Water Management

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Effects of Substrate and Irrigation Salinity on the Growth of *Sophora secundiflora* and *Cercis canadensis var. Mexicana*

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**Index Words:** Mexican redbud, salt stress, Texas mountain laurel, saline water irrigation

**Significance to Industry:** Texas mountain laurel (*Sophora secundiflora* (Ortega) Lag. ex DC.), native to Texas, New Mexico and Northeastern Mexico, is an evergreen shrub and well adapted to high temperatures, well drained alkaline soil and full sun. Mexican redbud (*Cercis canadensis* var. *mexicana* (Rose) E. Murr.) is a native landscape plant for many Southern and Western states. Due to the decreasing availability of high quality irrigation water, information on salt tolerance of landscape plants is of increasing importance. Root zone salt accumulation depends not only on the salinity level of irrigation water, but also on type of substrate or soil used. Therefore, quantifying the effect of saline irrigation water and substrate type on performance of popular landscape shrubs and trees would help improve irrigation management practices using poorer quality, higher salinity water.

**Nature of Work.** Seeds of Texas mountain laurel, treated with concentrated sulfuric acid for 30 min, were sown on 20 Nov. 2006 in plug cells (63 mL) filled with a germination mix of perlite, vermiculite and peat moss at 1:1:1 (by vol.). Seedlings were transplanted on 17 Jan. 2007 to 6-in pots containing Sunshine mix #4 (SunGro Hort., Bellevue, WA) and composted mulch (Western Organics, Inc., Tempe, AZ) at 1:1 (by vol.) amended with 5 kg·m⁻³ dolomitic limestone (Carl Pool Earth-Safe Organics, Gladewater, TX) and 1 kg·m⁻³ Micromax (Scotts, Marysville, OH). Mexican redbud seeds were scarified on 29 Nov. 2006 with concentrated sulfuric acid for 30 min followed by cold treatment at 4 °C for two months before germination. The same germination medium and growing substrates for Texas mountain laurel were used for Mexican redbud. From early May to mid-September 2007, plants were grown in a shade house with 25% light exclusion. On 2 Oct. 2007, plants of both species were transplanted to 2.6 L pots containing two types of substrates described below.

Since both species prefer well-drained soil, two substrates were formulated by mixing Sunshine mix #4 with composted mulch at 1:1 or 1:4 (by vol.) amended with 5 kg·m⁻³ dolomitic limestone and 1 kg·m⁻³ Micromax. A control nutrient solution was made by adding 0.5 g·L⁻¹ of 20 N–8.6 P–16.7 K (Peters, Scotts, Allentown, PA) to tap water creating an electrical conductivity (EC) of 1.6 dS·m⁻¹. The major ions in the tap water were Na⁺, Ca²⁺, Mg²⁺, Cl⁻, and SO₄²⁻ at 184, 52.0, 7.5, 223.6, and 105.6 mg·L⁻¹,
respectively. Solutions of moderate and high salinity levels (EC of 3.0 and 6.0 dS·m⁻¹) were created by adding appropriate amounts of sodium chloride (NaCl), magnesium sulfate heptahydrate (MgSO₄·7H₂O), and calcium chloride (CaCl₂) at 87:8:5 (by weight) to the nutrient solution. The composition of the treatment saline solutions was similar to that of the reclaimed water of local water utilities. A 100-L tank of saline solution was prepared each time for each treatment with confirmed EC. Plants were hand-watered when needed. The saline solution irrigation was initiated on 31 Oct. 2007 and terminated on 15 April 2008 for Mexican redbud and 12 May 2008 for Texas mountain laurel. On day 145, all containers were flushed with tap water to leach out the salts accumulated in the substrates since salt accumulation is common in peat-based growing media and in clay soils. After that, leaching fraction was increased to 30% ~ 50%.

Plant height and shoot growth were recorded four times during the experiment. Leachate was collected for EC measurement on a monthly basis. Upon termination, plant height, the number of shoots and the total length of shoots were recorded. Shoot dry weight (DW) was determined after being oven-dried at 70 °C to constant weight. Data were analyzed separately by species. For each species, the experiment was a split-plot design with irrigation water as the main plot and the substrate as subplots with 10 replications. All data were analyzed by a two-way ANOVA using PROC GLM (Version 9.1.3, SAS Institute Inc., Cary, NC).

