Water Management

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Performance of Experimental Bioreactors Developed for Removing Nitrate from Nursery Runoff Water

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Index Words: nutrient, nitrogen, remediation, bioremediation

Significance to Industry: Nutrient enrichment of public surface water bodies throughout the United States is becoming a major issue as the US EPA and state governments begin developing and enforcing Total Maximum Daily Loads (TMDLs) for nutrient-impaired water bodies. Previous work has indicated that significant amounts of nutrients can be leached from pots and production areas during normal irrigation and fertigation operations (1). Nitrate concentrations in nursery runoff or drainage water reported by others has ranged from 1.6 ppm to 304 ppm (2,3). In a zero-discharge situation, nutrient enrichment is not likely an issue. However, not all nurseries have the drainage infrastructure to insure zero-discharge conditions. For those nurseries, nutrient enrichment of drainage water can be reduced by only applying what the plant needs, careful irrigation management, and/or by employing runoff retention and remediation techniques. Constructed wetlands and retention ponds are effective nutrient removal and retention strategies for nurseries with the capacity to dedicate land area to non-production uses. However, this may not be practical, for smaller nurseries and those in areas where land is limited or too expensive. For those situations, the ideal water treatment system would be one that could be incorporated into the nursery production landscape without sacrificing production area. This system could collect and treat drainage water close to the individual production areas, rather than on a whole-nursery scale. It could be constructed beneath roadways, plant holding areas, or other areas used for production purposes.

Nature of Work: This project evaluated the performance of a flow-through bacterial-based denitrification system at a commercial foliage plant nursery in Fort Pierce, FL. This experimental, small-scale nitrate removal system relies on native microorganisms to convert nitrate-nitrogen in water to nitrogen gas, which is released into the atmosphere (Denitrification). The first version of the system was previously described in 2007 (5). Briefly, each system consists of four 64 gallon polyethylene tanks connected by 4-inch PVC pipe and fittings. Each tank is filled with approximately 30 gallons of Kaldness media. Kaldness media, a slightly buoyant material used in the aquaculture industry, provides surface area (256 ft² per ft³ of media) for anchoring the microorganisms, and porosity to allow adequate flow rates. Establishment and maintenance of an optimal community of microorganisms requires low-oxygen conditions and a continuous supply of nitrate and carbon.
Water was pumped continuously through the systems at a flow rate of 10 L/minute using waterfall pumps purchased at a local home supply store. The pumps were placed in a sump at the foliage plant nursery that receives water from two 10-acre production areas. The carbon source used in these studies was molasses, which was supplied using a high viscosity pump. Automatic water samplers were set up at the inflow and outflow points for each of the two systems (2 inflow and 2 outflow). Samples were collected every 15 minutes for each 24-hr interval monitored. Nitrate concentrations were quantified by ion chromatography. The total mass of nitrate-N pumped into each system and exiting the systems was estimated by multiplying the concentration by the volume of water pumped through the system during the monitored period.

**Results and Discussion:** Data from approximately 90 sampling events are reported. Results indicate that the system, when properly managed, offers much potential for removing nitrate from surface water quickly and with great efficiency. Inflow nitrate concentrations ranged from 0.7 to 1512 mg/L, and outflow concentrations ranged from undetectable-1012 mg/L. Percentage nitrate-N removal during each sampling event is shown in Figure 1. Routine removal of greater than 90% of the nitrate load was achievable when the system was operating under optimal conditions. The depression in removal efficiency seen from months January through April were due to air pockets developing in the molasses delivery line, resulting in insufficient carbon supply for the microflora. However, once this problem was discovered and management improved, greater than 95% nitrate removal has been consistently achieved. The average amount of nitrate-N pumped into the bioreactor systems was 2.3 kg during each 24-hr period. Thus, conceptually this system seems to offer much promise for removing nitrate efficiently and quickly from drainage water using very little actual production space.

While this system offers much promise, it may not be practical for all nurseries since it requires intensive management, relative to constructed wetland systems, to achieve optimal removal efficiencies. For a successful nitrate treatment system, the nursery operator needs to accurately estimate expected nitrate loadings/concentrations from production areas and typical runoff flow rates/volumes. In addition, they must allocate system management resources (materials and labor) for optimal nitrate removal efficiency. In addition, some uncertainty exists regarding the impact of pesticides on the functioning of the microorganisms. Current research is evaluating the potential toxicity of commonly used pesticides on denitrification activity and determining specific sizing parameters for designing site-specific systems.

**Acknowledgements:** This research was funded through the Floriculture and Nursery Research Initiative and the USDA-ARS. We also thank the South Florida Sugar Cane Growers Cooperative for their generous donation of molasses.
Literature Cited:

Figure 1. Percentage nitrate removal for duplicate bioreactor systems operating at a foliage plant nursery in Fort Pierce, FL.
Response of Texas and Florida Live Oak (Quercus virginiana) Seedlings to Water Deficit Treatments

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Index Words: provenance, stomatal conductance, water loss, drought

Significance to Industry: In many regions of the United States, drought, increasing population, and decreasing aquifer levels have made water conservation a top priority. In much of the Southeastern United States, live oak (Quercus virginiana) is a common landscape tree. A live oak which is more tolerant of xeric sites would be very beneficial to the nursery industry. Our research suggests that provenance (original source-plant location) differences exist in the response of seedling live oak to deficit irrigation and live oaks native to West Texas may be better adapted to xeric sites than live oaks from more mesic environments.

Nature of the Work: There is a decrease in water availability and an increase in water-use restrictions in many areas of the United States. Therefore, the need for more drought tolerant landscape plants is increasing. Live oak (Quercus virginiana) is an important landscape tree in the Southeastern United States. Live oak is native to several diverse regional environments (1), comprising both mesic and xeric climates (2). If industry professionals had a greater understanding of the role provenance plays in drought tolerance, nursery personnel could tailor plant selections to produce plants more suited to differing climatic regions (3). To date there is little information on water requirements of live oak, and if provenance plays a role in live oak drought tolerance. Therefore, objectives of this research were to compare gas exchange and water loss of live oak trees collected from three different provenances subjected to three irrigation regimes.

Research was conducted at the Texas Tech University Plant and Soil Science Greenhouse Complex located in Lubbock, Texas. In Fall 2005 acorns collected from Lake Alan Henry, Texas (xeric climate) were germinated in the greenhouse and grown according to local nursery standards. One-year-old seedlings of acorns collected from Groveland, Florida and Houston, Texas (mesic climates) were received May 2006. At this time, seedlings from each provenance were transplanted to 1 gallon (3.8 liter) containers and 0.4 oz (10 grams) of Osmocote 31-0-0 were added to each container. To acclimatize plants to the local climate all seedlings were placed outdoors under shade (50%).

