Water Management

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Section Editor

Benefits of Precision Irrigation of *Gardenia augusta* 'Heaven Scent'™: Reducing Shrinkage, Shortening the Cropping Cycle, and Economic Impact

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Index words: Gardenia, economic impact, substrate water content

Significance to Industry: Competition for water resources continues to increase due to population growth and increased agricultural and industrial water demand, resulting in decreasing availability of freshwater for agricultural-related activities (1). Increasing the efficiency of irrigation practices can decrease this strain on water resources. It also has many benefits for production nurseries; including better control over plant quality due to a reduction in foliar and root disease(s) (2), reduced water and fertilizer use, less leaching of nutrients, and reduced runoff (3). Irrigation is necessary during the production of containerized nursery crops due to the relatively small volume of substrate that is used to produce container plants. To assure rapid growth, it is crucial to supply the plants with adequate water and nutrients. However, excessive irrigation leads to conditions amenable to pathogens and can ultimately lead to significant crop losses (4). This is especially true in crops sensitive to "water mold" pathogens including pythium and phytophthora. *Gardenia* is one such crop, where losses are typically 30% per production season, with a large percentage of those losses directly related to production environments with excessive irrigation rates.

Soil moisture sensors monitor substrate water content, and when used in conjunction with a computer controlled irrigation system, can be used to initiate irrigation when substrate water content drops below a user-specified set point. Here we describe the use and economic benefit(s) of soil moisture sensors combined with a wireless network to remotely monitor environmental conditions, substrate water content of *Gardenia augusta* 'MADGA 1' PP#19988 ('Heaven Scent'™), and irrigation water applications. Such networks can provide growers with real-time information regarding the water status of their crops and provide valuable information regarding the efficiency of water applications. In the case of *Gardenia augusta* 'Heaven Scent'™, using soil moisture sensors to monitor soil moisture and control irrigation application eliminated crop losses due to root pathogens and substantially decreased the production cycle.

Nature of Work: Ten bays totaling approximately 20,000 ft^2 in an unheated greenhouse at a large commercial nursery were used for this research from late summer 2010 into spring 2011. Each bay (plot) contained approximately 2,340 *Gardenia augusta* 'Heaven Scent'™ in #2 containers filled with a bark-based substrate. Irrigation in five of the ten bays was controlled with a Moisture Clik irrigation controller (IL200-MC, Dynamax, Houston, TX), which uses a dielectric soil moisture sensor (SM200) to measure substrate water content. These controllers use a single soil moisture probe. To limit edge effects, irrigation in each bay was controlled based on the substrate water content in a container centrally located within each block of plants.

Irrigation controllers were set to come on when the substrate water content dropped below approximately 20% soil water content (0.20 $m^3 \cdot m^{-3}$). To prevent irrigation at night, the Moisture Clik controllers were connected to a 24 hour timer to power the controllers only between 8 am and 5 pm. Irrigation in the other five bays was controlled by nursery personnel, who were asked to irrigate according to their regular practices. Each bay was equipped with a water meter, and irrigation volumes were recorded monthly. Other than irrigation, plants were produced using the standard cultural practices of the nursery.

Results and Discussion: Many growers in the Southeastern U.S. suffer significant losses in *Gardenia*, typically 30% (but as high as 70%) crop shrinkage, due to root pathogens and associated mortality and reductions in quality. Our intention was to test whether sensor-controlled irrigation can reduce water use and shrinkage due to disease. Based on previous studies with *Hydrangea macrophylla* in the same production facility, we expected to observe water savings as high as 83% over standard irrigation practices (5). Yet our results indicated that sensor-controlled irrigation reduced irrigation by only 1.2% (183,219 gallons/plot with sensor controlled irrigation versus 185,521 gallons in the control). The confounding results relating to water use between the two treatments were due to the irrigation technician's independent decision to mimic the precision control system in the "standard irrigation" treatment he was charged with irrigating. While this action by the irrigation technician negated the ability to determine differences in irrigation quantity between standard irrigation practices and a precision irrigation control system, it did show that sensor-controlled irrigation systems can be used to train people to irrigate more efficiently.

Despite the lack of differences in irrigation, remarkable results were observed: Within both treatments, there was zero mortality across the entire 23,400 units due to pathogen pressure. The projected, typical losses were 2,000 units; therefore at an industry standard $6.50/unit sale price, and given that 100% of the viable crop is usually sold, avoided losses due to a lack of shrinkage amounted to $13,000. Also of note is that producing a salable crop took much less time than usual: 8 months instead of the typical 14 months, a 6-month or 43% shortening of the production cycle. While the exact cause of the reduction in production cycle duration is not clear, we hypothesize that lower volumetric water content increased substrate temperature, reduced pathogen pressure, and decreased fertilizer leaching; and that these factors increased plant growth rates. The reduction in production time decreased production costs (including elimination of some fertilizer and fungicide applications and associated labor costs); these avoided costs amounted to roughly $7,700. Finally, the reduction in growing time lowered the interest cost of holding growing plants in inventory by approximately $500, assuming simple interest at a rate of 8% per year. The total increase in profits from reduced production time and elimination of shrinkage thus totaled $21,200, corresponding to $1.06 savings per ft^2 per production cycle or $0.90 per plant per production cycle. This estimate does not include the potential profits associated with initiating a new production cycle in the same growing area earlier than projected due to the time reduction in the production cycle. At this level of savings, the $3,000 precision irrigation system installed in this study would have a payback period of less than 2 months.

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Evaluating the Effects of Pageant and Regalia on Drought Tolerance of Impatiens

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Index words: strobilurins, water use efficiency, pyraclostrobin, *Reynoutria sacchaliensis*

Significance to the Industry: In recent years there has been increasing interest in the use of plant protectants to increase or induce plant tolerance to environmental stresses in agronomic crops. Ideally plant protectants need to be low risk and provide an adequate benefit such as a yield increase or reduced irrigation requirements. Typical plant protectants on the market include, but are not limited to, herbicides, fungicides, insecticides, and anti-transpirants. Traditionally, these are referred to as crop health protectants and aid plant growth by preventing or attacking unwanted organisms. More recently, some chemical companies have expressed interest in exploring the use of these products specifically the strobilurin fungicides for ornamental crops.

Nature of Work: In 2009, BASF added “plant health” to their Headline Fungicide (pyraclostrobin) after approval by the EPA (2). The following year (2010), BASF launched Intrinsic™ brand fungicides into the turf and ornamental market labeled for plant health and disease control (3). Intrinsic brand includes Honor® SC Intrinsic™ brand and Insignia® SC Intrinsic™ brand. Honor® SC Intrinsic brand is a premix of two fungicides, boscalid and pyraclostrobin , targeting complex II and complex III, respectively, of fungal respiration. Pyraclostrobin is the product responsible for plant health benefits. There have been multiple reports indicating that pyraclostrobin increases nitrate reductase activity and antioxidant enzymes, as well as reduces the amount of CO_2 lost by the plant (1, 2, 6, 7).

Although it is known that Honor® and Insignia® SC Intrinsic™ fungicides stimulate growth and may improve plant health in agronomic crops (1), little research has evaluated these fungicides for similar effects with ornamentals. Therefore, the objective of this research was to evaluate two potential plant protectants, Pageant (boscalid + pyraclostrobin) and Regalia®SC (extract of *Reynoutria sachalinensis*), for increased plant tolerance to drought in *Impatiens walleriana* 'Super Elfin XP White'.

On May 5, 2010, *Impatiens walleriana* 'Super Elfin XP White' were potted from a 285-plug tray into 6" azalea containers for experiments Expts. 1 and 2. All containers were filled to the rim with Sunshine Mix #1 and lightly tapped twice on a hard surface to reduce air pockets. After potting, impatiens were watered thoroughly and placed in a controlled-environment greenhouse [70°F/65°F (day/night) temperatures] located at the Rodney R. Foil Research Center, Starkville, MS.

To determine volumetric water content (VWC), the physical properties of Sunshine Mix #1 were determined according to the method of Hidalgo et al. (5), with the substrate providing 90.9% total porosity, 28.3% air space, 62.6% water holding capacity, and 0.11 g/cc bulk density. The WATERSCOUT SM100 Soil Moisture Sensor attached to a handheld Sensor reader by Spectrum® Technologies, Inc, (Plainfield, IL). was calibrated to our soilless substrate. Calibration data and the water holding capacity value was then fitted to a regression model, yielding the equation VWC = 0.00076503*MW – 0.79736 (MW represents target mass wetness defined as a percentage).

Expt. 1a was initiated on June 14, 2010 by recording VWC and watering each container to its designated VWC: 85% (well-watered control), 70%, 55%, 40%, and 25%. Four rates of Pageant, based on 3.04 oz per 100 gallons, were used: 0, 0.5x (0.43 g/gal), 1.0x (0.86 g/gal), and 1.5x (1.29 g/gal). Foliar applications of Pageant were made once a week 3 hours after watering containers. Expt. 1a was conducted using a randomized complete block design with a 5 × 4 factorial treatment design with 6 replications (one plant per pot) per treatment combination. Expt. 1b was initiated on July 27, 2010 and conducted in a similar manner to Expt. 1a; however, based on results from Expt. 1a, only three moisture levels: 85%, 55%, and 25% were included. Exp. 1b was conducted using a randomized complete block design with a 3 × 4 factorial with 6 single pot replications. Expt. 2a was initiated on July 27, 2010 and materials and methods were the same as Exp. 1b, but only four rates of Regalia SC based on the label rate of 64 oz per 50 gallons were used: 0, 0.5x (18.927 mL/1 gal), 1.0x (37.854 mL/gal), and 1.5x (56.781 mL/gal). Regalia SC was applied once a week 1.5 hours after watering containers to designated VWC. Expt. 2b was initiated on September 7, 2010 and conducted in similar manner to Expt. 2a.

Initial VWC, daily VWC, total water applied, final growth index (FGI) [(height + width at widest point + width perpendicular)/3], shoot dry weight (SDW), and root dry weight (RDW) data were collected. Shoots were harvested by cutting the entire plant at the soil line to remove the entire upper portion of each plant. Roots were harvested by first soaking the container with substrate and roots in a 17.7-L container filled with tap water. After soaking for a minimum of 8 hours, substrate was washed from the roots over a screen to catch all fallen roots. Further washing removed all remaining small pieces of substrate from the roots. Shoots and roots were oven-dried in a forced air drier at 65°C for 72 hours. Data were analyzed with the GLIMMIX procedure of SAS (version 9.2; SAS Institute Inc., Cary, NC), with mean separation according to the Holm-Simulation method (alpha = 0.05).

Results and Discussion: Based on recorded daily VWC in Expt. 1a, well-watered (85%) containers were watered the same day after initial application (DAIA) of plant protectant whereas VWC maintained at 70% and 55% went 3 and 6 DAIA, and 25% and 40% went 9 and 11 DAIA, respectively (Fig. 1). As previously mentioned, well-watered (85%) containers were watered the same DAIA whereas VWC maintained at 55% and 25% went 5 and 10 DAIA, respectively (Expt. 1b).

Rates of Pageant had no effect on growth of impatiens with the exception of Pageant applied at the 1.0x rate resulting in greater RDW compared to the 0.5x and 1.0x rates (Table 1). Maintaining impatiens at 25% VWC resulted in significantly less growth than plants maintained at higher VWC, which was similar to the results of Blanusa et al. (4). There was no significant rate × moisture interaction in Exp. 1a, however there was a rate × moisture interaction with SDW in Expt. 1b (Fig. 2). After four 1.0x applications of Pageant, plants in containers maintained at 85% VWC had a greater SDW compared to the other treatments at 85% VWC. However, Pageant applied at the 1.0x rate to water-stressed plants (55% and 25% VWC) produced no differences in shoot dry weight compared to nontreated plants. These results were similar to previous reports in wheat which showed increased water-use efficiency after application of pyraclostrobin to well-watered plants, but not water-stressed plants (7).

Expt. 2. Based on recorded daily VWC, well-watered (85%) containers were watered starting the second day (Expt. 2a) and the same DAIA (Fig. 3). Whereas, containers maintained at 55 and 25% did not receive water until 8 and 13 DAIA (Expt. 2a) and 5 and 10 DAIA (Expt. 2b), respectively.