Results and Discussion. There were no interactions between the salinity of irrigation water and the type of substrate and no differences between the two substrates were found in any growth parameter and leachate EC for either species. Therefore, data were pooled across the two substrates. Leachate EC increased with time in all treatments for both species due to a lower leaching fraction (around 10%) (Fig. 1). Six weeks after the initiation of saline water treatments, leachate EC was 2 to 4 dS·m⁻¹ higher than that of irrigation solution. By day 140, the leachate EC was more than twice the EC of the irrigation solutions. In the present study, the components were similar for the two substrates, which led to similar salt accumulation. In addition to the type of substrate, leaching fraction and plant species affected leachate EC when plants were irrigated with saline solutions (1, 3, 4).

For Texas mountain laurel, plant height was not affected in the first three months by the salinity of irrigation water (Fig. 2). Six months after the initiation of saline water irrigation, plants were shorter when irrigated at 6.0 dS·m⁻¹ compared to the control and those irrigated at 3.0 dS·m⁻¹. Regardless of treatment, plants did not develop new shoots until the late part of the experiment and no differences were found among treatments in the number of shoots (data not shown). The final total shoot length at 3.0 dS·m⁻¹ and 6.0 dS·m⁻¹ was similar and was reduced by 40% compared to the control. Shoot DW at 3.0 dS·m⁻¹ and 6.0 dS·m⁻¹ was reduced by 25% and 46%, respectively, compared to the control. Similar results were observed for the total DW. Root DW of plants irrigated at 6.0 dS·m⁻¹ was reduced compared to the control.
For Mexican redbud, salinity of irrigation water affected the plant growth as early as three months after the initiation of the treatments (Fig. 3). Plants irrigated at 3.0 dS·m⁻¹ and 6.0 dS·m⁻¹ were shorter and shoot growth was slower compared to the control. Total and shoot DW of plants irrigated at 3.0 dS·m⁻¹ and 6.0 dS·m⁻¹ were reduced by more than 50% and root DW by 50% compared to the control. Salinity of irrigation water did not affect the number of shoots (data not shown).

Salinity tolerance can be evaluated by observing reductions in crop growth, yield, and/or quality induced by salinity stress. According to this criterion, Mexican redbud was less tolerant to salinity stress compared to Texas mountain laurel. In addition to salinity of the irrigation water, salinity tolerance was affected by growing conditions (2, 5). This experiment was conducted in the greenhouse during winter time when the light and temperature were relatively low, which could have limited water uptake by the plants. These plants may show growth reduction earlier if they are irrigated with the same saline solutions under higher temperature and light conditions.

Literature cited
Fig. 1. Leachate electrical conductivity (EC) of Texas mountain laurel (*Sophora secundiflora*) and Mexican redbud (*Cercis canadensis* var. *mexicana*) irrigated with water at EC of 1.6, 3.0, or 6.0 dS·m$^{-1}$ (control, EC 3, or EC 6). Vertical bars represent standard errors.
Fig. 2. Plant height, total shoot length (length of all shoots), dry weight of shoots, roots, and total of Texas mountain laurel (*Sophora secundiflora*) irrigated with water at EC of 1.6, 3.0, or 6.0 dS·m⁻¹ (control, EC 3, or EC 6). Means with same letters were not significantly different by Student-Newman-Keuls multiple comparison at $P = 0.05$. NS indicates nonsignificance. Vertical bars represent standard errors.
Fig. 3. Plant height, total shoot length (length of all shoots), dry weight of shoots, roots, and total of Mexican redbud (Cercis canadensis var. mexicana) irrigated with water at EC of 1.6, 3.0, or 6.0 dS·m⁻¹ (control, EC 3, or EC 6). Means with same letters were not significantly different by Student-Newman-Keuls multiple comparison at $P = 0.05$. NS indicates nonsignificance. Vertical bars represent standard errors.
An ETo-based Canopy Closure Model that Successfully Grows Medium Water Requiring Woody Shrubs

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Index Words: Nursery production, automated irrigation, container production, water conservation

Significance to industry: Irrigation controlled by local weather conditions can be more precise than time clock or manual control. Using algorithms and on-site weather station data eliminates the need for substrate moisture sensors and can be tailored to different crop sizes and species with little additional instrumentation. The system described here successfully produced a crop of Ligustrum japonica of commercial quality and within a normal commercial period with only triweekly manual inputs of average plant width.