In July and August 2006, twenty-one trees from each provenance were randomly selected, brought into the greenhouse, and assigned one of three watering treatments. Control plants (high irrigation) were irrigated every day to soil saturation. Moderate
drought plants (medium irrigation) were irrigated every two days, and severe drought plants (low irrigation) were irrigated every four days. Data collection occurred every fourth day prior to severe drought plants being irrigated. Mid-day stomatal conductance was measured using a porometer. To estimate seedling water loss, each container was weighed each day prior to irrigation and one hour after irrigation. Water loss was calculated using leaf area and the difference of the weight of the container after irrigation and the weight of the container prior to the next irrigation cycle. Stomatal conductance and water loss data were subjected to ANOVA appropriate for a completely randomized block design. For water loss data, if treatment differences were found means were separated by Fisher’s LSD. This experiment was replicated August 2006.

Results and Discussion: Due to similar results from each replication, results from the second experiment will be presented. Our results indicate live oak seedlings from Lake Alan Henry respond to water stress differently when compared to live oak seedlings from Houston or Groveland, Florida. Lake Alan Henry, Houston, and Groveland, Florida seedlings generally had lower mid-day stomatal conductance as irrigation frequency decreased (Figs. 1-3). In addition, Lake Alan Henry seedlings generally had greater stomatal conductance when compared to seedlings from Houston or Groveland, Florida. Also, for each irrigation treatment seedling water loss was greatest for Lake Alan Henry seedlings when compared to seedlings from other provenances (Fig. 4).

Our research suggests provenance differences exist in the response of seedling live oak to deficit irrigation and that live oaks native to West Texas may be better adapted to xeric sites than live oaks from more mesic environments. As water resources become more limited, nursery personnel can use this and similar research to come to a greater understanding of the role provenance plays in drought tolerance, and adapt plant selections to produce plant species more suited to differing climatic regions.

Literature Cited:
Figure 1. Effects of three irrigation treatments (high irrigation = irrigation every day, medium irrigation = irrigation every other day, and low = irrigation every fourth day) on mid-day stomatal conductance of containerized live oak (*Quercus virginiana*) seedlings from Lake Alan Henry, Texas. Each point represents the mean of 8 measurements. An asterisk indicates significant treatment effects (P < 0.05). Vertical bars represent standard error of the mean.
Figure 2. Effects of three irrigation treatments (high irrigation = irrigation every day, medium irrigation = irrigation every other day, and low = irrigation every fourth day) on mid-day stomatal conductance of containerized live oak (*Quercus virginiana*) seedlings from Houston, Texas. Each point represents the mean of 8 measurements. An asterisk indicates significant treatment effects (P < 0.05). Vertical bars represent standard error of the mean.
Figure 3. Effects of three irrigation treatments (high irrigation = irrigation every day, medium irrigation = irrigation every other day, and low = irrigation every fourth day) on mid-day stomatal conductance of containerized live oak (Quercus virginiana) seedlings from Groveland, Florida. Each point represents the mean of 8 measurements. An asterisk indicates significant treatment effects (P < 0.05). Vertical bars represent standard error of the mean.

Figure 4. Effects of provenance on water loss of containerized live oaks (Quercus virginiana) seedlings receiving high, medium, and low irrigation treatments. Each bar is the mean of 56, 28, and 14 measurements for high, medium, and low irrigation treatments, respectively. Different letters indicate significant treatment effects (P < 0.05).
Phytoremediation of Nursery Pond Water using Water Hyacinths

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Index Words: bio-filtration, *Eichhornia crassipes*, nursery irrigation ponds, nutrient runoff, storm water retention ponds, water hyacinth, water quality

Significance to Industry: Water quality is a concern in every part of the green industry, and nutrients and sediments in runoff are the primary pollutants which degrade water quality (3). Phytoremediation is the use of plants to remove contaminants. A phytoremediation system which uses aquatic plants to remove excess nutrients from nursery irrigation ponds has many benefits. Algae blooms and subsequent algaecide applications are reduced, in turn decreasing the chances for copper resistant algae. Excessive growth of other aquatic vegetation and subsequent herbicide applications are also reduced. Pond life expectancy (time between dredgings) is lengthened. Irrigation water quality is improved. The aquatic plants can become an additional crop using previously unproductive space or they can be harvested, composted and added to potting substrate or back into the landscape, or bagged and sold as a soil amendment to complete the nutrient recycling cycle. Phytoremediation is a best management practice, and contributes significantly to the sustainability of the overall production system.

Nature of Work: Nitrogen (N) and phosphorus (P) levels were monitored in two nursery ponds at Knotts Creek Nursery in Suffolk, Virginia for two years. N and P levels fell within the range reported in nursery runoff in other literature (1 and 6). Floating water hyacinth (*Eichhornia crassipes*(Mart.) Solms) was selected as the aquatic test plant because its remediation potential has been documented in both ponds and waste water systems (2 and 5). An inexpensive, site adaptable containment system was constructed and evaluated to keep the hyacinths in place in the pond in order to intercept and filter the nutrient loaded runoff effectively (4). In conjunction with the field work, the phytoremediation potential of water hyacinth was examined in two independent studies under nitrogen (N) rates of 0, 40, 80, 100, 150, 200, and 300 ppm. A modified Hoagland solution was added to ponds containing water hyacinths which were rated and measured weekly for four weeks. The study was conducted at the Virginia Tech Hampton Roads Agricultural Research & Extension Center in Virginia Beach, Virginia.

Results and Discussion: The hyacinths were slower to establish in the nursery ponds than in the greenhouse due to slowly warming water temperatures. Water hyacinths were most effective at remediation when water temperatures were at or above 50° F,
which may not coincide with early season nursery fertilization practices. To maintain optimum remediation, the hyacinths should be thinned periodically when overcrowding begins. In the greenhouse studies, the hyacinths accounted for 60-85% of the N removed from solution. Net productivity, as measured by dry matter gain, increased with an increase in N rate until 80 ppm. Above that level dry matter productivity was similar. While there is a limit to how much N the hyacinths can absorb, their rapid reproduction rate creates an ever expanding remediation biomass. Water hyacinth has some management challenges when used for phytoremediation in nursery ponds, but the studies prove that the “in pond” system works. Now, with the availability of floating mats and islands, other aquatic and wetland plants can be utilized for phytoremediation in nursery ponds.

**Literature Cited:**
Comparing Conventional to On-Demand Gravimetric Based Irrigation Scheduling for Containerized Nursery Crops

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Index Words: Pine Bark, Container Capacity, Leaching Fraction, Container Production

Significance to Industry: On-demand irrigation scheduling increased water application efficiency while growing an equivalent size plant when compared to conventional irrigation scheduling applied cyclically at 1200, 1500 and 1800 HR with a 0.2 leaching fraction. The on-demand system successfully used weight to maintain adequate substrate moisture content throughout the day, efficiently and frequently replacing water lost from evapotranspiration. A gravimetric means of irrigation scheduling holds promise to accurately provide water to containerized crops.