Differing rates of RegaliaSC had no effect on FGI or SDW of impatiens in Expt. 2a (Table 2). However, the use of Regalia SC at the 0.5x rate resulted in greater RDW compared to the 0.0x rate (nontreated) in Expt. 2a, whereas plants in Expt. 2b had greater FGI when Regalia SC was applied at 0.5x (16.7 cm) and 1.0x (16.0 cm) rates, compared to the 1.5x (13.1 cm) rate (Table 2). There was a significant difference in growth of impatiens when containers were maintained at 85% VWC compared to 55% and 25% VWC; however, there was no rate × moisture interaction.

Based on these results, Pageant, a strobilurin fungicide, has a limited affect when applied to well-watered (85% moisture) impatiens at the 1.0x rate but does not seem to increase water use efficiency in water-stressed impatiens. Furthermore, since there are multiple reports indicating yield increases and reduced water use in agronomic crops and turfgrass (2, 3, 8) further research should be conducted with other ornamental crops.

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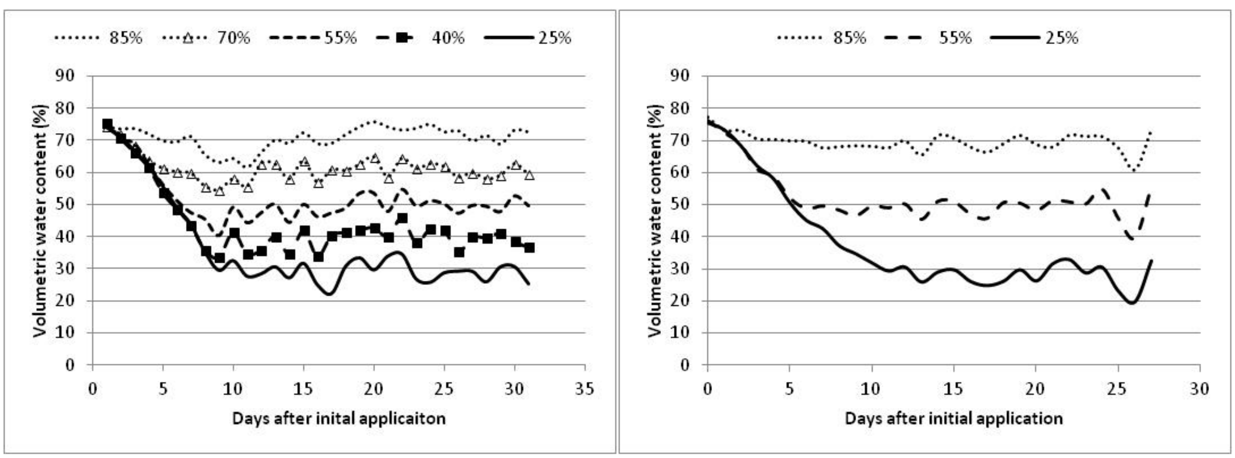

Figure 1. Percent daily volumetric water content (VWC) of *Impatiens walleriana* 'Super Elfin XP White' after weekly applications of Pageant maintained at 85% (well-watered), 70%, 55%, 40% or 25% VWC, Expt. 1a (left) and Expt. 1b (right).

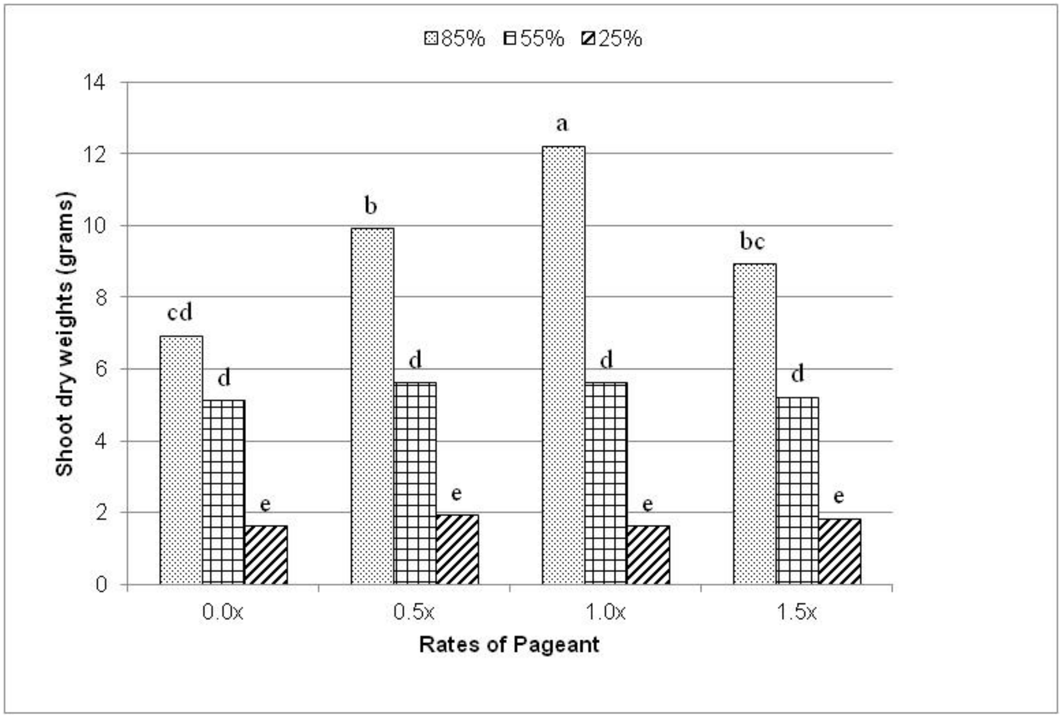

Figure 2. Effect of different rates of Pageant on shoot dry weight of *Impatiens walleriana* 'Super Elfin XP White' maintained at different volumetric water contents: 85% (well-watered), 55% or 25%. Means with the same letters are not significantly different according to the Holm-Simulation method, alpha=0.05.

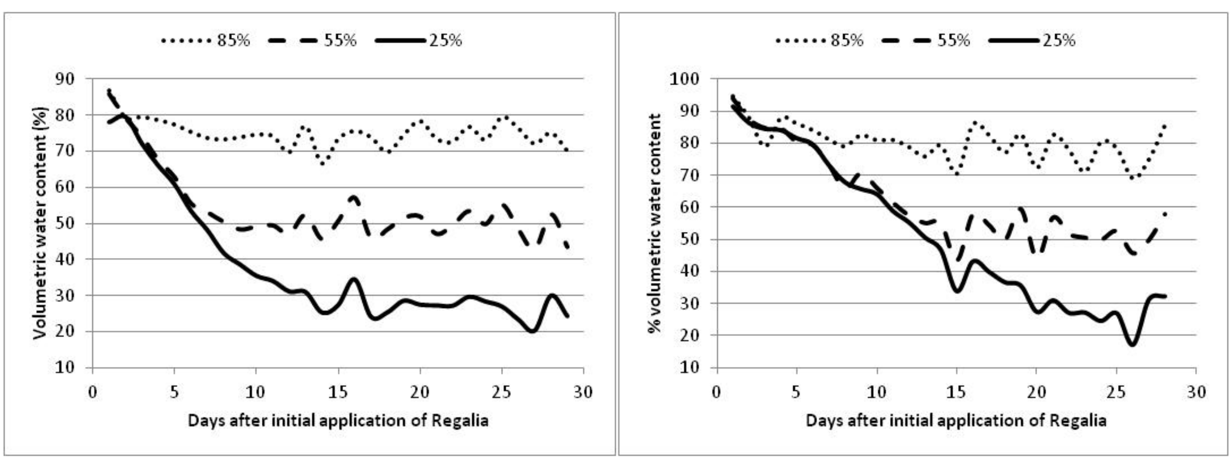

Figure 3. Percent daily volumetric water content (VWC) of *Impatiens walleriana* 'Super Elfin XP White' after weekly applications of RegaliaSC maintained at 85% (well-watered), 55% or 25% VWC, Expt. 2a (Left) and Expt. 2b (right).

Table 1. Growth of *Impatiens walleriana* 'Super Elfin XP White' after weekly foliar applications of four rates of Pageant to plants grown in soilless substrate maintained at different volumetric water contents.

	Experiment 1a, June 2010			Experiment 1b, July 2010		
Rates[z]	**FGI**[y] **(cm)**	**SDW**[x] **(g)**	**RDW**[w] **(g)**	**FGI (cm)**	**SDW (g)**	**RDW (g)**
0.0x	20.4 a[v]	5.5 a	0.43 ab	22.0 a	4.5 b	0.24 b
0.5x	19.6 a	4.7 ab	0.35 c	22.4 a	5.8 ab	0.36 ab
1.0x	20.5 a	5.4 ab	0.47 a	23.3 a	6.5 a	0.65 a
1.5x	19.2 a	4.5 b	0.40 bc	22.7 a	5.3 ab	0.42 ab
Moisture level[u]						
85%	25.6 a	9.2 a	0.70 a	29.6 a	9.5 a	0.62 a
70%	22.4 b	6.9 b	0.50 b	23.9 b	5.4 b	0.44 b
55%	20.1 c	4.9 c	0.42 b	14.4 c	1.7 c	0.19 c
40%	17.5 d	2.9 d	0.30 c	-	-	-
25%	14.1 e	1.2 e	0.15 d	-	-	-
Effects						
rate	0.3852[t]	0.1116	0.0158	0.8882	0.1723	0.0820
moisture	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
rate*moist	0.8045	0.2937	0.5375	0.1068	0.0081	0.1650

[z]Rates of Pageant applied weekly, based on recommended label rate: 0.0x, 0.5x (0.43 g/gal), 1.0x (0.86 g/gal) and 1.5x (1.29 g/gal).

[y]FGI - final growth indices [(height + width + perpendicular width)/3].

[x]SDW - shoot dry weight, oven dried for 72 hours @ 65C.

[w]RDW - root dry weight, oven dried for 72 hours @ 65C.

[v]Means (within a column) with the same letters within moisture level or rate are not statistically different according to the Holm-Simulation method for mean comparison, alpha=0.05.

[u]Percent moisture level of substrate was maintained based on volumetric water content.

[t]*p* value.

Table 2. Growth of *Impatiens walleriana* 'Super Elfin XP White' after weekly foliar applications of Regalia to plants grown in soilless substrate maintained at different volumetric water contents.

	Experiment 2a, July 2010			Experiment 2b, September 2010		
Rates[z]	**FGI[y] (cm)**	**SDW[x] (g)**	**RDW[w] (g)**	**FGI (cm)**	**SDW (g)**	**RDW (g)**
0.0x	21.9 a[v]	5.6 a	0.49 b	15 ab	2.6 a	0.30 ab
0.5x	23 a	6.4 a	0.74 a	16.7 a	2.6 a	0.45 a
1.0x	23.8 a	6.3 a	0.67 ab	16 a	2.7 a	0.47 a
1.5x	21.3 a	5.7 a	0.57 ab	13.1 b	1.5 b	0.16 b
Moisture level[u]						
85%	29.8 a	10.4 a	0.86 a	18.5 a	4.1 a	0.47 a
55%	24.1 b	5.9 b	0.60 b	15.8 b	2.4 b	0.36 b
25%	13.6 c	1.7 c	0.41 c	11.3 c	0.5 c	0.20 c
Effects						
rate	0.6117[t]	0.9250	0.0128	0.0028	0.0165	0.0991
moisture	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
rate*moist	0.6563	0.4524	0.7961	0.7022	0.4169	0.8878

[z]Rates of Regalia applied weekly, based on recommended label rate: 0.0x, 0.5x (18.927 mL/gal) 1.0x (37.854 mL/gal and 1.5x (56.781 mL/gal).

[y]FGI - final growth indices [(height + width + perpendicular width)/3].

[x]SDW - shoot dry weight, oven dried for 72 hours @ 65C.

[w]RDW - root dry weight, oven dried for 72 hours @ 65C.

[v]Means (within a column) with the same letters within moisture level or rate are not statistically different according to the Holm-Simulation method for mean comparison, alpha=0.05.

[u]Percent moisture level of substrate was maintained based on volumetric water content.

[t]*p* value.