Nature of Work: In mid-March 2005, rooted cuttings of Ligustrum japonica were transplanted into #3 containers at the Mid-Florida Research and Education Center in Apopka. The substrate was a commercially prepared blend (Florida Potting Soil, Inc., Apopka, FL) consisting of 70% pine bark fines: 30% Florida sedge peat: 10% sand, amended with dolomite and micro-nutrients. Ninety-six containers were placed on ground cloth within each of 8 production areas where overhead irrigation was independently controlled and metered. Plants were initially placed pot-to-pot and topdressed with 2 oz of 18-6-13 Polyon (Harold’s Fertilizer Inc.) and the recommended rate of OH II (Scotts Co., Marysville, OH). Prior to plant placement, sprinkler heads were adjusted to a minimum Christiansen Uniformity Coefficient of 0.85 and application rates were calculated for each pad. The first 3 weeks after transplanting, all plants were given 0.25 inches of overhead irrigation daily to establish the liners. Thereafter irrigation was automatically controlled for half the pads or adjusted manually. Automatic control used a computer system that received input from onsite weather sensors (Beeson, 2004). These meteorological variables were used to calculate reference evapotranspiration (ETo) each midnight. ETo is an estimate of the depth of water loss from a theoretical short grass crop under the same environmental conditions. This concept was established in the late 1990’s for consistent calculation of ETo worldwide (Allen et. al., 1998). ETo was then utilized in a irrigation algorithm to calculate required irrigation application rates for each of 4 production pads. The algorithm is based on changes in plant transpiration related to canopy size and canopy closure. Canopy closure was simply an estimation of the average percentage of bed area covered by plant canopies. It was calculated as the average canopy width of 10 plants, squared, then divided by bed area allocated to each plant. Allocated bed area using the square configuration was simply the distance on center between two containers squared. With small plants the percent was as little as 12%, but increased up to 250% as plants grew and canopies overlapped. Irrigation of manual control pads was adjusted every 3 weeks, balancing between the 70 inch annual allocation allotted to nurseries in...
Southwestern Fla., and maintaining growth similar to algorithm irrigated plants. Rainfall occurring during the previous 24 hr was deducted from calculations of daily irrigation need. Canopy measurements of average widest width, the width perpendicular to average widest width and average height were recorded on 10 plants within each production pad generally every 3 weeks. These were multiplied together to calculate a canopy volume (GI, m³). Additionally, mean canopy widths required by the algorithm were calculated. Cumulative irrigation depth, and growth measurements (height, GI, average width and projected canopy area) were analyzed as a split-split plot, with irrigation treatment as the main plot, blocks as the subplot and time as the sub-sub plot (Snedor and Cochran, 1980). Final harvest data was analyzed as a factorial, with 2 irrigation treatments x 4 blocks with 10 plant replicates each.

Irrigation regime had no effect on shoot height nor increases in canopy volume (data not shown). Both average canopy width and projected canopy area (width 1 x width 2) were comparable between the algorithm and control regimes throughout the production period.

While there were no differences in plant growth, cumulative irrigation depth applied varied (P>0.05) between the two treatments (Fig.1). By 85 days after transplanting, cumulative irrigation based on the algorithm was less than that applied by the manual control. This difference remained through the end of the production period. Over the latter half of the experiment’s duration, rainfall was exceptionally low, both in frequency and quantity (data not shown). This was especially prominent from early fall (September, ca. day 290) through final harvest in late April to mid-May. Low rainfall likely caused more irrigation of the algorithm treatments than would have been expected under average rainfall years and likely extended the production time of the manual control plants.

Treatments were considered to have obtained commercial maturation when at least 85% of measured plants met or exceeded canopy dimension of 18 in. average width and 24 in. average height (Gaskalla, 1998). Plants under algorithm control achieved this marketable percentage in 418 days with an average cumulative irrigation depth of 66.7 in (Fig. 1). It took an additional 2 weeks for manual control plants to obtain 85% marketable size. These plants were harvested after receiving 83 in. of supplemental irrigation, an additional 16 inches over the production time span.