Nature of Work: Water management is at the core of container nursery production (9). Currently, leaching fraction (LF = volume leached / volume applied) is the recommended method to assure adequate irrigation volume is applied to hydrate the substrate and prevent salt build-up. The current LF recommendation is ≤ 0.20 or ≥ 80% water application efficiency {WAE = [(volume applied - volume leached) / volume applied] x 100} (11). Ruter (7) and others have found that cyclic application of irrigation increased WUE, improved substrate rewetting, and decreased leachate volume. Research has demonstrated irrigation applied in the afternoon reduces substrate temperature and plant water stress presumably by maintaining adequate available water (AW) which leads to increased growth (2, 7). Irrigation applied at 1200, 1500, and 1800 HR resulted in 63% greater total plant dry weight compared to plants irrigated at 0300, 0500, and 0700 HR (8). Therefore, the ideal time to irrigate is before water becomes limiting and the plant begins to experience mild water stress, reducing growth. Both irrigation volume and time of application should be considered when developing a water management plan.

Lysimeters have long been used in field crop irrigation to determine rates of water loss via evapotranspiration (5). Gravimetric techniques have been used by researchers to determine water content in a container and to detect points at which plant water stress may occur (3, 6). Beeson (1) successfully used a suspension lysimeter in a nursery setting to measure substrate AW. However, little work has been done using this system in a container nursery to control irrigation scheduling. Irrigation scheduling includes determining both irrigation volume and timing of water application.
An irrigation control system has been devised for containerized nursery crops which uses the gravitational method of irrigation via a load cell/computer interface (load cell). The load cell, equivalent to a scale, acts as a transducer, converting force [weight] into a measurable electrical output which can be monitored continuously, providing real-time feedback from crops within a grower’s nursery. With this system, the irrigation scheduling can be automated based on weight (1 g = 1 mL); a direct measure of water added via irrigation and water lost via evapotranspiration. Therefore, the system can be used to apply precise amounts of water when substrate water content is depleted avoiding crop stress and subsequent reduction in crop growth. In addition, the precision of returning only the water lost results in little water leaching from the container and increases crop water use efficiency. This directly decreases agrochemical (nutrient and pesticide) losses from container crops decreasing environmental impact and increasing nutrient-use efficiency/pesticide efficacy.

The objective of this experiment was to compare two methods of irrigation scheduling: conventional, in which the crop was cyclically irrigated at 1200, 1500, and 1800 HR to maintain a 0.2 LF, and on-demand, in which plants were irrigated, regardless of time, to remain between maximum (98% to 94%; by weight) and minimum (94% to 90%) soilless substrate container capacity thresholds. Thresholds were adjusted within given ranges to maintain a 0.15 LF. Therefore, the upper and lower threshold were decreased, maintaining 4% range, when ≈ 15% water applied via irrigation was being leached per day. The experiment was conducted on a gravel pad at the North Carolina State University Horticulture Field Lab, Raleigh, NC (lat. 35°47'37'', long. -78°41'59'') in a randomized complete block design with four blocks, seven containers per replication, and 14 containers per block. Plants were irrigated via pressure compensated spray stakes [Acu-Spray Stick; Wade Mfg. Co., Fresno, CA (200 mL min⁻¹)]. Simulated container nursery plots were used to collect and quantify water applied and effluent which were used to determine and adjust leaching fraction daily. In addition, this data was used to calculate time averaged application rates [TAAR = water applied (mL) ÷ application duration time (min)].

Uniform rooted stem cuttings of *Cotoneaster dammeri* C.K. Schneid. ‘Skogholm’ were potted on 19 April 2007 into 14 L (#5) containers (C-2000, Nursery Supplies Inc., Chambersburg, PA) using an 8:1 pine bark:sand (by vol.) substrate. Containers were top-dressed with 71.2 g (0.16 lb) 16N-2.6P-9.0K (16-6-11 six month controlled-release fertilizer, Harrell’s Inc., Lakeland, FL). Electrical conductivity and pH of the substrate solution were measured every 3 weeks. The substrate solution was collected via the pour-through nutrient extraction procedure (10).

One plant per replication (4 per treatment) was positioned on a load cell (total of 8). Real time monitoring of container weight (plant + substrate + container) was performed using a low profile, two-beam, single aluminum point load cell with a 30 kg capacity (± 0.02% error) (Model RL 1042, Tdea-Huntleigh Inc, Covina, CA). The load cell was mounted between two 15 cm x 15 cm (5.9 in), 0.06 cm (0.2 in) thick square aluminum plates. One aluminum spacer 0.6 cm (0.25 in) inch thick was attached between the top and bottom plates and the load cell to keep debris out. The top surface area was
expanded with a 23 x 23 cm (9.1 in) square, 3 mm (0.12 in) thick aluminum plate. The load cells were connected to a CR3000 Micrologger® via an AM32 multiplexer (Campbell Scientific, Logan, UT). Weight was recorded every 15 minutes, and every 10 seconds when the water was running. Container capacity was determined by placing the container from the load cell into a 20 L (5 gal) water-filled bucket. Containers were removed after ≈ 2 hr when the substrate was fully saturated (as evidenced by a glossy sheen of water at the substrate surface), placed on the load cells, and allowed to drain until 0000 HR (12 AM) the following morning at which time weight was automatically recorded for each individual replication.

The experiment was initiated on 7 June 2007. Plants were harvested 65 days after experiment initiation. Tops (aerial tissue) were removed from two plants per replication (total of 8 containers per treatment). Plant roots were placed over a screen and washed with a high pressure water stream to remove substrate. Tops and roots were dried at 65°C (150°F) for 5 days and weighed. All data were subjected to analysis of variance and means were separated with Fisher's Protected Least Significant Difference, $P = 0.05$ when appropriate.

Results and Discussion: On-demand irrigation was able to grow an equivalent plant (mean = 104.5g ± 6.5) when compared to conventional irrigation scheduling method. Root:top ratio (mean = 0.12 ± 0.004) was unaffected by irrigation treatment. Leaching fraction was reduced from 0.14 to 0.06 when irrigated on-demand as opposed to conventionally. The on-demand system initially (June) had only 2.0 cycles occurring over a 2.0 hr time duration and by August required 7.5 cycles occurring over 13.5 hrs; whereas cycle number (3 cycles) and duration (min) were fixed by the conventional irrigation schedule (Table 1). This dynamic irrigation system resulted in maintaining a lower TAAR throughout the study than the conventional method of irrigation scheduling. Lamack and Niemiera (4) reported a reduction in TAAR, increased water application efficiency and decreased leaching. The increased leaching under the conventional irrigation schedule resulted in a 28% decrease in electrical conductivity after 64 days. This reduction in nutrient leaching may be the reason for the 36% (0.5 mg·g⁻¹ P) phosphorus concentration increase in tops of Skogholm cotoneaster when irrigated on-demand versus the conventional method (Data not shown).

On-demand irrigation scheduling can effectively apply water via micro-irrigation to containerized crops without decreasing crop growth. On-demand irrigation scheduling decreased water and nutrient leaching when compared to conventional irrigation scheduling. More research needs to be conducted to determine dynamics of container capacity in overhead and micro-irrigated systems and its effect on gravimetric based irrigation control. In addition, feasibility of on-demand irrigation scheduling application in commercial nurseries needs to be assessed.