Water Quality Assessment of Two Creeks in Nursery-Dominated Sub-Watershed at Base Flow

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Index Words: Nursery, runoff, turbidity, pollutants, nutrients, surface water

Significance to Industry: Water quality issues associated with surface water (rivers, creeks, stream and lakes) have changed since the enactment of the Clean Water Act (CWA) in 1972. Most of these issues now relate to non-point source pollution from agricultural and other commercial activities in the landscape. Nursery crop production activities can contribute to both point and non-point source pollution. While the majority of ornamental plants in Tennessee are in-field grown; plowing, liming and fertilization of nursery fields can result in the runoff of tons of soil and essential crop nutrients at a watershed scale. Thus, the protection of surface water continues to pose a major challenge to researchers and growers. The question becomes, does field nursery crop production contribute to the impairment of surface water resources like rivers, streams and creeks? Sound water quality assessment tends to shed some light to the aforementioned question. There is a strong correlation between surface water quality and land use within a watershed. Subsequently a study of this nature is very important to the green industry, considering the role the industry plays in water utilization (irrigation) as well as in the agrarian economy. In 2010, the greenhouse and nursery industry ranked 4th in the leading commodities for cash receipts in Tennessee and also contributed about $297,867,000 to the state's economy (1, 2). In middle Tennessee, Collins River watershed spans Warren, Dekalb and Grundy counties, and large concentration of nursery crop production exists within these counties. Therefore, the potential for nutrient enrichment and sediment loading by overland and subsurface flow to creeks and streams, in a sub-watershed dominated by nursery crop production, exists. These creeks are usually conduits for contaminants flow to relatively large rivers like the Collins River. In a 2009 survey conducted by EPA (www.epa.gov/lakessurvey), the agency identified poor stream habitat and high level of nutrients as widespread stressors impacting surface water quality in the United States. Additionally, fluvial sediment was also identified as one of the major pollutants that impair surface waters (5, 6). Our goal is to assess the water quality of in-flow creeks to the Collins River, the data collected could be used by State and local regulatory agency to provide improved watershed decision making in a sub-watershed dominated by nursery crop production systems.

However, while growers are being viewed as contributors to surface water quality degradation, our preliminary data indicate otherwise. We found essential crop nutrients like nitrogen and phosphorus to be relatively low in the creeks monitored; suggesting efficient use of fertilizers by growers or non-use of fertilizers in their field production systems. Notwithstanding, good BMPs (Best Management Practices) of individual nursery fields could enhance stream water quality and total maximum daily loads (TMDL) of essential nutrients at the watershed scale.

Nature of Work: Two creeks, Hills Creek and Mountain Creek in Warren County Tennessee, were sampled. These creeks are tributaries of the Collins River. Land use in the study area is predominantly agricultural, being comprised of nursery crops primarily. A third water body, East Fork Stones River**,** located in Rutherford County, Tennessee was sampled in conjunction with Hills Creek and Mountain creek. The East Fork Stones River was sampled because there was no nursery crop production in the sub-watershed where this river is located. Rainfall supplies nearly all the crop production water demand, both in Warren and Rutherford Counties. The data from the East Fork Stones River will not be presented in this publication. Grab water samples were collected from the creeks with weighted bailers from corresponding bridges. Water samples were collected weekly for eight weeks during the fall of 2011. The water samples were collected mostly during base flow (normal stream flow) and in very few instances after rainstorm events. Rainfall events occurred in week 2 and 6. Samples were collected at two different locations (upstream and downstream) of the water bodies. During each creek/river visits, water samples were collected in 500-ml LDPE (low density polyethylene) sample containers, placed in a cooler with ice and then transported to the lab for analysis. The water samples were analyzed for nitrate-N, ammonium-N and Ortho-P; as well as the following cations: sodium, potassium, magnesium and calcium. Standard methods for water sample analyses were used to analyze all the nutrients of interest (4). In order to determine other water quality parameters of interest: dissolved oxygen (DO), total dissolved solids (TDS), specific conductance (SpCond), turbidity, temperature and pH were monitored with Eureka Manta™ DataSondes or data logger units (Eureka Corp Austin TX), interfaced with the applicable sensors and deployed in the creeks to at least a 45-cm depth and real-time water quality data of the above mentioned parameters was recorded in situ. The Manta (data loggers) were calibrated according to instrument specifications and programmed to record measurements every 10 minutes. While sampling, visual observation of aquatic habitats and wildlife present in the creeks were also noted.

Results and Discussion: The average concentrations of nutrients in the creeks are presented in (Table 1). The nitrogen data represents the summation of the water nitrate-nitrogen and ammonium-nitrogen; nitrite was highly negligible. The phosphorus (P) reported constitutes the dissolved P in the water. It ranged from 0.02 ppm in Mountain creek to 0.08 ppm in Hills creek. It is worth mentioning that the dissolve form of phosphorous usually serves as potential nutrient for algae in the water and as such may support eutrophication in surface water. However there was no visual incidence of eutrophication in either creek. Some of the cations determined are important because they are present in agricultural liming materials (i.e. calcium and magnesium) that are widely used by farmers. Both creeks have relatively low concentrations of cations, except for calcium and magnesium. Considering the hydro-geologic conditions of Middle Tennessee, with abundance of limestone rocks, that tend to weather into terrains referred to as karst, it is expected that calcium and magnesium will be relatively high in the creeks. Calcium concentration ranged from 46 ppm to 94 ppm in Hills creek. Figures 1a and 1b depict selected water quality parameters of Hills Creek and Mountain Creek. Hills Creek had the lowest average turbidity value (~2.5 NTU). Turbidity values tend to increase when suspended particles (silt, clay, colloids, bacteria etc) in the water increase. Turbidity is a quick way to screen for water quality problems; it also correlates very well with suspended sediments in creeks and streams. Specific conductance is important in water quality because it is a measure of dissolved salts in the water. Hills creek had the highest specific conductance (Figure 1a). The total dissolved solids (TDS) of Hills Creek were also higher than that of Mountain Creek. Certain biotic organisms are useful in determining surface water quality as they are indicator of polluted or non-polluted water. Crayfish were observed in Mountain Creek during our sampling period. Crayfish presence indicates moderately clean water. Thus, they are seldom found in polluted waters (7). Several fish were also observed in all the streams sampled. Fish presence can also be used to indicate water quality because of their sensitivity to water pollution. Most of the fish found were in the family of Sunfish (*Centrarchidae*). Fish in this family are moderately tolerant to pollution and habitat alterations (3). Based on the number of fish observed in both Mountain Creek and Hills Creek, the former creek tends to have a better water quality characteristic than the later creek. All in all, the creeks monitored didn’t seem to be greatly polluted during base flow conditions. However during storm events, large volumes of sediments were added to the streams from surface runoff, especially in areas where the landscape has been disturbed.

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Table 1. Selected nutrient parameters - Hills Creek and Mountain Creek.

	Concentration in parts per million-(ppm)											
	Nitrogen		Phosphorus		Sodium		Magnesium		Calcium		Potassium	
Week	HC*	MC*	HC	MC	HC	MC	HC	MC	HC	MC	HC	MC
1	9.99	15.18	0.03	0.04	3.59	1.86	15.07	8.55	45.65	38.10	1.57	1.33
2	6.96	5.42	0.02	0.04	8.16	2.00	35.10	6.27	72.60	27.45	3.81	0.87
3	7.08	8.20	0.03	0.02	6.85	2.84	26.45	6.09	56.60	27.20	2.78	0.80
4	9.31	10.26	0.05	0.02	7.96	2.65	32.05	6.14	87.25	27.05	3.24	0.75
5	2.06	8.20	0.08	0.05	7.39	1.69	31.30	9.08	93.50	36.20	3.18	0.94
6	5.67	2.21	0.05	0.03	6.39	2.00	27.66	4.88	68.65	24.35	2.50	1.41
7	3.13	10.49	0.02	0.02	6.72	1.33	33.10	5.48	81.50	25.45	2.64	1.08
8	12.53	11.91	0.02	0.03	6.71	1.39	33.85	4.48	83.25	23.40	2.70	1.46

* HC – Hills Creek
*MC – Mountain Creek

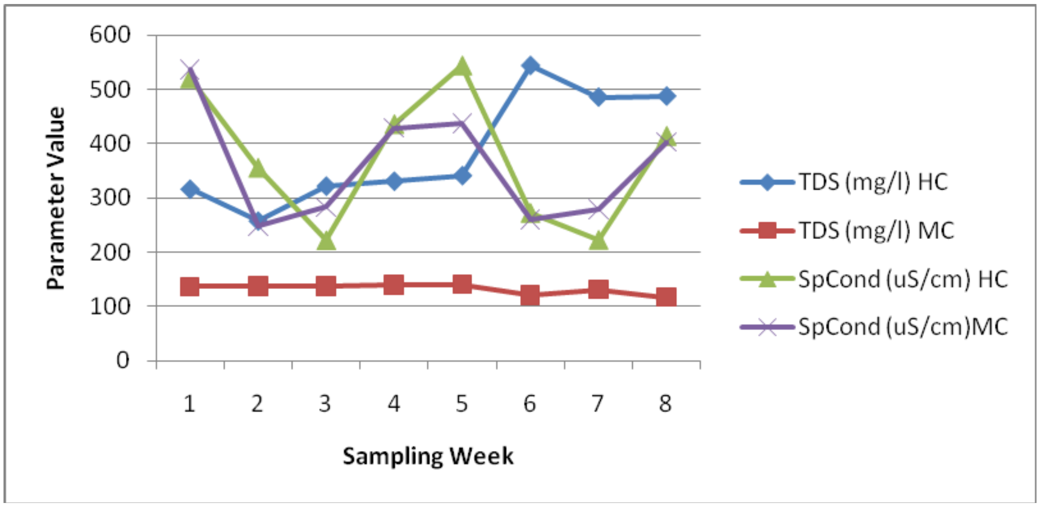

Figure 1a. Selected Water Quality Parameters - Hills Creek and Mountain Creek.

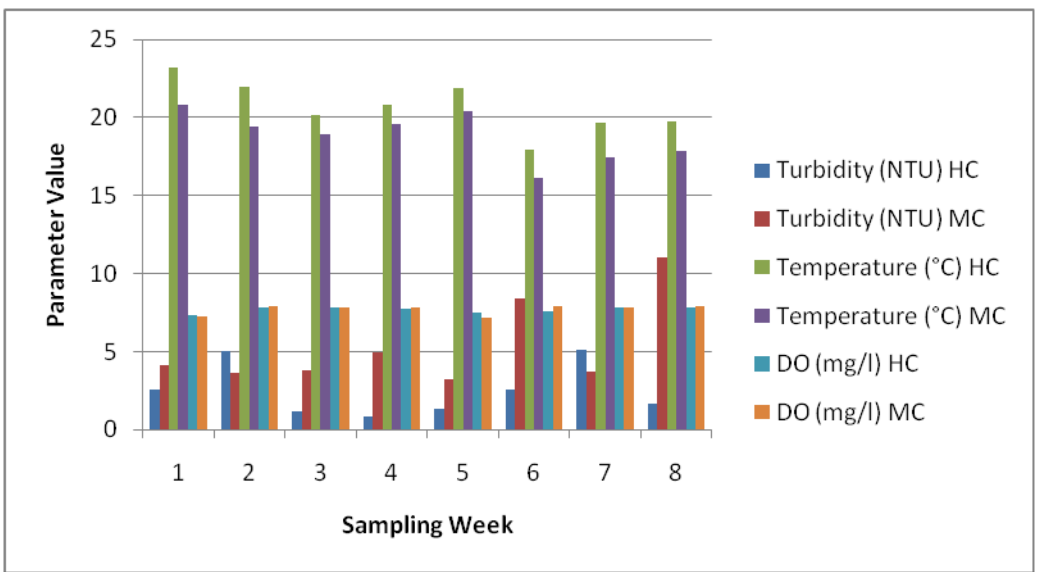

Figure 1b. Selected Water Quality Parameters - Hills Creek and Mountain Creek.

Estimating daily water use of snapdragon in a hydroponic production system

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Index Words: cut-flower, Nutrient Film Technique, load cell, modeling

Significance to Industry: Efficient irrigation and nutrition management in ornamental production is critical to ensure plant quality and profitability. However, little information is available about the exact water needs of plants on a daily basis. We used a load cell system and wireless sensor network to monitor the evapotranspiration (ET) and cultural factors (substrate water, light, temperature, and relative humidity) of snapdragon (*Antirrhinum majus* L.) in a hydroponic system, to quantify daily water use (DWU) as a function of plant age and changing environmental factors. Daily water use was positively correlated with days after planting (DAP), daily light integral (DLI), and vapor pressure deficit (VPD). In particular, DWU of snapdragon grown in a perlite hydroponic environment was highly affected by VPD. Preliminary data indicates that a regression model using these parameters can accurately predict the amount of irrigation required to match snapdragon plant water use in this system, improving the efficiency of both irrigation and nutrient management.