Irrigation was more efficient in producing plant growth using the algorithm than by manual control (Fig. 2). This began after 20 inches of irrigation had been applied and continued until nearly 40 cumulative inches of irrigation. During this span, the GI was higher, indicating greater canopy volume for plants irrigated with the algorithm relative to the manually controlled treatment. This differential returned in the Spring (> 40 inch) when growth of algorithm irrigated plants initiated sooner and were irrigated more proportion to their growth than the control plants.
Literature Cited


Figure 1. Mean cumulative irrigation depth applied to each irrigation regime of *Ligustrum japonica* during production from March 2005 to May 2006. Algorithm irrigated plants are circles while control plants are triangles.
Figure 2. Mean canopy volumes as a function of cumulative irrigation for algorithm (circle) and manual control plants (triangle) of *Ligustrum japonica*. At harvest (last point each treatment), at least 85% of measured plants had obtained marketable size for #3 containers.
Daily Water Use of Abutilon and Lantana at Various Substrate Water Contents

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Index Words: Perennials, automated irrigation, modeling

Significance to Industry: Efficient water use and better irrigation control are increasingly important in ornamental production. To ensure production of high quality plants (and profits), sufficient irrigation is critical. However, excessive irrigation can reduce profits and result in unwanted leaching, runoff, and poor plant quality. Little information is available about the water needs of plants. We used an automated irrigation system which allowed control and quantification of daily water use to quantify environmental effects on daily water use (DWU) of plants. Abutilon and lantana used more water, and had larger leaves and more shoot dry matter at higher volumetric substrate water contents ($\theta$). DWU was positively correlated with days after planting (DAP), daily light integral (DLI), and maximum vapor pressure deficit ($\text{VPD}_{\text{max}}$). A regression model using these parameters can predict the proper amount of irrigation for abutilon and lantana, and can make their irrigation more efficient.

Nature of Work: Efficient irrigation can save water, while increasing plant growth and quality. However, little information is available regarding the water requirements of ornamental plants. A recently-developed automated irrigation system, based on user-defined set points for substrate water content, makes accurate irrigation control possible (Nemali and van Iersel, 2006) and facilitates studies of plant water requirements. The objective of this work was to quantify the effects of $\theta$ and environmental conditions on plant growth and water needs.

Rooted cuttings of Lantana camara ‘Silver Mound’ and Abutilon x hybridum ‘Fairy Coral Red’ (James Greenhouse, Colbert, GA) were transplanted into 8 L trays (6 cuttings per tray), filled with soilless substrate (60% peat – 40% perlite, Fafard 2P, Fafard Anderson, SC) mixed with 30 g of slow-release fertilizer (Osmocote 14-14-14; The Scotts Co., Marysville, OH). Plants were grown in a greenhouse and irrigated with an automated irrigation system (Nemali and van Iersel, 2006), which maintained $\theta$ at 0.08, 0.14, 0.20, 0.26, 0.32, 0.38, 0.44, or 0.50 m$^3\cdot$m$^{-3}$ (v/v). A datalogger recorded the DWU of each group of plants. Temperature, relative humidity (RH), and $\text{PPF}$ were measured throughout the experiment, and the daily light integral (DLI) was calculated from the $\text{PPF}$ measurements. $\text{VPD}_{\text{max}}$ was calculated from the maximum temperature and the minimum relative humidity. At 67 DAP, plants were harvested and shoot dry weight and the area of 10 full-grown leaves per tray were measured.
The experimental utilized a randomized complete block design with a split plot (two species), two blocks, and eight \( \theta \) treatments. The experimental unit was a group of 6 plants in a single container. The effects of \( \theta \) on plant growth were tested with linear regression. To determine the effect of plant age and environmental conditions on DWU of plants grown at a \( \theta \) of 0.50 m\(^3\)·m\(^{-3}\), multiple regression was performed (Proc GLM, SAS Systems, Cary, NC). Backward selection was used to select the significant parameters (\( P < 0.05 \)) to include in the model.