Acknowledgements: We would like to thank William Reece, Greg Kraus, and Ben Exstrom for technical assistance, Harrels, Inc. for fertilizer, Pacific Mulch for pine bark, and Nursery Suppliers, Inc. for containers. Research was funded in part by USDA-ARS Floriculture and Nursery Initiatives grants (SCA #58-6618-2-2027).
Literature Cited:
Table 1. Cycle duration and number, water use and time averaged application rate for Skogholm cotoneaster grown in 8:1 pine bark:sand (by vol.) under two irrigation regimes.

<table>
<thead>
<tr>
<th>Irrigation Treatments</th>
<th>Cycle duration (^z) (hr)</th>
<th>Number of cycles</th>
<th>Water applied per day (L)</th>
<th>TAAR(^y) (mL min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>June</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>6.0(^x)</td>
<td>3.0(^x)</td>
<td>0.9 a(^w)</td>
<td>2.7 a</td>
</tr>
<tr>
<td>On-demand</td>
<td>4.9</td>
<td>2.0</td>
<td>0.5 b</td>
<td>1.6 b</td>
</tr>
<tr>
<td><strong>July</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>6.0(^x)</td>
<td>3.0(^x)</td>
<td>1.5 a</td>
<td>4.1 a</td>
</tr>
<tr>
<td>On-demand</td>
<td>10.2</td>
<td>3.5</td>
<td>1.1 b</td>
<td>2.2 b</td>
</tr>
<tr>
<td><strong>August</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
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<td>3.0(^x)</td>
<td>2.3</td>
<td>5.4 a</td>
</tr>
<tr>
<td>On-demand</td>
<td>13.5</td>
<td>7.5</td>
<td>2.0</td>
<td>3.3 b</td>
</tr>
</tbody>
</table>

\(^z\)Duration of time from beginning of first daily cycle to end of last daily cycle

\(^y\)Time averaged application rate (TAAR) = total water applied daily (mL) ÷ total run time (min)

\(^x\)Dictated by treatment selection.

\(^w\)Means within a column and variable not followed by the same letter are significantly different as determined by Fishers Protected LSD \(P = 0.05\).
Remediation of Phosphorus-rich Nursery Runoff via Vegetated and Non-vegetated Subsurface-flow Constructed Wetlands

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Index Words: Phosphorus, Water quality, Secondary treatment, Fired clay, Sustainability

Significance to Industry: Mixed, surface- to subsurface-flow wetland systems are highly effective at remediating both nitrogen (N) and phosphorus (P) from nursery production area runoff. Subsurface-flow cells lined with calcined clay (CC, also known as industrial mineral aggregate) or brick averaged 91.9 ± 1.7 % phosphorus removal efficiency over a five-month period, while vegetated secondary treatment phosphorus removal efficiency averaged 94.9 ± 1.2 %. The CC was more effective at polishing effluent water quality than the brick and may sorb P from effluent for a longer period of time. However, even though brick was not as efficient as CC, it may be useful in settings where P remediation requirements are not rigorous, such as when effluent will be recycled for irrigation water. Further, since brick is a recycled product, it may be a more environmentally sustainable choice as a remediation substrate.

Nature of Work: This research utilized a mixed design, incorporating both a surface-flow and subsurface-flow treatment. The pilot-scale system was designed to optimize both N and P removal efficiency. We characterized P removal efficiency (PRE) of the secondary constructed wetland systems (CWSs), which were established using either crushed brick or calcined clay and were either vegetated or non-vegetated. Crushed brick and calcined clay were previously identified as having high P sorption capacity (1). Fired clays facilitate remediation of highly recalcitrant nutrients, like phosphorus (2), from production area runoff (3).

The experimental setup for the primary treatment mesocosms utilized twenty-four 380-liter (100 gal) Rubbermaid tanks. Simulated nursery runoff was supplied using a 20-2-20 commercial-grade soluble fertilizer (Southern Agricultural Insecticides, Inc., Hendersonville, NC) with 15 mg/L (ppm) N and 5 mg/L (ppm) P supplied to each tank with a 4-day hydraulic retention time. The secondary, subsurface-flow treatments received effluent from the primary treatment mesocosms, and consisted of twenty four 190-liter (50 gal) Rubbermaid stock tanks that were filled with 90.7 kg (200 lbs) of either recycled crushed brick or calcined clay. Six of the twelve crushed brick and calcined clay filled mesocosms were planted with the following plant species: Iris neomarica caerulea ‘Regina’, Carex laxiculmis ‘Hobb Bunny Blue’ (Hobb bunny blue sedge), Carex plantaginea (seersucker sedge), Canna ‘Paton’, Canna ‘Intrigue’, Typha minima (dwarf cattail), Acorus gramineus ‘Dwarf Green’ (dwarf sweet flag), Alocasia wentii (hardy...
elephant ear), Colocasia antiquorum 'Black Beauty' (black beauty elephant ear), and Iris louisiana. Water quality parameters monitored included NO$_3^-$, NO$_2^-$, PO$_4^{3-}$, SO$_4^{2-}$, and pH. Anions were determined using a Dionex AS50 ion chromatograph (Dionex Corp., Sunnyvale, CA). Only the phosphorus data are discussed in this proceeding. Mesocosms were planted in August of 2006 and sampling began on 14 May 2007, continuing weekly through 7 October 2007. Total phosphorus was determined using a Thermo Intrepid 1000HR ICP-OES-IRIS (Thermo Scientific, Waltham, MA). Data were analyzed using SAS PROC GLM procedure (SAS Institute Inc. Cary, NC).

Results and Discussion: The secondary subsurface-flow treatment mesocosms were filled with either coarse CC or crushed brick. Half were planted with horticultural cultivars, while the other half remained unplanted. The clay and brick, vegetated (veg.) and non-vegetated (nonveg.) treatments were assigned randomly to receive effluent from primary treatments. The secondary treatments were targeted at reducing total phosphorus in effluent.

Phosphorus removal efficiency (PRE) in the secondary treatment mesocosms was relatively steady (Figs. 1A and 2A). Throughout the experiment, system (SYS) PRE for CC-veg. and CC-nonveg. treatments did not differ significantly. System PRE was calculated as the difference in nutrient concentration between the initial inflow concentration and secondary treatment outflow concentration. However, CC-veg. treatment PRE was consistently higher than CC-nonveg. treatment PRE (Figure 1A). Over 166.9 ± 4.4 and 209.6 ± 3.4 g of P were fixed by the CC-nonveg. and CC-veg. treatments respectively over the 6 months of sampling. The CC treatment was very efficient and reduced secondary effluent concentration to 0.24 ± 0.05 mg/L for nonveg. and 0.13 ± 0.02 mg/L P for veg. mesocosms. Although P export concentration from the CC treatment was higher than the eutrophication limiting target concentration of < 0.05 mg/L P; CC treatment demonstrated the potential this technology has for greatly reducing P export.