Nature of Work: Optimizing irrigation can provide better root zone water and nutrient management, to maximize plant growth, quality and health (1), as well as improving the efficiency of expensive inputs (2). However, little information is available regarding real-time water requirements of ornamental plants in production. We used a load cell-based evapotranspiration measurement system to measure real-time substrate water additions and loss, to model continuous plant water requirements. The objective of this work was to quantify the daily water use (DWU) of snapdragon in a hydroponic greenhouse production system, to better understand the environmental variables which had the greatest affect on water use by a large, three-dimensional plant canopy.

Seedlings of *Antirrhinum majus* L. 'Opus Fresh White' were transplanted to a perlite bag (72" × 12"). Six seedlings were transplanted in each one of eight holes in six identical growing bags (a total 48 seedlings per bag) in a commercial greenhouse (Flowers by Bauers, Jarrettsville, MD) and grown from Jul. 9 to Aug. 25, 2011. Each growing bag was filled with approximately 40 L of perlite (Grade A-20; Pennsylvania Perlite Co., Bethlehem, PA). The plants were fertigated six to seven times a day using drip irrigation, following normal cultural management conditions. A modified Hoagland's solution was applied for 5 minutes at each fertigation event. Each bag was placed on top of a load cell apparatus, consisting of a lightweight aluminum tray that rested on two load cells (ESP-35; Transducer Techniques, Temecula, CA). The load cells were connected to a datalogger (CR10X; Campbell Scientific, Logan, UT) via multiplexer (AM416; Campbell Sci.). The datalogger measured the bag weight every 5 sec, and recorded the average and weight change every 5 min. Daily water use was calculated from the change in bag weight over the day. To measure the light interception of the plants, light levels above and below the canopy were measured with a photosynthetically active radiation (PAR) sensor (SQ-110) and custom line quantum sensors (SQ-319; Apogee Instrument, Logan, UT), respectively. Intercepted DLI (IntDLI) was calculated from DLI above the canopy minus DLI below the canopy. Temperature and relative humidity sensors (EHT; Decagon Devices, Pullman, WA) and capacitance soil moisture sensors (EC-5; Decagon Devices) were connected to a wireless sensor network (EM50R; Decagon Devices) to continuously monitor the canopy environment and the substrate water content (θ, v/v) of the perlite bags. The vapor pressure deficit (VPD) was calculated from temperature and relative humidity. To measure the water balance, water influx and efflux were measured with a flow meter (25PN; Badger meter, Milwaukee, WI) and six rain gauges (ECRN 50; Decagon Devices) mounted at the end of each load cell apparatus, to collect and measure any runoff.

At 48 days after planting (DAP), plants were harvested and shoot height, shoot dry weight, and leaf area of 8 random plants per bag were measured. The quality of the plants was determined by measuring floral spike length greater than 20 cm, within 15-20 cm, and less than 15 cm, and grading them as grade 1, 2, and 3, respectively. To determine the effect of plant age and environmental conditions on the DWU of snapdragon, multiple regressions were performed (Proc REG, SAS Systems, Cary, NC). A stepwise selection was used to select the significant parameters ($P < 0.05$) to include in the model, and the best fit model with logical variables was selected.

Results and Discussion: The substrate water contents (θ; v/v) of perlite bags were maintained within very narrow range of 0.32 ± 0.02 $m^3 \cdot m^{-3}$ (mean ± SD). At harvest, shoot height was 97.6 ± 7.6 cm, shoot dry weight was 4.97 ± 1.47 g, and leaf area was 372.6 ± 111.2 cm^2 (mean ± SD). The average quality of the plants was 50, 16, 16, and 18% for grades 1, 2, 3, and culled, respectively.

The load cell-based ET measurement system was able to accurately monitor water loss from the perlite bags. Although flow meter and rain gauges could give water balance through influx and efflux of irrigation amount, the precision of the flow meter (i.e., 1 gallon increments) and the occasional clogging of perlite in the rain gauges made it difficult to acquire a reliable measurement using these sensors (Fig. 1). However, the load cell-based ET system accurately measured the bag weight change, making it possible to calculate DWU, as well as hourly water use with good precision (i.e. ± 1.07 g per bag).

Cut-flower snapdragon DWU ranged from 27.6 to 94.2 mL/plant. As previous research has reported (3; 4), DWU fluctuation was strongly correlated with DAP ($r = 0.63$, $P < 0.001$) and was tightly correlated with daily light integral (DLI) and VPD (Fig. 2). From the stepwise regression selection, the model with two interaction variables (DAP × IntDLI and DAP × VPD) was selected as the best fit model (Fig. 3). Although DAP×DLI also gave a good correlation with DWU (r = 0.64, P < 0.001), this term was not significant with DAP×VPD variable in the model. From the best fit model, approximately 81% DWU was explained by the model:

$$DWU = 0.01497 * DAP \times IntDLI + 1.44188\ DAP \times VPD + 11.49 \quad (\text{Adj. } R^2 = 0.806)$$

Both model variables were highly significant (P < 0.01). DWU increased with increasing DAP, because of an increase in plant size over time. DWU also increased with increasing IntDLI and VPD, which is not surprising since PAR affects stomatal opening and VPD is the driving force for transpiration. From the partial R^2 calculation, the DAP × IntDLI term had value of 0.28, and DAP × VPD term had a value of 0.54. From a previous study estimating the DWU of petunia, Kim et al. (3) indicated DLI was the most determinant environmental factor on petunia water use. However, our results indicate that VPD had a larger determinant effect on the DWU than DLI in this snapdragon experiment. Baille et al. (4) reported the ET of nine ornamental plants, and separated the environmental effects on ET by total solar radiation and VPD. They reported that the ET of *Gardenia*, *Impatiens*, *Pelargonium*, and *Schefflera* were mostly determined by total solar radiation (> 80%). However, the ET of *Begonia* was largely determined more by VPD (55%) than total solar radiation (4). This suggests a species-dependent behavior of ET, with different sensitivities to PAR and VPD; our results suggest that snapdragon appears to be more like *Begonia*, with a greater sensitivity to VPD than DLI.

The required environmental data for this model can be easily acquired from simple weather stations, and this preliminary model may provide some insight for snapdragon growers for estimates of daily water use, without the need for expensive and complicated load-cell setups. We are following up with additional experiments to determine the sensitivity of this model to environmental conditions at different times of the year and with different cultivars. Nevertheless, our results suggest that it is possible to estimate the daily water requirements of plants from simple measurements of environmental parameters.

Acknowledgement: We gratefully acknowledge the support of USDA-NIFA, under Specialty Crops Research Initiative Award # 2009-51181-05768. We also gratefully acknowledge equal financial support from the Growers, Universities and Companies involved in this project. Without this support, none of this research and development would be possible.

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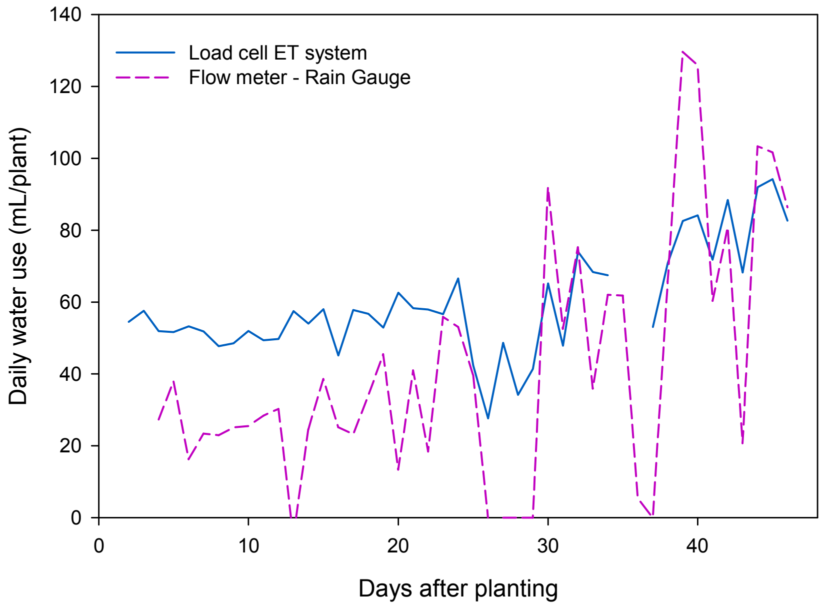

Fig. 1. Daily water use estimation of cut flower snapdragon production in a hydroponic system. A Load cell-based evapotranspiration measurement system and a water balance system using flow meter and rain gauges were compared. The lack of flow meter precision and occasional perlite clogging the rain gauges resulted in the lower reliability of the water balance system.

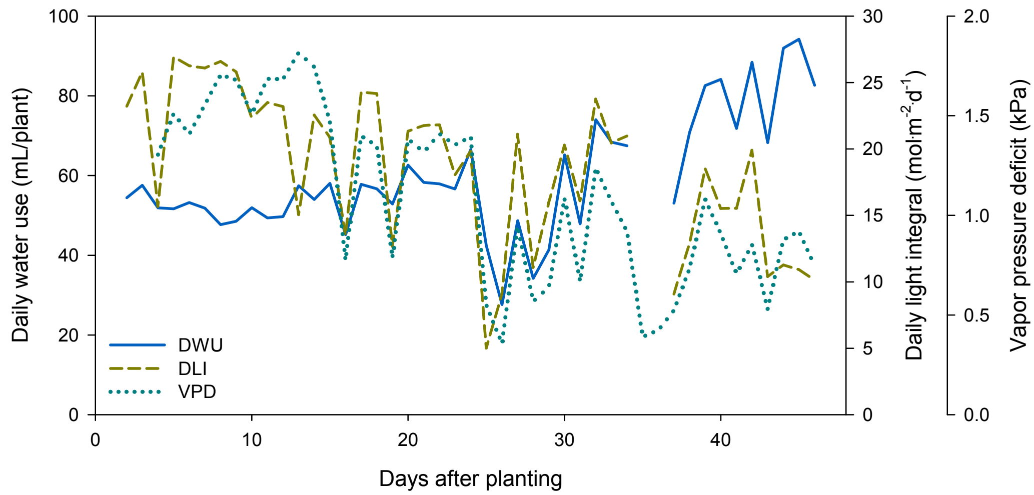

Fig. 2. A comparison of daily water use (DWU) of snapdragon ‘Opus Fresh White’ in a hydroponic system with separated values of daily light integral (DLI) and vapor pressure deficit (VPD) in the greenhouse during the production period. VPD was averaged over the entire day.

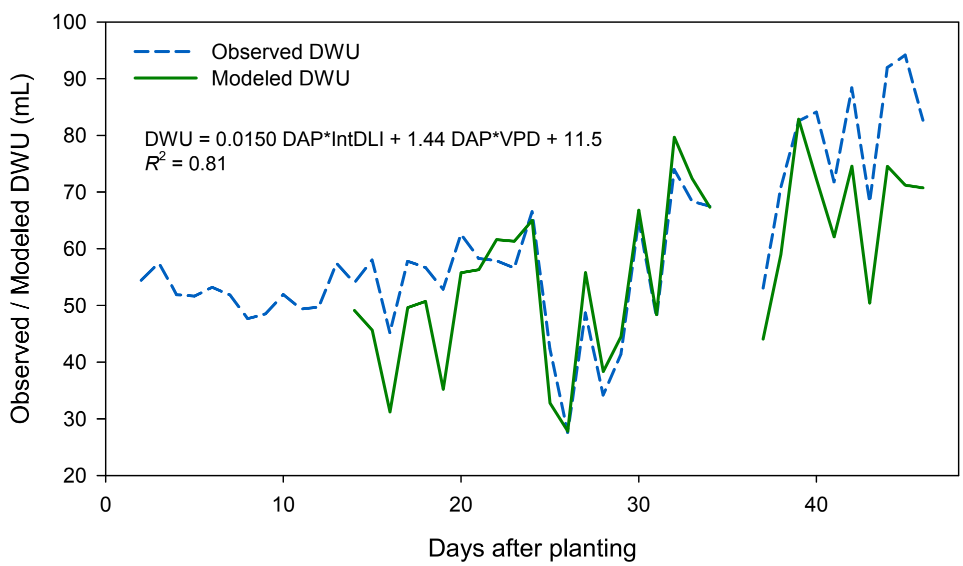

Fig. 3. Observed daily water use and the integrated model DWU of snapdragon ‘Opus Fresh White’ grown in perlite bag in a hydroponic system over 48 days. The model was based on the effect of days after planting (DAP), canopy intercepted daily light integral (IntDLI), and vapor pressure deficit (VPD). The first 10 days of the model was not included, due to lack of IntDLI data.