**Results and Discussion:** The irrigation system kept \( \theta \) close to the set points during most of the experiment (Fig. 1). Unfortunately, irrigation was not controlled during a 9-day period because of an electrical problem. Plant growth of both species was affected by \( \theta \). Both species used more water, and had larger leaves and higher shoot dry matter at higher \( \theta \) (Fig. 2). Water use increased from approximately 4 to 10 L/plant as \( \theta \) increased from 0.08 to 0.50 m\(^3\)·m\(^{-3}\). Low \( \theta \) reduced leaf elongation (smaller leaves) and dry weight of both species was reduced by about 50% at a \( \theta \) of 0.08 as compared to 0.50 m\(^3\)·m\(^{-3}\). However, even at 0.08 m\(^3\)·m\(^{-3}\) plants never wilted since they regularly received water. When water availability decreases, turgor potential typically decreases, thereby inhibiting cell elongation, leaf expansion, and plant growth. Gaura, salvia, and marigold also were smaller when exposed to drought (Burnett and van Iersel, 2008; van Iersel and Nemali, 2004). Mild drought stress can be used as a cultural method for the control of plant size, but when the drought stress is too severe, plant quality decreases. Thus, precise irrigation control can be used to improve quality, while assuring efficient water use.

At a \( \theta \) setting of 0.50 m\(^3\)·m\(^{-3}\), DWU ranged from 20 to 300 mL/plant and was strongly correlated with DAP, DAP\(^2\), and DAP×DLI (\( r > 0.7 \), \( P < 0.0001 \)) and was less correlated with VPD\(_{\text{max}}\) (\( r = 0.4 \), \( P < 0.0001 \)). More interactions and environmental variables were tested in multiple regression analysis but were removed from the model because they did not improve the model fit. In the lantana model, there were systematic differences in DWU among the two trays with a \( \theta \) set point of 0.50 m\(^3\)·m\(^{-3}\), which was accounted for by a tray-specific variable. DWU could be modeled accurately based on environmental conditions and DAP:

- **Abutilon:**
  \[
  \text{DWU} = (4.63 + 0.888 \times \text{DAP} + 0.0090 \times \text{DAP} \times \text{DLI} - 0.0116 \times \text{DAP}^2 + 1.62 \times \text{VPD}_{\text{max}})^2
  \]
  \( (r^2 = 0.95) \)

- **Lantana:**
  \[
  \text{DWU} = (9.17 + 0.456 \times \text{DAP} + 0.0112 \times \text{DAP} \times \text{DLI} - 0.00568 \times \text{DAP}^2 + 1.79 \times \text{VPD}_{\text{max}})^2
  \]
  \( (r^2 = 0.94) \)

All model variables were highly significant (\( P < 0.0001 \)). DWU increased with increasing DAP, because of an increase in plant size over time. DWU also increased with increasing DLI and VPD\(_{\text{max}}\), which is not surprising since light affects stomatal opening and VPD is the driving force for transpiration. There was a strong correlation between DWU and the estimated DWU from the above equations (\( P < 0.0001 \), \( r^2 = 0.96 \)) (Fig. 3). The required environmental data for these models can be easily acquired from simple
weather stations, and this model may provide growers estimates for the required irrigation volume. Although these models fit excellently under these experimental conditions, more experimental data are needed to develop models with wider applicability. Nonetheless, our results suggest that it is possible to estimate the daily water requirements of plants from simple environmental parameters.

**Literature Cited:**


![Fig. 1. Volumetric water content of the substrates over the course of the experiment. Dotted lines indicate the substrate water content at which the irrigation was turned on (set points). Note that the irrigation system failed on May 10, and plants were not irrigated from May 10 - May 20.](image-url)
Fig. 2. Leaf area (top), shoot dry weight (middle), and cumulative irrigation amount (bottom) of lantana and abutilon at substrate water contents ranging from 0.08 to 0.50 m$^3$·m$^{-3}$.
Fig. 3. Daily measured and modeled water use over the course of the experiment (top) and a regression of measured versus modeled DWU of abutilon (bottom).
Soil Moisture Sensor-Based Irrigation Reduces Water Use and Nutrient Leaching in a Commercial Nursery