The brick-veg. and nonveg. treatments showed less consistent PRE. Initially, brick-veg. and nonveg. PRE was very high (99%). However, after May PRE in both declined slightly to around 89.7 ± 2.2 %, with the outflow concentration averaging 0.5 ± 0.1 mg/L P (Fig. 2). Phosphorus removal efficiency for the brick-nonveg. treatment began to decline during September and by October the treatment was exporting 1.6 ± 0.4 mg/L P, a concentration higher than the primary mesocosm's effluent. However, the brick-veg. treatment continued to effectively reduce P export below the primary mesocosm's effluent to 0.4 ± 0.1 mg/L. Secondary (SEC) PRE was calculated as the difference in nutrient concentration between primary outflow and secondary treatment outflow. When SEC removal efficiencies were compared, CC-veg. treatments consistently fixed more P and maintained positive removal efficiency (80.2 ±0.02 %) in comparison with CC-nonveg (36.6 ± 0.06 %, Fig. 1B). Brick-veg. and nonveg. treatments exhibited similar trends with initially high PRE. Secondary PRE by the brick-veg. treatment was 67.7 ± 2.9 % and relatively consistent, similar to the CC-veg. treatment. However, brick-nonveg SEC PRE began to decline after May and by September consistent P desorption occurred (Fig. 2B). At this time, brick-nonveg. treatment P sorption sites
were likely saturated. Plant uptake of P accounted for the additional 105.9 ± 4.5 and 42.7 ± 3.9 g of P fixed by veg. brick and CC treatments, respectively. Both veg. secondary treatments had a higher PRE than the nonveg treatments.

Acknowledgement: Financial support for this project was provided from a USDA/ARS specific cooperative agreement # 58-6618-2-0209 for “Environmental Resource Management Systems for Nurseries, Greenhouses, and Landscapes” as part of the USDA ARS Floriculture and Nursery Research initiative. Analytical support provided by Joseph Albano and Chris Lasser.

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Figure 1. Total P removal efficiency (bars) and effluent concentration (lines) of secondary subsurface-flow mesocosms with calcined clay (CC). Mesocosms were either vegetated (veg) or non-vegetated (Non Veg). (A) represents system $^a$ P removal efficiency and (B) secondary P removal efficiency.

$^a$System = \[1 - \frac{P_{\text{secondary}}}{P_{\text{inflow}}}; \quad \text{Secondary} = \left[1 - \frac{P_{\text{secondary}}}{P_{\text{primary}}}\right]; \quad * \text{ represent statistically significant differences (} P < 0.05). \] Values are the average of 8 replicates ± standard error of the mean.
Figure 2. Total P removal efficiency (bars) and effluent concentration (lines) of secondary subsurface-flow mesocosms with brick root-bed media. Mesocosms were either vegetated (Veg) or non-vegetated (Non Veg). (A) represents system \(^a\) P removal efficiency and (B) represents secondary P removal efficiency.

\(^a\)System = \[1 – (P_{secondary} / P_{inflow})\]; Secondary = \[1 – (P_{secondary} / P_{primary})\]; * represent statistically significant differences \((P < 0.05)\). Values are the average of 8 replicates ± standard error of the mean.
Irrigation Levels Affected Performance of *Gaillardia* Species

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**Index Words:** Drought stress, Landscape irrigation, Water conservation

**Significance to Industry:** *Gaillardia* species are native to North America and are listed as drought tolerant annual or perennials of the sunflower family. Information on garden performance of six *Gaillardia* species grown in a desert environment with different irrigation levels would help consumers and growers select drought tolerant plant materials for improved landscape performance.

**Nature of Work:** Low maintenance, drought tolerant plant species are becoming increasingly desirable in regions where water shortage or frequent drought occurs. Herbaceous perennials are a popular commodity for urban landscapes due to increasing diversity and low maintenance (2). The objective of this study was to characterize the response of six *Gaillardia* species to various irrigation levels.

Seeds of *Gaillardia aristata*, *G. pulchella*, *G. x grandiflora* ‘Burgundy’, *G. x grandiflora* ‘Painters Palette’, *G. x grandiflora* ‘Arizona Sun’, and *G. pulchella* ‘Sundance Bicolor’ were germinated in plug trays filled with Sunshine Mix No. 4 (SunGro Hort., Bellevue, WA). Seedlings were transplanted on 11 April to 500 mL containers (4-in pots) filled with the same medium and were transplanted again to 9 raised beds in the field on 22 May. The raised beds were 1.5 x 6 x 0.2 m (5 x 20 x 0.66 ft) in size and were filled with Blue Point loamy sand mixed with Canadian sphagnum peat moss at a 2: 1 ratio (by vol.). The planting density was 2.7 plants/m² (0.24 plants/ft²) for all species. A slow-release fertilizer (Osmocote 14.0 N–6.1 P-11.6 K, Scotts-Sierra Hort. Products, Marysville, OH) was applied on 1 June at 1.0 kg/m³ (1.0 oz/ft³) and Micromax (Scotts-Sierra Hort. Products) at 1.0 kg/m³ (1.0 oz/ft³).

The experiment used a split-plot design with irrigation regimen as the main plot and the six species as subplots. The irrigation treatments include three irrigation levels, 60%, 100%, and 145% reference evapotranspiration (ET₀). The irrigation treatments were initiated on 15 June and repeated three times. There were four plants per species in each subplot. ET₀ was determined according to Penman-Monteith method (1). Plants in all beds were irrigated daily between 9 and 10 AM through a micro-spray drip irrigation system, one emitter per plant (Roberts Irrigation Products, Inc., San Marcos, CA). Each raised bed was equipped with a flow meter to ensure a similar amount of irrigation water to be delivered to the raised beds in the same treatment. The environmental conditions (air temperature, solar radiation, relative humidity, and wind speed) were recorded via an on-site weather station. To quantify growth, plant height and two perpendicular canopy widths were measured three times and a growth index was calculated as
follows: Growth index = [height + (canopy width1 + canopy width 2)/2]/2. At the end of experiment, shoots were severed at the soil surface and fresh weights were recorded immediately at the field. Dry weights (DW) of shoots were determined after oven-drying at 70C (158F) to constant weights. Plant canopy temperatures were determined in the middle afternoon on two days in August with a hand-held infra-red thermometer (Omegascope, Model OS530HR, Omega Engineering, Stamford, CT). The average air temperature during the measurement period was also recorded. The differences between canopy temperature and air temperatures were calculated as a measure of drought stress in the three irrigation treatments. At the end of the experiment, leaf osmotic potentials ($\psi_s$) were determined by sampling a few leaves from the middle section of the shoots in the early morning according to Niu and Rodriguez (3).

All data were analyzed by a two-way ANOVA using PROC GLM. When interactions between irrigation treatment and species were significant, multiple comparisons were conducted separately using Student-Newman-Keuls (SNK) at $P = 0.05$. Whenever there were no significant interactions, data were pooled across the treatments or species and the significance of the main effect was tested by SNK multiple comparison. All statistical analyses were performed using SAS (Version 9.1.3, SAS Institute Inc., Cary, NC).