Salt Tolerance of Ornamental Chile Pepper

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Index Words: landscape irrigation, salt tolerance, water reuse

Significance to Industry: High quality irrigation water for green industry is becoming increasingly limited. Alternative water source such as municipal reclaimed water is being used for irrigating landscapes in some areas in the Southwest. Ornamental chile peppers are popular for container-grown plants as well as bedding plants providing unique foliar and fruit colors (1, 2, 3). However, information in the responses of ornamental chile peppers to irrigation water with elevated salts is limited. This study quantified the responses of 11 ornamental chile peppers to elevated salinity. Our results indicated that most cultivars were moderately tolerant to salinity with little or no foliar salt injury, although growth is reduced at elevated salinity. 'NuMex Memorial Day' was most sensitive among the 11 tested cultivars with foliar damage and significant growth reduction.

Nature of Work. Seeds of 11 cultivars of ornamental chile peppers (NuMex Twilight, NuMex Centennial, NuMex Christmas, NuMex April Fool's Day, NuMex Cinco de Mayo, NuMex Valentine, NuMex Easter, NuMex Halloween, NuMex St. Patrick's Day, NuMex Memorial Day, NuMex Thanksgiving) were sown on 2 Jun in plug cells filled with Redi-earth Plug & Seedling Mix (SunGro Hort., Bellevue, WA) and covered with 0.25 inch coarse vermiculite. Germinated seedlings were transplanted to 6-inch round plastic pots filled with Sunshine Mix No. 4 (SunGro Hort., Bellevue, WA).

Saline solutions at electrical conductivity (EC) of 1.3 (nutrient solution, control, no addition of salts), 4.1, and 8.1 $dS \cdot m^{-1}$ were created by adding appropriate amounts of sodium chloride (NaCl) and calcium chloride ($CaCl_2$) at 2:1 (molar ratio) to nutrient solution. The EC of tap water was 0.8 $dS \cdot m^{-1}$ and the major ions in the tap water were Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} at 184, 52.0, 7.5, 223.6, and 105.6 $mg \cdot L^{-1}$, respectively. Saline solution irrigation (treatment) was initiated on 15 July and irrigation frequency was determined based on cultivar (biomass), treatment, and climatic conditions to avoid overwatering and water stress. The temperatures in the greenhouse during the experimental period were at 33.3 ± 2.6 C (mean ± SD) during the day and 25.6 ±1.6 C at night. The daily light integral (photosynthetically active radiation) was measured at 18.6 ± 3.0 $mol \cdot m^{-2} \cdot d^{-1}$.

Experiment was terminated on 9 Sept. Upon termination of the experiment, shoots were severed at the substrate surface. Leaves, stems and fruits were separated and the dry weights (DW) were determined after oven-dried at 70 °C to constant weight. Foliar salt damage was rated by giving a score to every plant from 0 to 5, where 0 = dead, 1 = over 90% foliar damage (salt damage: burning, necrosis, and discoloration); 2 = moderate (50-90%) foliar damage; 3 = slight (<50%) foliar damage; 4 = good quality with minimal foliar damage; and 5 = excellent without any foliar damage. Leaf osmotic potential was determined as described in Niu et al. (3). Specifically, leaves were sampled from the middle section of the shoots in the early morning at the end of the experiment, sealed in a plastic bag, and immediately stored in a freezer at –20 °C until analysis. Frozen leaves were thawed in a plastic bag at room temperature before sap was pressed out with a Markhart leaf press (LP-27, Wescor, Logan, UT) and analyzed using a vapor pressure Osmometer (Vapro Model 5520, Wescor, Logan, UT).

The experiment was a split-plot design with salinity of irrigation water as the main plot and species subplot with 10 replications. All data were analyzed by a two-way ANOVA using PROC GLM. When the main effect was significant, linear regression was performed using PROC REG. To determine the differences among salinity level on plant growth, Student-Newman-Keuls multiple comparisons were performed. All statistical analyses were performed using SAS software (Version 9.1.3, SAS Institute Inc., Cary, NC).

Results and Discussion. Plants irrigated with nutrient solution (no additional salts) and saline solution at EC of 4.1 $dS{\cdot}m^{-1}$ did not have any foliar damage, regardless of cultivar. However, plants of some cultivars irrigated with saline solution at EC of 8.1 $dS{\cdot}m^{-1}$ had foliar damage (Table 1). 'NuMex Memorial Day' had the most severe damage and had an average score of 2.45. 'NuMex Thanksgiving', 'NuMex Twilight', 'NuMex Cinco de Mayo', and 'NuMex April Fools' had little or no foliar damage. Salinity treatment decreased leaf osmotic potential for most cultivars but not on 'NuMex Easter' and 'NuMex Halloween' (Table 1) and the degree of decreasing in leaf osmotic potential varied among cultivars.

Shoot dry weight (DW) was reduced by elevated salinity except for 'NuMex Thanksgiving' (Table 2). The reduction percentages by salinity varied with cultivars. For example, the shoot DW of 'NuMex Memorial Day' was reduce by 73.7% in EC 8.1 compared to the control, followed by 'NuMex Centennial' and 'NuMex Christmas' by 50% to 52%, 'NuMex Easter' at 46%, 'NuMex St. Patrick' at 48%, and the rest of the cultivar had a reduction below 40%. The highest shoot DW reduction in 'NuMex Memorial Day' coincided with lowest visual score, indicating that this cultivar was most sensitive to salinity. Although the foliar damage in other cultivars were minor, the low visual scores are generally found in plants with larger shoot DW reduction when irrigated with saline solution. The final plant size (growth index) of 'NuMex April Fools' and 'NuMex Centennial' were not affected by the salinity treatments (Table 3). All other cultivars became shorter and more compact as salinity of irrigation water increased. In summary, all cultivars were moderately tolerant to saline water irrigation except for 'NuMex Memorial Day', which was the most sensitive among the 11 cultivars with severe foliar damage at EC 8.1 $dS{\cdot}m^{-1}$ and 70% shoot growth reduction compared to the control.

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Table 1. Leaf osmotic potential measured of 11 ornamental chile pepper cultivars irrigated with saline solution at electrical conductivity (EC) of 1.3 (control, nutrient solution), 4.1, or 8.1 $dS{\cdot}m^{-1}$ for 8 weeks.

Cultivars	**Osmotic potential**			**Visual Score**
	Control	**EC 4.1**	**EC 8.1**	**EC 8.1**
April Fool's Day	-1.80 a	-1.72 a	-2.01 b	4.98
Centennial	-1.82 a	-2.02 b	-2.44 c	4.8
Christmas	-1.58 a	-1.69 b	-1.76 b	4.69
Easter	-1.83 a	-1.95 a	-1.88 a	4.91
Halloween	-1.2 a	-1.16 a	-0.99 a	4.88
Cinco de Mayo	-0.82 a	-0.98 a	-1.34 b	5
Memorial Day	-1.35 a	-1.52 a	-1.89 b	2.45
St. Patrick's Day	-1.49 a	-1.82 b	-1.72 b	4.87
Thanksgiving	-1.57 a	-1.78 b	-2.03 c	5
Twilight	-1.64 a	-1.97 b	-2.15 b	5
Valentine	-1.58 a	-1.71 b	-1.90 c	4.83

[z] means with the same small letters in the same row (among treatment) were not different tested by Student-Newman-Keuls multiple comparisons at *P* = 0.05.

Table 2. Shoot dry weight of 11 ornamental chile pepper cultivars irrigated with saline solution at electrical conductivity (EC) of 1.3 (control, nutrient solution), 4.1, or 8.1 $dS·m^{-1}$ for 8 weeks.

Cultivars	Shoot Dry Weight (g/plant)			Reduction (%)
	Control	EC4.1	EC8.1	EC8.1
April Fool's Day	20.9 a	16.7 b	13.18 c	36.9
Centennial	54.7 a	42.8 b	27.1 c	50.5
Christmas	15.0 a	11.9 b	7.2 c	52.5
Easter	23.4 a	21.5 a	12.6 b	46.2
Halloween	20.4 a	17.9 a	13.3 b	34.6
Cinco de Mayo	18.4 a	19.6 a	12.6 b	31.5
Memorial Day	19.5 a	13.3 b	5.1 c	73.7
St. Patrick's Day	16.3 a	16.7 a	8.5 b	47.7
Thanksgiving	42.0 a	39.5 a	35.9 a	14.5
Twilight	43.5 a	31.7 b	27.4 b	37.0
Valentine	16.4 a	17.1 a	10.8 b	34.1

[z] means with the same small letters in the same row (among treatment) were not different tested by Student-Newman-Keuls multiple comparisons at *P* = 0.05.

Table 3. Growth index [(height + width1 + width 2)/3] of 11 ornamental chile pepper cultivars irrigated with saline solution at electrical conductivity (EC) of 1.3 (control, nutrient solution), 4.1, or 8.1 $dS \cdot m^{-1}$ for 8 weeks.

Cultivars	Growth Index (cm)			Reduction (%)
	Control	EC4.1	EC8.1	EC8.1
April Fool's Day	31.9 a	27.4 a	27.5 a	13.8
Centennial	46.7 a	30.4 a	33.7 a	27.8
Christmas	25.2 a	25.0 a	19.3 b	23.4
Easter	32.7 a	28.7 b	22.9 c	29.9
Halloween	29.8 a	25.6 b	24.2 b	18.7
Cinco de Mayo	29.3 a	29.1 a	25.1 b	14.4
Memorial Day	25.7 a	24.2 a	16.2 b	37.0
St. Patrick's Day	24.1 a	23.8 a	18.7 b	22.5
Thanksgiving [y]	109.1 a	101.5 b	73.0 c	33.0
Twilight	59.9 a	51.8 a	39.6 b	33.9
Valentine	29.1 a	26.7 ab	23 b	21.0

[z] means with the same small letters in the same row (among treatment) were not different tested by Student-Newman-Keuls multiple comparisons at $P = 0.05$.
[y] Height but no width were measured.

Influence of Micobial Community Development in Substrates Used to Filter Zoospores from Recycled Irrigation Water

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Index Words: Biological filtration; *Phytophthora nicotianae*; substrates; slow filtration

Significance to Industry: Slow sand filtration is an increasingly viable option for treating irrigation and run-off water at nurseries that grow ornamental plants because it is low cost after installation, needs minimal maintenance, and does not require harsh chemicals (1, 2, 3, 4, 5). However, the slow flow rate of water through slow sand filters does not encourage nurseries that require large volumes of water for irrigation to adopt this technology. The efficacy of slow sand filtration is based not only on physical and chemical properties of the sand but also on the microflora present in the water system and the microbial community that develops on and in the sand (4). We evaluated the effects of microbial communities that developed on four alternative filter substrates (crushed brick, calcined clay, Kaldnes® medium, and polyethylene beads) and sand for removing zoospores of *Phytophthora nicotianae* from recycled irrigation water. These substrates could be used as slow filters or in modified subsurface flow constructed wetland systems to mitigate plant pathogens in irrigation water at ornamental plant nurseries while increasing the flow rate through the filter system. Use of slow filters in commercial nurseries could reduce the incidence of diseases caused by pathogens that have propagules that are dispersed in water, which should reduce the amount of fungicides applied to manage these diseases.

Nature of Work: *Phytophthora nicotianae* attacks over 200 plant species worldwide and is one of the most common pathogens attacking nursery plants in the southeastern USA (6, 3, 7; Jeffers, *personal observation*). Because zoospores of *P. nicotianae*, as well as other species of *Phytophthora*, can be disseminated through recycled irrigation water, it is essential to treat recycled water before re-use to avoid irrigating with infested water. Our objective in this study was to evaluate the filtration efficacy of five substrates, sand, crushed brick, calcined clay, Kaldnes® medium, and polyethylene beads, after microbial community development to remove zoospores of *P. nicotianae* from recycled irrigation water. The ability of each substrate without a microbial component to filter zoospores was reported previously (8).

