µS/cm = 0.001 S/m