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Index words: hydrangea, runoff, substrate water content

Significance to Industry: High quality irrigation water is becoming increasingly scarce and it is becoming more important to use the available water efficiently. One approach to more efficient irrigation is the use of soil moisture sensors to control irrigation. Soil moisture sensors can detect when the substrate water content drops below a grower-defined set point and can be used to automatically turn on the irrigation when needed. Using this approach on a hydrangea crop in a commercial nursery from May 6 – July 23, 2008 resulted in large water savings: plots irrigated using standard irrigation practices used 133,000 gallons during this period, as compared to only 23,300 gallons for plots with soil moisture sensor-controlled irrigation. Excessive irrigation in the control plots also resulted in more nutrient leaching: on June 13, substrate EC in control plots was 0.94 mS/cm, while substrate EC in soil moisture sensors-controlled plots was 1.51 mS/cm. Thus, soil moisture sensors are a highly effective tool for reducing both water use and nutrient leaching.

Nature of Work: Continuing population growth and increased urbanization threaten water availability for agriculture, including greenhouses and nurseries. Thus, efficient water use is increasingly important. More efficient irrigation practices not only reduce water use, but also save energy and reduce leaching and runoff of fertilizer. In addition, better water management may reduce the incidence of root diseases and may be used for growth control (Burnett and van Iersel, 2008). One method for improving irrigation practices is the use of soil moisture probes to open and close solenoid valves based on the amount of water in the substrate. The objective of this work was to quantify water savings that can be achieved using soil moisture probes for irrigation control.

Seven bays in an unheated greenhouse at a large commercial nursery were used for this research in spring and summer of 2008. Each bay contained several hundred ‘Mini Penny’ hydrangeas in #2 containers filled with a bark-based substrate. Irrigation in four of the seven 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. Since these controllers use a single probe, irrigation in each bay was controlled based on the substrate water content in a single container.
The irrigation controllers were set to come on when the substrate water content dropped below approximately 0.20 m$^3$·m$^{-3}$. To prevent irrigation at night and keeping the foliage wet, the Moisture Clik controllers were connected to a timer to power the controllers from 8 am to 5 pm. Irrigation in the other three bays was controlled by nursery personnel, according to their regular irrigation practices. Each bay was equipped with a water meter, and irrigation volumes were recorded with dataloggers. Two soil moisture probes (EC-5, Decagon, Pullman, WA) were installed in each plot and connected to dataloggers (EM50, Decagon) to monitor the substrate water content. Substrate solution EC was measured with a SigmaProbe (Delta T devices, UK) on June 13. Other than irrigation, plants were produced using the standard cultural practices of the nursery.

Results and Discussion: Water savings from soil moisture sensor-controlled irrigation became apparent quickly (Fig. 1, top). During the first 10 days of the experiment, control plants received approximately 6200 gallons/bay, while plants irrigated using the Moisture Clik controllers received less than half of that amount. The Moisture Clik controllers also proved to be the more reliable system, since control plants did not get irrigated on May 17 and 18 (a weekend), during which the substrate water content in control plots dropped to as low as 0.05 m$^3$·m$^{-3}$ (Fig. 2). A more detailed look at the irrigation data shows that control plants were watered using a timer. On May 14, irrigation in the control plots came on for 20 minutes every hour from 8 am to 12 pm. Control plots received approximately 1200 gallons during this period, while Moisture Clik-controlled plots received less than 200 gallons during this same period. Differences in water use between the two treatments became larger during the summer, as the frequency of irrigation in the control plots was increased. Over the course of the experiment (May 6 – July 23), control plots received 133,500 gallons of water compared to 23,270 gallons in Moisture Clik-controlled plots, a savings of 83%. Overall, substrate water content in Moisture Clik-controlled plots was more stable than that in control plots (Fig. 2). Moisture Clik controllers not only reduced water use, but also reduced leaching. Substrate solution EC on June 13 was 0.94 mS/cm in control plots as compared to 1.51 mS/cm in Moisture Clik-controlled plots, indicating that more fertilizer had been leached out of control pots. Overall, these findings are similar to those of Ristvey et al (2004), who showed that using TDR probes for irrigation control resulted in water savings of 60-85% (with similar reductions in leaching of N and P) compared to cyclic irrigation.