To evaluate the influence of the microbial community on filtration efficacy of each substrate, a continuous recirculating-flow system was constructed to allow the natural microflora present in the irrigation water to develop a community within each substrate. Run-off water collected from a retention pond at a commercial greenhouse was used for this study. Water samples from the retention pond were tested before use to document that *Phtyophthora* spp. were not present already.

Three sets of six columns were constructed with transparent poly-vinyl chloride (PVC) pipe (Figure 1). Each column was 5 cm in diameter and 95 cm tall and was fitted with injection and sampling ports at specified depths, depending on the substrate (Figure 1). The sump tank was filled and maintained with 20 L of runoff water. A submersible pump supplied water from the sump to a manifold mounted at the top of the columns; the manifold evenly distributed water to each column. Each column in a set was filled with one substrate to a specific depth: 10 cm for sand, calcined clay, and brick and 60 cm for Kaldnes® medium and polyethylene beads. Substrate depths that allowed some zoospores to pass, based on previous research (8), were selected so the effect of the microbial community could be determined. The flow rate in all columns was maintained at 10-30 mL/min, which is three times faster than the flow rate recommended for conventional slow sand filtration (2, 9, 10). After passing through the flow meter at the bottom of a column, the effluent was recirculated into the sump to be redistributed. Water was recirculated continuously for 21 days to allow the natural microflora in the irrigation water to develop a community in each substrate. Bacterium density within each substrate and the number of zoospores of *P. nicotianae* captured in the effluent from each column were measured when the recirculating system was set up (Day 0) and after 21 days of constant water recirculation (Day 21).

Zoospores of *P. nicotianae* were produced and quantified in the laboratory as reported previously (8). A standardized number of zoospores (12 mL of a zoospore suspension, 1×10^3 zoospores/L) was injected into each column 5 cm above the top of the substrate. Immediately after injecting zoospores, two 1-L aliquots of effluent were collected from each column. Water samples (in 50-, 100-, and to 200-mL aliquots based on anticipated CFU counts from preliminary studies) were passed through polycarbonate membrane filters (47 mm in diameter) with 3-µm pores; a total of 600 mL was filtered from each 1-L aliquot. The filters then were inverted onto 90-mm-diameter petri dishes containing PARPH-V8, a medium selective for species of *Phytophthora* (11, 12). Dishes were placed at 25°C, the filters were removed at 24 h, and colony-forming units (CFU) were counted at 24 h and 48 h.

The density of bacteria in the microbial layer that developed on each substrate was quantified based on the methods of Calvo-Bado et al. (2003) and the standard heterotrophic plate count method no. 9215 (14). Approximately 1 g (wet weight) of substrate was collected from each column, and water was collected at 58 cm from the base of the control column because it did not contain a substrate. Each substrate sample was added to 10 mL of sterile distilled water, and the suspension was mixed vigorously for 10 sec every 2-3 min for 15 min. Using sterile distilled water, a series of 1:10 dilutions was made for each sample, and aliquots were pipetted onto trypticase soy agar (TSA; Becton, Dickinson, and Company, Sparks, MD). To enumerate microbial populations, 10 µL of each dilution was plated in triplicate, and plates were held at 20°C for 6 days before colonies were counted.

Each experimental unit contained six columns, one for each substrate and the control. One set of columns was used in each trial of the experiment. Three replicate trials were conducted, each with a different column set, fresh substrates, and water collected on a different date. Data were analyzed statistically using two-way analysis of variance (ANOVA) with time (0 and 21 days) and substrate treatment as main effects; means were separated by Fisher's protected least significant difference (LSD) with $P \leq 0.05$ for *P. nicotianae* density and $P \leq 0.10$ for bacteria enumeration. All analyses were conducted using JMP (v.8.0.2) statistical software (SAS Institute, Cary, NC). Results from filtrations in each trial were normalized and reported as percent zoospore removal in each substrate column. Zoospore removal was calculated by comparing the number of zoospores passing through each substrate to the number of zoospores in the control column, which represented the actual number of zoospores present in the recirculating water:

$$\text{Zoospore removal (\%)} = \frac{CFU_{control} - CFU_{substrate}}{CFU_{control}} \times 100 \qquad [1]$$

Zoospore removal is the percentage of zoospores removed by both physical and biological filtration for each substrate. The significant effects of time and substrate treatments on microbial community development were evaluated using Fisher's protected LSD but with $P \leq 0.10$ because of the inherent variability among bacterium densities.

Results and Discussion: Both substrate treatment and time significantly affected zoospore removal in this study. Zoospore removal was significantly greater after continuously circulating irrigation water for 21 days through the different substrates than before circulation began on Day 0, except for Kaldnes medium ($P < 0.0001$; Figure 2). Percentages of zoospores removed on Day 0 and Day 21, respectively, were: sand, 64 and 99%; brick, 64 and 94%; clay, 45 and 93%; beads, 33 and 86%; and Kaldnes medium, 38 and 64%. The significant increase in zoospore removal over time was likely due to increased microbial activity within each substrate. There also was a significant difference in zoospore removal among substrate treatments ($P = 0.0018$) on Day 0, before irrigation water was recirculated through the columns, due to physical filtration differences.

Bacterium densities that developed in the different substrates were significantly affected by both substrate treatment ($P \leq 0.10$) and time ($P \leq 0.05$). Densities of bacteria among the substrate treatments differed significantly after irrigation water was recirculated continuously through the columns for 21 days ($P = 0.0618$) but not before water began recirculating ($P = 0.2537$; Figure 3). There was a decline in bacterium density in the control column over time; this likely was because the substrates in the other columns were removing bacteria from the water as water was being recirculated. At Day 21, bacterium densities were greatest in the sand and calcined clay treatments and least in the polyethylene bead and Kaldnes® medium treatments (Figure 3). Bacterium densities (CFU/g) for each column on Day 0 and Day 21 were: control, 2.5 $\times 10^5$ and 6.7 $\times 10^4$; sand, 2.6 $\times 10^6$ and 2.5 $\times 10^7$; brick, 3.3 $\times 10^6$ and 1.1 $\times 10^7$; clay, 4.3 $\times 10^6$ and 2.0 $\times 10^7$; bead, 1.7 $\times 10^6$ and 6.8 $\times 10^6$; and Kaldnes medium, 8.4 $\times 10^5$ and 3.9 $\times 10^6$.

This experiment was designed so that zoospore removal on Day 0 represented physical filtration of zoospores from water while the difference between zoospore removal at the beginning of the experiment and 21 days later represented the role of the microbial community that developed on the substrates in zoospore removal. Although there was a significant difference in zoospore removal among substrate treatments at Day 0, this difference diminished and zoospore removal increased in all but one substrate by Day 21, suggesting that the microbial community enhanced zoospore removal. The removal of zoospores by sand, crushed brick, calcined clay, and bead substrates did not differ statistically on Day 21; beads needed six times the substrate depth as sand, clay, and brick to achieve a similar level of efficacy in zoospore removal (i.e, sand, crushed brick, and calcined clay at 10 cm were as effective as beads at 60 cm). Kaldnes® medium was the only substrate in which an increase in microbial load did not significantly influence zoospore removal from Day 0 to Day 21 (Figures 2 and 3). It is unclear why this discrepancy occurred, but this substrate had the largest pore size (8) so perhaps the microbial community was unable to fill all the gaps. In the other four substrates, zoospore removal was greater after the microbial community developed (Figures 2 and 3). Our results corroborate results from several other studies where increased density of bacteria in a substrate increased removal of the pathogen propagules from water (15, 16, 17, 18).

The approach utilized in this study enabled quantification of the microbial filtration component for various substrates at sub-optimal filter depths. If greater substrate depths were used, the effects of microbial community development on filtration may not have been observed due to the effectiveness of physical filtration alone. Although there was not a significant difference in the removal of zoospores on Day 21 among sand, crushed brick, calcined clay, and beads, the percentage of removal by sand (99 ± 0.5%, Figure 2) was nearly 100% in our experimental system. Although it is not known how many zoospores of *Phytophthora* spp. are needed to cause disease on most plants, removing the greatest number of zoospores from water was the goal of this research and likely would be the goal for a nursery that was recycling irrigation water.

To determine if these results are consistent with those on a large-scale filtration system, sand, crushed brick, and clay should be incorporated in a large-scale model with flow rates equivalent to those used in this experiment, which are faster than the current model of slow sand filtration. These three substrates were the most effective at filtering zoospores and only required 10 cm of depth; whereas the beads required 60 cm and may not be as efficient on a large-scale. These substrates are both effective and economical; however, calcined clay is less stable and more expensive than sand and crushed brick. Eventually, we plan to incorporate a subsurface filtration module into a constructed wetlands system, so nurseries in the southeastern USA have an ecologically-based, low-maintenance treatment system to cleanse recycled irrigation water.

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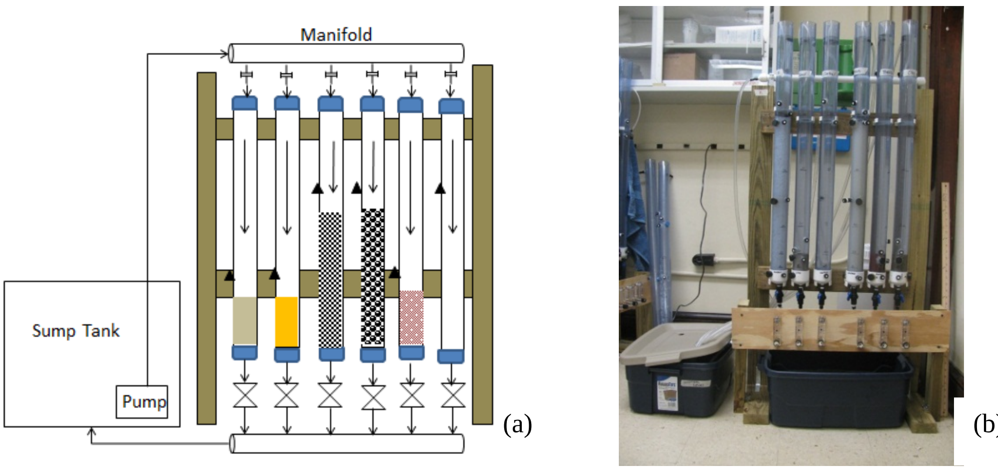

Figure 1. Diagram (a) and photograph (b) of the recirculating system used in this study. Water is held in the sump tank, and the pump supplied water to the manifold where it is dispersed evenly to the six columns. Each column holds one substrate at a fixed depth (left to right): sand at10 cm; crushed brick at 10 cm; calcined clay at 10 cm; polyethylene beads at 60 cm; Kaldnes® medium at 60 cm; and an empty column (control). Flow meters at the bottom of each column control the flow of water through that column. **A:** The arrows in each column represent the direction of the flow of water and the black triangles on each column represent the injection point.

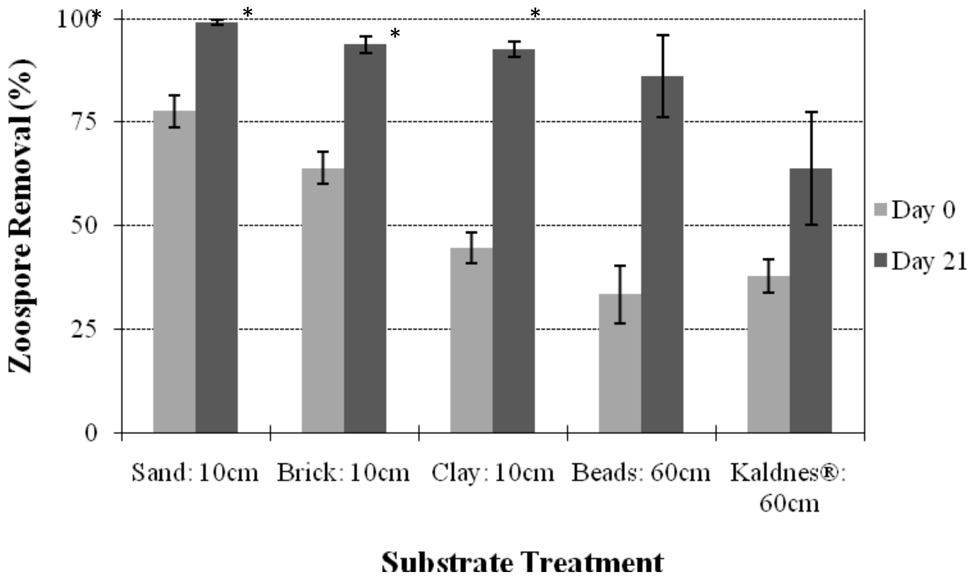

Figure 2. Removal of zoospores of *Phytophthora nicotianae* from irrigation water by five substrate treatments (sand, crushed brick, and calcined clay at 10 cm deep and polyethylene beads and Kaldnes medium at 60 cm deep) initially (Day 0) and after 21 days of continuous recirculation (Day 21). The percentage of zoospores removed was based on the number of zoospores in the control treatment minus the number of zoospores captured in effluent leaving each column. Error bars are standard errors of the means. * indicates there was a significant difference ($P \leq 0.05$) in zoospore removal between Day 0 and Day 21 for an individual substrate treatment.