**Results and Discussion:** Irrigation regimen did not affect the shoot DW of ‘Arizona Sun’ and *G. pulchella* (Fig. 1). Irrigation levels at 60% ET$_0$ led to lower shoot DW in ‘Burgundy’, *G. aristata*, and ‘Sundance Bicolor’ compared to 145% ET$_0$. However, no differences in shoot DW were found between 60% ET$_0$ and 100% ET$_0$ and between 100% ET$_0$ and 145% ET$_0$ in these species. Shoot DW of ‘Painters Palette’ was significantly different among the three irrigation levels. There were no differences in growth indices among irrigation treatments in all species except for ‘Painters Palette’ and ‘Sundance Bicolor’ (Fig.2). Growth indices of ‘Sundance Bicolor’ measured in the end of July and early September were lower at 60% ET$_0$ compared to the other two levels. In ‘Painters Palette’, the growth index in early September was lower at 60% ET$_0$ but no differences were found in July. Although not statistically different, the growth indices in *G. pulchella*, ‘Burgundy’ and *G. aristata* tended to be lower at 60% ET$_0$. The differences between canopy temperatures and air temperatures were affected by irrigation treatment and species. However, no interactive effects between irrigation level and species were found. When pooled across treatments, only ‘Sundance Bicolor’ had a canopy temperature greater than the air temperature (i.e., a positive value, Table 1). Canopy temperature of ‘Arizona Sun’ was the same as air temperature, and all other species had lower canopy temperatures compared to the air temperature. This indicates that ‘Sundance Bicolor’ was most drought-stressed. Among the irrigation levels, 60% ET$_0$ led to higher canopy temperatures but no differences were found between 100% ET$_0$ and 145% ET$_0$, indicating that plants irrigated at 60% ET$_0$ were stressed. No interaction between irrigation treatment and species was found on leaf osmotic potential. Also, no differences were observed for leaf osmotic potential among species. However, irrigation levels at 60% ET$_0$ and 100% ET$_0$ lowered osmotic potential (-1.49 MPa and – 1.43 MPa) compared to 145% ET$_0$ (-1.27 MPa) (data not shown), indicating osmotic adjustment for plants in the 60% ET$_0$ treatment.
Minimum irrigation requirements of landscape plants should be based on maintaining aesthetic value rather than maximizing growth. Although growth was generally reduced by the lowest irrigation level, all six species maintained good appearance. Therefore, we conclude that the minimum irrigation level of 60% ET0 is sufficient for all of these species. As for the relative drought tolerance among these species, further research may be needed.

Literature Cited:

Table 1. Differences between canopy temperatures and air temperatures (ΔT) measured in the middle afternoon.

<table>
<thead>
<tr>
<th>Species</th>
<th>∆T</th>
<th>Treatment</th>
<th>∆T</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. grandiflora ‘Arizona Sun’</td>
<td>0.000 a z</td>
<td>60% ET0</td>
<td>2.581 a</td>
</tr>
<tr>
<td>G. pulchella</td>
<td>-0.303 ab</td>
<td>100% ET0</td>
<td>-1.421 b</td>
</tr>
<tr>
<td>G. grandiflora ‘Burgundy’</td>
<td>-1.869 b</td>
<td>145% ET0</td>
<td>-1.421 b</td>
</tr>
<tr>
<td>G. aristata</td>
<td>-2.178 b</td>
<td>145% ET0</td>
<td>-1.421 b</td>
</tr>
<tr>
<td>G. grandiflora ‘Painters Palette’</td>
<td>-2.225 b</td>
<td>145% ET0</td>
<td>-1.421 b</td>
</tr>
<tr>
<td>G. grandiflora ‘Sundance Bicolor’</td>
<td>2.792 a</td>
<td>145% ET0</td>
<td>-1.421 b</td>
</tr>
</tbody>
</table>

z Means within the column followed by the same letters are not significantly different tested by Student-Newman-Keuls multiple comparison at P = 0.05.
Figure 1. Shoot dry weights of *Gaillardia aristata*, *G. pulchella*, *G. x grandiflora* 'Burgundy', *G. x grandiflora* 'Painters Palette', *G. x grandiflora* 'Arizona Sun', and *G. pulchella* 'Sundance Bicolor' grown in the field and irrigated at three levels: 60%, 100%, or 145% evapotranspiration (ET<sub>0</sub>).
Figure 2. Growth indices of *Gaillardia aristata*, *G. pulchella*, *G. x grandiflora* ‘Burgundy’, *G. x grandiflora* ‘Painters Palette’, *G. x grandiflora* ‘Arizona Sun’, and *G. pulchella* ‘Sundance Bicolor’ grown in the field and irrigated at three levels: 60%, 100%, or 145% evapotranspiration (ET$_0$).
The Relationship Between Photosynthetic Activity, Container Moisture and Growth in *Hibiscus rosa-sinensis* L.

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Index Words: gas exchange, drought, water use efficiency, water deficit

Significance to Industry: Water is a crucial resource in nursery crop production. Recent water shortages have made production difficult for horticultural enterprises. Identifying an irrigation model that uses water efficiently and that would be readily adoptable by growers would reduce excess water use, avoid nutrient leaching, and allow growers to better cope with drought. The proposed irrigation model uses photosynthesis as a sensitive gauge of plant water use. It is derived with a minimum of empirical data and uses a simple system to evaluate the use of container water content to trigger irrigation valves. It was determined that irrigating at the point prior to photosynthetic rate reduction decreased water usage without reducing plant growth.

Nature of Work: Water is critical to plant survival as a carrier for nutrients, a substrate in reactions, and the hydraulic force behind growth. Without sufficient water, photosynthesis, vegetative biomass, and yield are reduced (Kozlowski, 1979). Recently, the nursery industry has been severely impacted by drought (Ding et al., 2008). Regulations have restricted container irrigation in many major nursery production states and scientists and nursery producers predict a reduction in water availability for nursery crop production (Beeson et al., 2004).

Various methods can be used to model crop water use. The Penman-Monteith equation, stem heat balance, gravimetric techniques, soil moisture sensors, leaf temperature, and modeling based on empirically-derived plant characteristics have all been used to gauge water loss. However, irrigation technology based on crop models has not been adopted on a large scale by the nursery industry (Beeson et al., 2004). This is in part due to the diversity of nursery crops and the need to develop individual crop coefficients. Development of an irrigation model based on photosynthetic rates as an indicator of plant water status would require a minimum of data collection for model development and could easily be modified for use with other species. The objectives of this study were to develop and evaluate a photosynthesis-based irrigation model for *Hibiscus rosa-sinensis*.

Uniform cuttings of *H. rosa-sinensis* ‘Cashmere Wind’ were potted into trade one gallon (3.7 liter) containers (Nursery Supplies, McMinnville, OR) with MetroMix 280 (Sun Gro Horticulture, Bellevue, WA) one month prior to imposing treatments. Substrate moisture
levels were measured and controlled using ECHO-5 dielectric probes (Decagon Devices Inc, Pullman, WA) connected to a CR1000 datalogger (Campbell Scientific Inc., Logan, UT). Probes were installed perpendicular to the substrate surface, 1.96 inches (5 cm) from the sidewall, with the sensor overmold just below the substrate surface. Plants were watered then allowed to drain to container capacity. To determine the relationship between container water content and photosynthetic rate, photosynthesis was measured over a range of increasingly drier container moisture contents (100 to 45 percent of container capacity) by withholding irrigation. Single leaf gas exchange measurements were taken between 10 am and 2 pm with a LI-COR 6400 infrared gas analyzer (LI-COR, Lincoln, NE). Irrigation treatments were selected based on set points for container water content that corresponded to between 100 and 69 percent of maximum photosynthetic rates (Table 1). Irrigation valves were triggered when the average probe millivolt reading decreased below the set point. The irrigation valve remained open to deliver the volume of water necessary to return the container to container capacity.