Shoots of 16 plants per plot were harvested at the end of the experiment, and no differences in shoot dry weight or marketability were observed. However, these data may not be completely reliable, since all plants were pruned in early July, which may have masked differences in growth that could have occurred before then. An unexpected side effect of the Moisture Clik controllers was a drastic increase in weed pressure. We suspect that the excessive irrigation in control plots may have resulted in a water-logged soil and low survival of weed seedlings. Reducing the irrigation volume may have created more favorable conditions for weeds. Overall, this study shows that soil moisture sensors can be used in commercial nurseries to control irrigation. This
can result in major water savings, although the exact magnitude of savings is likely to differ among nurseries due to differences in irrigation practices and crops. Future research will also address whether soil moisture sensors can be used to impose a mild, controlled drought stress that might reduce stem elongation and decrease the need for plant growth retardants.

**Literature Cited**

Figure 1. Comparison of irrigation volume using standard nursery practices (control) and using a Moisture Clik irrigation controller. The Moisture Clik applies water based on substrate water content. The top figure shows water use during a 10-day period, while the bottom figure provides more detailed data for a single day.
Figure 2. Substrate water content of hydrangeas irrigated using standard nursery practices (control) or irrigated using a Moisture Clik irrigation controller as measured with EC-5 soil moisture probes over a 2½ month period. Note that the Moisture Clik results in much more stable water contents in the substrate.
Cornus, Gas Exchange, and Drought

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Index Words: water deficit, water use efficiency, dogwood, C. kousa, C. florida, Constellation®, ‘Cherokee Princess’, ‘National’, nursery, irrigation

Significance to Industry: Water is a limiting resource for nursery crop production. An irrigation model that could be transferred across species would be readily adoptable by growers and, hence, would minimize 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 and is derived with a minimum of empirical data. This research suggests the model is transferrable to other woody species at least for certain photosynthetic targets, but further research is needed.

Nature of Work: Numerous techniques 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 determine water loss. Unfortunately, irrigation technology based on crop models has not been adopted on a large scale by the nursery industry (Beeson et al., 2004). The diversity of nursery crops and the need to develop individual crop coefficients has contributed to low adoption of existing technology. Previously, an irrigation model based on photosynthetic rates as an indicator of plant water status was developed using Hibiscus rosa-sinensis as the model crop, with the hypothesis that the model could be easily modified for use with other species (Fulcher et al., 2008). Specifically, an irrigation model was based on the relationship between substrate moisture content and photosynthetic rate. The relationship was a sigmoidal curve with a wide range of substrate moisture contents supporting maximum or near maximum photosynthetic rates (Figure 1). A setpoint was established which reflected the substrate water content at which photosynthesis began to drop, which corresponded with a reduction in stomatal conductance.

Dogwood is an ideal species to test to what extent a simple photosynthesis–based irrigation model is transferrable for several reasons. Dogwood is a valuable nursery crop, increasing the relevancy of the research (USDA, 1997). Dogwood hybrids and parents are available in the trade. Using two species and their hybrid facilitates an assessment of how similarly or differently related plants use water, which serves as an indication of how transferrable the model is. Based on the literature, sensitivity to water stress differs for dogwood taxa and thus water requirements and irrigation models may vary across taxa (Dirr, 1998).
The objectives of this research were 1) to determine the relationship between photosynthesis and substrate moisture content for two dogwood species (C. kousa 'National' and C. florida 'Cherokee Princess') and their hybrid (C. x Constellation®), and 2) to determine if multiple setpoints are necessary for the three taxa as a gauge of model transferability.