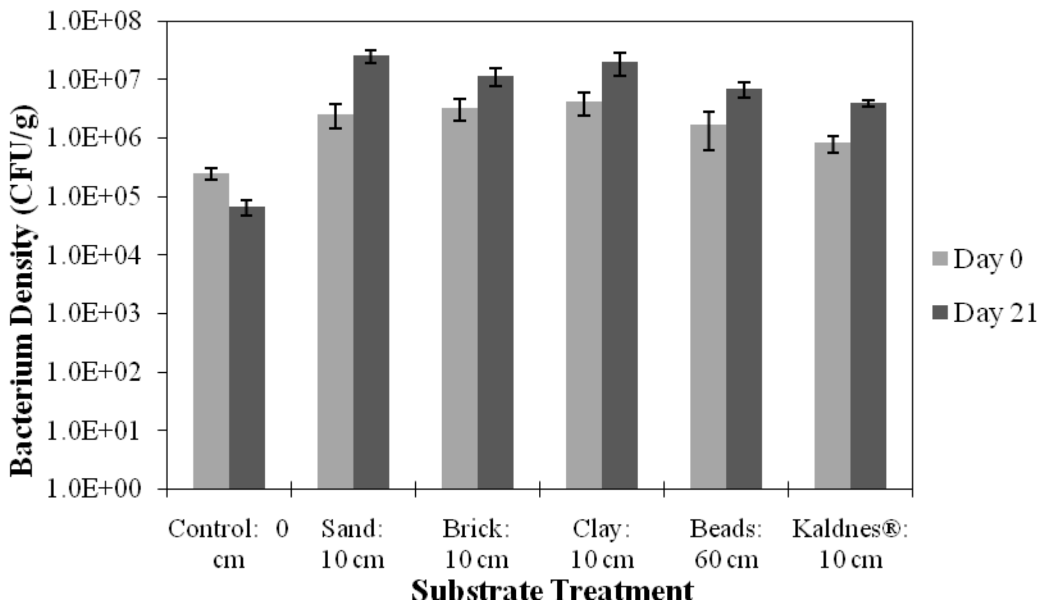

Figure 3. Density of bacteria (CFU/g of substrate [wet weight]) that developed in five substrate treatments before (Day 0) and after (Day 21) irrigation water was circulated continuously through the substrates for 21 days. Treatments were: sand, crushed brick, and calcined clay at 10 cm deep and polyethylene beads and Kaldnes medium at 60 cm deep. Samples for enumeration were collected 5 cm below the top of the substrate. Error bars are standard errors of the means.

Development of an Elevated Dissolved Oxygen Treatment System

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Index words: irrigation, oxygen, aeration, substrate, nursery crops, ornamentals, Cornus, dogwood, Forythia

Significance to the industry: Container production has potential for suboptimal oxygen levels in the root zone. The Water D.O.G.™ Iron Hunter HD did increase dissolved oxygen levels above those in municipal water supplies. Increasing dissolved oxygen levels can lead to increased biomass, more full and healthy root system, and decrease susceptibility to disease. Future work will examine the effect of growth on multiple species and how elevated dissolved levels affect root rot infection.

Nature of work: Container nursery crops have condensed root systems that are often grown in non-permeable containers (i.e. non-fabric, black polyethylene). These containers limit the gaseous diffusion between the atmosphere and the rhizosphere to the surface of the containers. Toxic by-products of anaerobic respiration (4), carbon dioxide supply, and high temperatures can deplete root zone oxygen levels. Thus, the potential for suboptimal rhizopheric oxygen conditions exists. Additionally, while oxygen is vital for root respiration, a range of acceptable rhizospheric oxygen levels in container production is not known.

While an adequate amount of air space in a substrate after free water has drained (Ea) is important in container production, there are no universally accepted standards for substrate physical properties (1). Roots require adequate oxygen to grow and function and a poorly aerated substrate will restrict root growth and plant development (6). According to Mathers (5), most sources agree that Ea values above 30% are too high and that Ea must be greater than 20% in order to promote root growth and reduce host susceptibility to root rot. Factors that can also influence Ea in a substrate are the particle size distribution, composition, bulk density and time, or aging (5).

Studies by Holtman, et al. (3) and Soffer and Burger (7), show that plants experiencing a higher dissolved oxygen level had increased yield as well as increased root health and length. Although these studies have not been applied to nursery crops, our hypothesis is that plants treated with oxygen infused water will gain more biomass than plants grown with untreated water. To properly measure the effect of dissolved oxygen on a crop it is important to design and build a water treatment system that provides a consistently elevated dissolved oxygen concentration compared with untreated controls (7).

There are mechanisms for increase dissolved oxygen concentration in water. The Water D.O.G.™ (W.D.) Iron Hunter HD machine (Water D.O.G. Works, Minnetonka, MN) is a “Dissolved Oxygen Generator”. The machine can serve several different functions such as: industrial water purification applications, specialized water for hospital disinfecting, and residential usage in addition to use in agriculture. The W.D.’s main purpose is to assist in the treatment of hard water issues. The W.D., is able to oxidize 100% of iron and manganese minerals in water, and is able to remove iron oxide, and hydrogen sulfide odors. For agricultural use the W.D. is used to inject micro oxygen bubbles into irrigation water.

The process by which the W.D. is able to eliminate some of the components of hard water as well as producing higher dissolved oxygen contents in water is called electrolytic hydrolysis. Electrolytic hydrolysis is the process by which an electric current is used to split water into oxygen gas and hydrogen gas while water is flowing. This method of hydrolysis is less expensive, and more energy efficient than other methods of hydrolysis. The oxygen bubbles produced by the W.D. are approximately 70 microns in diameter, which is slimmer than that of human hair (75 microns). The small size allows more oxygen to be produced within the flowing water in the treatment.

The objectives of this research are to: 1) evaluate a commercial oxygenation system (Water D.O.G.™ Iron Hunter HD) for providing elevated dissolved oxygen levels in irrigation water and 2) conduct preliminary investigations into response of two species to container substrate and elevated dissolved oxygen level in irrigation water.

Two treatments were used, W.D. and a control treatment. Each treatment was supplied by a single water source. The inflowing water was from the Tennessee River and had been treated by the municipal water treatment facility. Water was supplied to the treatments via 3/4” SCH-40 PVC pipe. After treating the water, a black polyethylene tubing ~16 mm (~0.5 in.) main line was used to transport treated water to the plot, a distance of about 18 ft. Each main line was then divided into two sub-mains that connected to two lateral lines each. The plot had the capability to supply 32 different “stations” per treatment, eight per lateral line. Spaghetti tubing (36 in. long, 3mm. in diam.) was connected to each emitter (two gph pressure-compensating drippers (Woodpecker, NetafimUSA Fresno, CA) allowing for 64 containers in the plot. For experiments with plants, the spaghetti tubing ends were secured in the containers just under, or at the substrate surface. A pressure regulator was used to decrease water pressure to 25 psi and a 120-mesh water filter was used. Pressure gauges were attached to the outflowing PVC pipe to ensure 25 psi pressure was maintained.

The system was verified by conducting series of experiments during the summer measuring the dissolved oxygen levels for each treatment. For verifying water treatments, 4 blocks were randomly selected and samples were tested during the month of July while 5 blocks were randomly selected, sampled and tested during the month of September. All eight blocks in the month of October were sampled.

Cornus florida seedlings and *Forsythia* x *intermedia* cuttings were potted into individual #1 nursery containers (1-gal) (Nursery Supplies Inc. etc.) with either a heavy substrate containing pine bark, silt and sand, or a 85:15 pine bark: peat substrate. The heavy substrate had a total porosity of 63%, container capacity of 47%, an air space of 15.8% and a bulk density of 0.53 g/cc. The peat substrate had a total porosity of 89.9%, container capacity of 61.3%, an air space of 28.6% and a bulk density of 0.16 g/cc. Plants were placed in the plot on black weed mat. *Cornus florida* was selected because of its perceived high oxygen rhizosphere requirement (2). *Forsythia* x *intermedia* was chosen because of its perceived tolerance of a range of rhizospheric oxygen levels. The experiment with *Forythia* was initiated on July 22, 2011. The experiment with *Cornus* was initiated on August 18, 2011. The design was a completely randomized design in a 2 (substrate) x 2 (water treatment) factorial arrangement with 8 blocks. Each of the 4 treatment combinations was randomly placed in each block so that each of the 8 blocks had all 4 combinations. The plants were watered two times a day, once in the morning and once around 1:30 in the afternoon for 3-4 minutes.

On the day of July 28, 2011 the initial heights of the plants were taken. On October 13, 2011 the final heights were measured (Tables 2 and 3). For dry weights, plants were harvested on October 17 and dried at 55 °C for 24 hours starting October 18. (Dry weight was monitored for an additional 2 hours to ensure that no further weight loss had occurred; plants were removed from the oven and weighed.) Shoot dry weight was composed of leaves and stems above the substrate surface. Root dry weight was all tissue below the substrate surface.

Results and discussion: The dissolved oxygen content from the W.D. remained consistently higher than the dissolved oxygen levels from the control at each data collection (Table 1). The dissolved oxygen concentration in the W.D. treatment averaged 4.1 mg/L higher than in the control treatment (n=3 from each treatment).

Dissolved oxygen concentration and substrate had no effect on dogwood height (Table 2). There was no water treatment by substrate interaction. Dissolved oxygen level had no effect on plant height for forsythia (Table 3). There was no water treatment x substrate interaction. Substrate did affect *Forsythia* plant height. *Forsythia* plants in the pine bark: peat substrate, were taller than plants potted in the heavy substrate.

For *Cornus*, there was no effect of water treatments and no substrate by water treatment interaction for any dry weight measurement (Table 4). Substrate did significantly affect root dry weight. Plants growing in the pine bark:peat substrate had root dry weights nearly twice that of those growing in the heavy substrate. For *Forsythia*, there was no difference in total dry weight, shoot dry weight or root dry weight due to water treatment and no water treatment by substrate interaction occurred (Table 5). Root, shoot and total dry weight were greater for plants growing the pine bark:peat-based substrate.

It was hypothesized that *Cornus*, with a sensitive root system and perceived intolerance of low oxygen levels, would benefit from elevated dissolved oxygen in irrigation water.

There was a slight, but not significant, trend toward increasing height and dry weights for *Cornus* subjected to the elevated dissolved oxygen treatment. High rainfall between the months of July and October (15.19 inches above normal rainfall) may have mitigated the growth effects of the elevated dissolved oxygen treatment, as plants did not need watered as often as they would have in a typical season. Also, while both experiments were shorter than a production cycle, *Cornus* had an even shorter experiment than the *Forsythia*. A longer period would have given the plants more time to respond to the elevated dissolved oxygen levels.

Pine bark:peat substrate increased biomass growth for *Forsythia*. The *Cornus* plants appeared to be under more stress than the *Forsythia* due to extreme heat, as indicated by the small amount of growth for plants regardless of treatment. Perhaps under more moderate environmental conditions and /or a longer growing season, the *Cornus* seedlings would have responded to the substrate or all treatments to a greater degree.

An irrigation system capable of delivering elevated dissolved oxygen to container nursery crops was developed. In preliminary short-term experiments using this system, there was no effect of elevated dissolved oxygen on plant height or dry weight. There was greater biomass for forsythia growing in the peat and pine bark substrate. Further work will examine the effect of elevated dissolved oxygen under a longer growing season and on other plant species.