Photosynthesis and leaf water potential were measured 3 times for each treatment, just prior to an irrigation event. Biomass was determined after 10 weeks and water use efficiency was calculated as the amount of water used per dry mass accumulation. The experiment used a completely randomized design with 4 irrigation treatments and 8 plants per treatment.

**Results and Discussion:** Photosynthetic rate remained relatively constant between approximately 11 and 18 moles of CO$_2$ m$^{-2}$·s$^{-1}$ until plants dried below 60 percent of container capacity (Figure 1). Sixty percent of container capacity corresponded to a leaf water potential of approximately -1.0 MPa. It is common for photosynthetic rates to remain high as plant water potentials decline until a critical point where stomates close (Boyer, 1970). Four irrigation set points between 89 and 61% of container capacity were established to evaluate the hypothesis that plant growth would not be affected by reduced substrate moisture until photosynthesis also declined. A photosynthesis-based irrigation model assumes that photosynthetic rate is a sensitive indicator of the water status of the plant, that growth would not be compromised due to a transient reduction in plant water potential, and osmotic adjustment, if it occurred, would only benefit plants grown under the model. A sigmoidal curve ($r^2 = 0.62$) was used to predict photosynthetic rates at each set point (Figure 1). The actual photosynthetic rates followed the predicted trends as indicated by percentage of maximum photosynthesis and mean prediction error (Table 1). However, the driest treatment did show a lower photosynthetic rate than was predicted as might be expected because this set point corresponds to a variable portion of the photosynthetic rate curve (Figure 1).

Photosynthetic rate, stomatal conductance, transpiration rate, and leaf water potential were not different for plants in the three wettest irrigation treatments but were reduced in the driest treatment (data not shown). Plants grown under the wetter treatments used 1.4, 1.2, and 1.05 times more water during the course of the experiment than plants in the driest treatment (data not shown). Total dry mass accumulation was 20.5, 22.3, 21.2, and 18.7 grams for the plants at the 89, 81, 69, and 61 percent of container
capacity treatments, respectively (data not shown). It is possible that a more severe reduction in dry mass did not occur for the driest treatment because plants were not subjected to a constant water deficit but rather maintained a container moisture content comparable with the other treatments for most of each irrigation cycle. Water use efficiency was significantly greater for the three driest treatments compared to the wettest treatment (Table 1). These data show that conservative irrigation schedules are possible without incurring a growth “penalty”.

A photosynthesis-based irrigation model was developed and evaluated for container-grown *Hibiscus rosa-sinensis*. Substantial water savings without a significant decrease in growth was achieved by selecting irrigation regimes for efficient water use. This research demonstrates a novel basis for irrigation that could be adopted by the nursery industry with minimal development of species-specific prerequisite data and with the potential for considerable water savings.

**Literature Cited:**

**Table 1. Evaluation of a photosynthesis-based irrigation model.**

<table>
<thead>
<tr>
<th>Setpoint (percentage of container capacity)</th>
<th>Predicted photosynthetic rate ($\mu$moles CO$_2$ m$^{-2}$·s$^{-1}$)</th>
<th>Percentage of predicted maximum photosynthesis</th>
<th>Actual photosynthetic rate ($\mu$moles CO$_2$ m$^{-2}$·s$^{-1}$)</th>
<th>Percentage of actual maximum photosynthesis</th>
<th>Water use efficiency (dry matter/water applied) g/l</th>
<th>lbs/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>14.7</td>
<td>100</td>
<td>13.9±0.66$^z$</td>
<td>100</td>
<td>1.62a$^y$</td>
<td>0.014a$^y$</td>
</tr>
<tr>
<td>81</td>
<td>14.7</td>
<td>100</td>
<td>14.0±0.43</td>
<td>100</td>
<td>2.18b</td>
<td>0.018b</td>
</tr>
<tr>
<td>69</td>
<td>14.4</td>
<td>98</td>
<td>13.6±0.52</td>
<td>98</td>
<td>2.32b</td>
<td>0.019b</td>
</tr>
<tr>
<td>61</td>
<td>10.3</td>
<td>69</td>
<td>8.17±0.90</td>
<td>58</td>
<td>2.13b</td>
<td>0.018b</td>
</tr>
</tbody>
</table>

$^z$mean prediction error is the square root of the summation of squared residuals divided by sample size.

$^y$means within a column followed by the same letter were not significantly different (Tukey’s HSD $a=0.05$)
Figure 1. Relationship between container moisture content and photosynthetic rate in container-grown *Hibiscus*. Line is predicted from 136 photosynthetic measurements taken over a range of container water contents. Photosynthesis=$14.6844/(1+\exp(-(\text{millivolts}-361.9237)/15.4806))$. 

Container Moisture Content  
(Percent of Container Capacity, Upper Abscissa)  
(Millivolts, Lower Abscissa)
Towards Precision Scheduling of Water and Nutrient Applications, Utilizing a Wireless Sensor Network on an Ornamental Tree Farm

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Index Words: real-time, cost-effective, data, irrigation, environmental, nutrient, management

Significance to the Industry: We have deployed a twelve-node commercial wireless sensor network (Decagon Devices Inc.; Pullman, WA), in two blocks of trees on a commercial tree farm near Frederick, Maryland. The sensor network is monitoring the soil water status at three depths within the root zone of six Acer rubrum 'Franksred' Red Sunset® and six Cornus florida 'Cherokee Princess' trees in real time. We are sensing soil temperature and soil electrical conductivity and measuring rainfall, irrigation water applications, air temperature, relative humidity and photosynthetically active radiation (PAR) on a 15-minute time interval for each block. The primary objectives of this study are to evaluate the performance of these sensors and the capability of the network to provide real-time data to the owner/irrigation manager, so that he can make more effective day-to-day decisions for the precise management of water and soluble nutrients to field-grown trees.

This study will continue for at least a two-year period. The ultimate objectives of this research are to determine whether these management systems are cost-effective in reducing input costs (including labor), and whether they improve water, nutrient and systemic insecticide uptake efficiency and minimize the environmental effects of production practices. Additionally, we would like to explore extending the life of the tree inventory on the farm, by optimizing initial growth rates, and at the appropriate time, to minimize water and nutrient inputs to slow tree growth and extend the “marketing window” of saleable trees. This paper provides information on the design and set-up of this sensor network, together with sensor calibration and operational data.