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Table 1. Average dissolved oxygen during experiment.

Treatment	Dissolved Oxygen Level (mg/L) July	September	October
Water D.O.G.	17.2a[z]	11.4a	12.4a[z]
Control	12.6b	8.1b	8.2b
p value	0.0001	<0.0001	<0.0001

[z]means within a column followed by the same letter were not different (Tukeys HSD =0.05).

Table 2. Average height for *Cornus florida* after 49 days after treatment.

Substrate	Water Treatment	Height (cm)
Heavy	Water D.O.G.	21.5a[z]
	Control	18.0a
Light	Water D.O.G.	20.1a
	Control	19.0a
Source	**DF**	**F statistic**
WaterTrt.	1	2.27 [NS]
Substrate	1	0.05 [NS]
Water Trt. x Substrate	1	0.38 [NS]

[z]means within a column followed by the same letter were not different (Tukeys HSD α=0.05).

Table 3. Average height for *Forsythia* x *intermedia* after 90 days after treatment.

Substrate	Water Treatment	Height (cm)
Heavy	Water D.O.G.	20.0a[z]
	Control	18.1a
Light	Water D.O.G.	24.8a
	Control	25.0a

Source	DF	F statistic
Water Trt.	1	0.18^{NS}
Substrate	1	8.51***
Water Trt. x Substrate	1	0.30^{NS}

[z]means within a column followed by the same letter were not different (Tukeys HSD α=0.05).

Table 4. Dry Weight of *Cornus florida* after 56 days of elevated dissolved oxygen treatment.

Substrate	Water Treatment	Total Dry Weight (g)	Shoot Dry Weight (g)	Root Dry Weight (g)
Heavy	Water D.O.G.	1.5a	0.87a	0.64a[z]
	Control	1.2a	0.77a	0.4 a
Light	Water D.O.G.	1.8a	1.0a	0.75a
	Control	1.7a	0.89a	0.78a

Source	DF	F statistic	F statistic	F statistic
Water Trt.	1	0.99^{NS}	0.86^{NS}	0.71^{NS}
Substrate	1	3.42^{NS}	1.16^{NS}	6.59**
Water Trt. x Substrate	1	0.18^{NS}	0.02^{NS}	1.37^{NS}

[z]means within a column followed by the same letter were not different (Tukeys HSD α=0.05).

Table 5. Dry Weight of *Forsythia* x *intermedia* after 97 days of elevated dissolved oxygen treatment.

Substrate	Water Treatment	Total Dry Weight (g)	Shoot Dry Weight (g)	Root Dry Weight (g)
Heavy	Water	3.8a	2.1a	1.7a[z]
	D.O.G. Control	2.7a	1.4a	1.2a
Light	Water	8.8a	5.7a	3.1a
	D.O.G. Control	8.9a	5.6a	3.3a

Source	DF	F statistic	F statistic	F statistic
Water Trt.	1	0.28 ^{NS}	0.27 ^{NS}	0.19 ^{NS}
Substrate	1	32.84***	31.44***	21.64***
Water Trt. x Substrate	1	0.41 ^{NS}	0.16 ^{NS}	0.88 ^{NS}

[z]means within a column followed by the same letter were not different (Tukeys HSD α=0.05).

Effects of Managed Substrate Moisture Content on Zinnia Growth Under Zero and Near-zero Leachate Treatments

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Significance to Industry: As water demand increases, amount of water permitted for irrigation use by horticulture crop producers will likely decrease. Furthermore, increasingly environmental concerns and regulations over water quality necessitate the prevention of irrigation runoff from production sites. Many nursery and greenhouse operations collect, store, and treat irrigation runoff in order to decrease water consumption and prevent irrigation runoff. Growing crops under near-zero or zero leachate irrigation regimes would significantly reduce resources and space needed to treat and collect runoff. *Zinnia* in this experiment grown at substrate moisture levels maintained slightly lower than container capacity were similar in size to plants grown under a 0.20 leachate fraction but produced greater leaf area and shoot biomass. There was also a 12% decrease in applied irrigation volume realized compared to plants produced under a 0.20 leachate fraction.

Nature of Work: Water is a finite resource (5). Water availability to the horticulture crop production industry is becoming increasingly limited due to growing competition with urban and industrial consumption and legislative restrictions on agricultural use (2). Leaching of nutrients such as nitrates, phosphates, and heavy metal trace elements into the runoff from green industries is also of concern (3). Laws in some states such as Maryland, Delaware, and California restrict nutrient applications and the concentrations of nutrients allowed in water leaving nursery and greenhouse production sites (2). As a result, many nursery and greenhouse operations must spend valuable space and resources to store and/or treat runoff. The reduction or elimination of leachate would both reduce water consumption and reduce resources and space required to store and/or treat leachate runoff. However, precise substrate water status measurements and irrigation control are needed in order to supply adequate water while avoiding excess water supply that results in leaching. This study was conducted using a system that precisely measures and controls substrate moisture content in real-time using gravimetric data. The objective was to determine the effect of substrate moisture content on *Zinnia* growth, water consumption, and water application efficiency.

On 17 December 2010, sixty *Zinnia* ‘Profusion Knee High Red’ seedlings were transplanted into round 5 inch containers. Containers were filled with a uniform mass of

Sunshine LB2 commercial potting mix. Samples of substrate were used to determine substrate water content at time of potting. A topdress of Osmocote Plus 15-9-12, a 3-4 month controlled release fertilizer, was applied at a rate of 3 grams per container. Plants were treated with Subdue Maxx at 1 oz/100 gallons and Cleary 3336F at 10 oz/100 gallons for protection from root and shoot disease. Containers were placed on 15 electronic scales in groups of four in a tray that drained any leachate into a container next to the scale. The scales were tared with the tray and four empty containers, so that only the weight of the substrate and plant were reflected in the recorded weight. On 21 December 2010, containers were irrigated to saturation and allowed to drain for one hour to container capacity at which point the weight of each container-substrate-plant unit was recorded. This weight is referred to as Effective Container Capacity (ECC) (6). An automatic system applied irrigation throughout the experiment so that the weight of the four container units on each scale were maintained at 70%, 80%, 90%, or 100% of ECC which equated to gravimetric water contents (GWC=weight of water/weight of wet substrate) of 0.83, 0.85, 0.86, and 0.88, respectively. A moisture characteristic curve (MCC) was created using the Modified Long Columns method (1) to determine the estimated substrate matric potential values of Sunshine LB2 at these water contents. Weight of the container units was allowed to drop 10% below the target weight before irrigating. A fifth group of containers were irrigated to a 0.20 leachate fraction (LF=amount of water leached/amount of water applied) as needed when subjectively judged to be necessary. This treatment was meant to reflect standard commercial production practice. Each treatment was replicated three times on three separate scales in a randomized block design. A Microsoft Excel macro monitored container unit weight in real-time and controlled irrigation events. Irrigation was applied through pressure regulated 1 gallon per hour drip emitters. Growth indices were recorded 3, 6, and 8 weeks after initiation (WAI) of irrigation treatments. Flower number, shoot dry weight, leaf area, substrate pH and EC were all recorded 8 WAI. Amount of water evapotranspirated throughout the study was calculated by determining the sum of weight change after each irrigation event. Leachate amounts were collected and measured daily. Amount of water evapotranspirated plus amount water leached equals total amount of water applied. Water application efficiency (WAE) was calculated as amount of water evapotranspirated divided by total amount of water applied. Plant water use efficiency (WUE) was calculated as the grams of shoot dry weight divided by liters of water evapotranspirated. Data were analyzed by GLM ANOVA and Regression using IBM SPSS Statistics software (Version 19, SPSS Inc., Chicago, IL).

Results and Discussion: The MCC revealed that targeted matric potential among substrate managed for moisture content ranged from 2.78 kPa to 1.64 kPa (Table 1). Total irrigation applied per plant and total water evapotranspirated per plant increased linearly with increased target ECC percentage. WAE ranged from 94.9% to 100% among substrates managed for moisture content. Although applied irrigation per plant was highest among the control group, amount of water evapotranspirated was only lower among substrates maintained at 70% ECC. WAE was lowest among the control group at 73.1%.

By 8 WAI, plants among all treatments were similar in growth index (Table 2). Despite being similar in size, shoot dry weight among plants grown under 90% ECC was greater than all other treatments. The differences in shoot dry weight are most likely due to differences in leaf area. Leaf area was greatest among plants grown under 90% ECC and significantly greater than that of the control group or plants grown under 70% ECC. Number of flowers among plants grown under 90% ECC was significantly greater than that of all other treatments except 80% ECC. Water use efficiency was significantly lower than all other treatments among plants grown under 100% ECC at 2.75 g/L. WUE among other treatments ranged from 3.29 g/L to 3.53 g/L. At harvest, substrate pH values ranged from 5.9 to 6.5, while EC ranged from 1.15 $dS \cdot m^{-1}$ under 100% ECC to 1.78 $dS \cdot m^{-1}$ under 70% ECC (data not shown). Analysis by ANOVA revealed no significant pH or EC differences between treatments.

The actual range of targeted GWC was relatively small. Despite small differences in maintained GWC, there were significant differences in water usage and WAE. Maintaining moisture content just below container capacity at 90% ECC resulted in a 10% decrease in applied irrigation compared to maintaining moisture content at 100% ECC and a 12% decrease compared to the control group. Leaf area responded strongly to substrate moisture content. Reduction in leaf area is one of the first morphological responses to water deficit (4). Leaf area of plants in the control and 70% ECC groups were both lower than those in the 90% ECC group. While a lower leaf area was expected in plants maintained at 70% ECC, the low leaf area of plants in the control group may be due to the degree of water deficit the substrate was allowed to reach before each irrigation event. More frequent irrigations may have resulted in a higher leaf area. Shoot dry weight was lower among plants grown under 100% ECC than those grown under 90% due to a lower leaf area and fewer flowers. Growth may have been inhibited in this treatment due to lack of air space in the substrate. Allowing the substrate to dry to lower moisture content before returning it to 100% ECC may result in better root gas exchange and greater growth. Ongoing research is evaluating the balance needed between adequate water supply and air supply for root gas exchange.

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Table 1. Effects of managed substrate moisture content on water consumption, evapotranspiration, and water application efficiency.

Target ECC %	Average Target Gravimetric Water Content	Avg Target kPa	Total mL irrigation applied per plant	Total mL water evapotranspirated per plant	WAE[Z]
70	0.83	2.78	2823	2823	100
80	0.85	2.41	3277	3275	99.95
90	0.86	2.03	3727	3688	98.95
100	0.88	1.64	4145	3941	94.92
Significance[Y]			L*** Q***	L*** Q**	L* Q*
Control			4238	3096	73.07

[Z] Water application efficiency equals amount of water evapotranspirated divided by total amount of water applied over the course of the study.

[Y] Regression response non-significant (NS), linear (L), or quadratic (Q) at the 0.05 (*), 0.01(**), or 0.001 (***) level.

Table 2. Plant measurments as affected by managed substrate moisture content.

Target % of CC Weight[X]	Growth Index 3 WAI[Z]	Growth Index 6 WAI	Growth Index 8 WAI	Shoot Dry Weight (g)	Leaf Area (cm^2)	Flower #	WUE[Y]
70	15.8 [W] b[V]	27.9 a	36.6 a	9.6 b	728 b	24 b	3.41 a
80	17.7 ab	29.6 a	37.4 a	11.0 b	859 ab	26 ab	3.36 a
90	17.7 ab	30.0 a	39.4 a	13.1 a	1082 a	29 a	3.53 a
100	17.8 ab	28.7 a	36.9 a	10.9 b	920 ab	24 b	2.75 b
Control	18.8 a	29.0 a	38.2 a	10.7 b	765 b	22 b	3.29 a

[Z] Weeks after initiation of irrigation treatments.

[Y] Water use efficiency calculated as grams of shoot dry weight divided by liters of water evapotranspirated.

[X] Percent of weight when substrate is at container capacity at which irrigation events were ceased. Weight was allowed to drop to a 10% deficit from upper target weight before irrigation event initiated.

[W] Growth index calculated as (height+width+width)/3.

[V] Means within same column with the same letter are similar according to Tukey's Honestly Significant Difference test.