Nature of Work: Raemelton Farm is a historic farm once owned by Charles Carroll, a signatory to the Declaration of Independence. This 185-acre farm was originally a part of a 17,000 acre estate owned by Carroll and his heirs, located in Frederick County, Maryland. The present owner has established an ornamental tree farm on Raemelton, and is keenly interested in maintaining the sustainability of the farm, while minimizing
input and labor costs. A commercial (Decagon Devices, Inc.) twelve-node wireless sensor network was installed in two blocks of trees on the farm during March, 2008 (Fig. 1).

The sensor network is monitoring the soil water status at 15, 30 and 45-cm (6, 12 and 18-inch) depths within the root zone of six *Acer rubrum* ‘Franksred’ Red Sunset® and six *Cornus florida* ‘Cherokee Princess’ trees in real time (Fig. 2). Soil temperature and soil electrical conductivities are also being monitored at a 15-cm depth for several trees per block; additional sensors are monitoring rainfall, irrigation water applications, air temperature, relative humidity and photosynthetically active radiation (PAR) on a 15-minute time interval for each block, so that the owner can precisely manage water and nutrient applications. These specific blocks of trees were chosen since *Acer rubrum* represent a species with one of the largest water and nutrient requirements on the farm, while *Cornus florida* represent a slow-growing, lower input model species. As such, the average data from the sensors in each block will be used to make water management decisions for similar species on a day-to-day basis. Low-volume flow meters (Model A1; 1 - 10 L/min, Great Plains Industries, Wichita, KA) have been installed on the four irrigation laterals where the replicate trees are located within each block (n=4), to monitor irrigation water and fertigation applications. The intention is to irrigate three trees on one lateral based on current best management practices; the other three trees will be irrigated based on soil moisture sensor data from July, 2008, onwards. Monthly trunk diameter data, using dendrometers installed at 150-cm (*Acer rubrum*) and 50-cm (*Cornus florida*) trunk heights, are being taken to provide a non-destructive measure of plant growth over the season. This will be correlated with rainfall, irrigation water and nutrient applications per tree, to ascertain any significant growth differences between irrigation treatments.

**Results and Discussion:** Data is relayed from each Em50R sensor node in the field (Fig. 3) using a Data Station radio receiver [2] attached to a personal computer in the main farm office that communicates at a frequency of 2.4 GHz. The DataTrac software [3] provides an easy-to-use graphical environment to plot data from each sensor, over the time period of interest (Fig. 4). The software automatically organizes and stores the data from each sensor from each Em50R node in the field. Specific soil calibration data (Fig. 5) can be easily inputted into the software for each sensor, and reports with chart and summary statistic data can be easily created and saved as Portable Document Format (PDF) files for management or archival purposes. Data can also be edited and exported for use by other software programs.

Soil-specific calibration data for the predominantly silt-loam soils were calculated following the procedure outlined by Cobos in a Decagon application note, available online [1]. Briefly, three undisturbed soil cores were carefully extracted from the soil in the row of each block and brought to field capacity in the lab. Six EC-5 cm (2-inch) sensors were embedded in the center of each soil core and attached to a Campbell CR10X datalogger (Campbell Scientific, Logan UT). Soil cores were then slowly dried in an oven at 40°C over the next 8 days, until a constant dry weight was achieved. The weight of each soil core was taken at 14h00 every day, and the corresponding output value (mV) of the sensor noted at the same time. Data were plotted and the quadratic (best-fit) curve was fitted to the data (Fig. 5). The mean regression curve values were
then inputted into the DataTrac software for all EC-5cm sensors, to provide real-time soil water content data (Fig.4).

As can be seen from the illustrative data in Fig. 4, soil moisture values ranged from a low of about 23% to transient values over 45% during May 2008, depending on soil sensor depth. The data from the 15-cm sensor was highly variable over time, compared to the 30-cm and 45-cm sensors. While this larger variability in the upper root zone was not unexpected, the relatively rapid drawdown from 45% to 30% over 4 days following heavy rainfall (15-cm sensor; 12-16 May) was quite unexpected, but perhaps could be explained by the very good drainage characteristics of these specific silt loam soils on this farm. The rather high soil moisture content and the low variability at 45-cm depth was also interesting, possibly reflecting the higher clay content of the sub-soil at this depth. Drip irrigations were initiated on 28 May in the Acer rubrum block providing a total of 40 liters (10.5 gallons) per tree during that time (data not shown). Although not obvious from the Cornus florida data shown in Fig. 4, we have observed a clear drawdown of 6" soil moisture levels in the Acer rubrum block during warm, sunny days, with little drawdown at night. We expect that with this type of precision data, we should be able to better match specific irrigation requirements for trees during the hotter and typically drier months of summer. Soil temperatures at 6" depth in the Acer rubrum block averaged 13.7 C (11.2 C min; 16.4 Cmax) and 13.5 C (9.2 C min; 18.5 C max) in the row and in the grass aisle, respectively during May. Maximum PAR increased from about 950 to 1150 μmoles/m²/s during May, but notably, there were six days where the maximum PAR was less than 650 μmoles/m²/s (Fig. 4).

Although the data that we have gathered thus far from this sensor network is relatively limited, it can be seen that this type of technology has the capability to provide growers with site-specific data that can greatly aid irrigation and other management decisions. Over the next two years, we will be gathering additional data to provide growers with information on the cost-effectiveness of these systems. Our goal is to help growers improve the efficiency of sustainable production practices, maximize the yield and quality of their products, and the profitability of the farm.

Literature Cited:

Acknowledgements: We gratefully acknowledge funding from the Horticultural Research Institute of the American Nursery and Landscape Association, the Chesapeake Bay Trust and the Maryland Department of Agriculture, whose support has made this research possible.
Fig. 1. Aerial view of Raemelton farm, showing approximate location of *Cornus florida* (A) and *Acer rubrum* (B) blocks, and where the sensor nodes are located within each block. The radio receiver and computer are located in the main office (C).

Fig 2. Location of Em50R nodes 1-3 in the *Acer rubrum* block. The pipe in the soil houses the three embedded EC-5 / Ech20-TE sensors at 6, 12 and 18-inch depths in the root zone (inset).

Fig 3. Em50R node (#7) with PAR sensor and tipping rain gauge shown in the background in the *Cornus florida* block. The radio antenna is mounted on the top of the node (slightly obscured).
Fig 4. Ech20-DataTrac software graphical interface, showing example data from Em50R node #7 for May, 2008. Soil EC-5 moisture sensor data indicated by arrows; Vertical bars represent precipitation data in 0.05 inch increments during each rainfall event (illustrates rainfall intensity); Photosynthetically-active radiation (PAR) data are plotted in 15-min increments throughout each day.
Fig 5. Soil calibration data for five soil cores from Raemelton farm; the Maple 1 soil core values were discarded due to a datalogger malfunction. EC-5cm soil moisture sensor output (mV) is plotted against the percent volumetric water content of each soil core (mol / mol), weighed daily. The fitted quadratic regression was very highly significant (P > 0.0001). Mean regression values were inputted into the EchoTrac software and were used to provide quantitative soil water content data from the soil sensors in the two blocks (n=18 per block).