In February 2007, 30-36" bareroot liners of 'National', 'Cherokee Princess', and Constellation® were potted with a bark-based substrate into trade seven gallon containers and grown in a pot-in-pot system with cyclic irrigation. Plants were fertilized with 90 grams per plant of 19-4-8, 5-6 month release complete fertilizer (Harrell’s, Inc. Sylacauga, AL) each April. On August 19, 2008, ECHO-5 moisture probes (Decagon Devices, Pullman, WA) were installed vertically, midway between the sidewall of the container and the trunk, and so that the overmold was two inches below the surface of the substrate. Plants were hand watered, drained to container capacity, and bagged and sealed around the trunk utilizing a previously tested technique that allowed minimal evaporative water lost and excluded irrigation and rainwater. Substrate moisture content, stem water potential, and gas exchange were measured under initial, well-watered conditions and daily while water was withheld, except for the second day of the experiment when data were collected twice. Plants were watered after four days of withholding water, terminating the drought treatment. Containers were weighed to determine the relationship between probe values for water content and actual substrate water content. The experiment used a completely randomized design with seven treated and five control replicate plants per taxa. Data were subjected to statistical analyses (SAS Institute, Inc., Cary, NC).

Results and Discussion: There was a strong correlation between container weight and substrate moisture content (Substrate Moisture Content = 78.9175+ 16.7668*Container Weight), $r^2=0.85$, (data not shown). This indicates probe placement was satisfactory for representing total container moisture content. The use of pot-in-pot eliminated the confounding factor of high root zone temperature, which often accompanies drought stress and container production.

The relationship between container moisture content and photosynthetic rate for ‘Cherokee Princess’, ‘National’ and Constellation® was characterized by a three parameter sigmoidal curve for each taxon although none were as distinct as that of Hibiscus ‘Cashmere Wind’ (Figure 1). For ‘National’ there was a relatively steady decrease in photosynthesis as substrate moisture level decreased. Constellation® had a relatively high photosynthetic rate at the onset of the experiment (Figure 1 and Table 1) and was able to maintain a higher photosynthetic rate as the substrate dried. The high initial photosynthetic rate corresponds with unpublished light curve data for Constellation®. ‘Cherokee Princess’ had a relatively gradual decline in photosynthetic rate as substrate moisture decreased. Constellation® and ‘Cherokee Princess’ were able to maintain high photosynthetic rates relative to their maximum early in the drought stress when compared with ‘National’. When substrate moisture content decreased to approximately 82%, photosynthesis decreased by approximately half for all three dogwood taxa. The relationship between photosynthesis and substrate moisture
content curves did not closely parallel the sigmoidal curve for hibiscus where photosynthesis was maintained at high levels over a range of moisture conditions. Hibiscus maintained maximum photosynthetic rates until substrate moisture content decreased to 65% of container capacity, dogwood photosynthetic rates began to decline at approximately 93% of container capacity.

In order to determine if one setpoint could maintain a common substrate moisture level that maximized photosynthesis for the three taxa, the predicted photosynthetic rate (80% of maximum) and the corresponding substrate moisture levels were calculated for each replicate taxa. There was no significant difference in substrate moisture levels. A substrate moisture content of on average 86% container capacity maintained photosynthetic rates at 80% of maximum for all three taxa (Table 2). This suggests that one irrigation setpoint is sufficient for all three taxa. However, further calculations will need to be made to determine if this is true at all moisture levels.

The relatively rapid decline in photosynthetic rates for all three taxa was contrary to previous experiments conducted in a controlled environment with *C. kousa* and *C. florida*. In these experiments the relationship between substrate moisture content and photosynthetic rate exhibited a similar curve as seen in hibiscus, with a wide range of substrate moisture contents supporting maximum or near maximum photosynthetic rates (data not shown). Gas exchange and vapor pressure (VPD) data taken during both sets of experiments suggest that the extremely high VPD during the outdoor experiment caused a substantial decrease in stomatal conductance, reducing not only photosynthesis but also transpiration. These putative environmental impacts on photosynthesis present a challenge to transferability of the photosynthesis-based irrigation model from controlled environment to outdoor settings and perhaps across climatic regions.

A photosynthesis-based irrigation model was developed and evaluated for container-grown dogwood taxa. At least on a limited basis, the photosynthesis-based model is transferrable to these dogwood taxa. Further research is necessary to determine to what extent the model is transferrable to these dogwood taxa and to other woody plants.

**Literature Cited:**
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=$14.6844/\left(1+\exp\left(-\frac{\text{millivolts}-361.9237}{15.4806}\right)\right)$. 

Substrate Moisture Content
(Percent of Container Capacity, Upper Abscissa)
(Millivolts, Lower Abscissa)
Figure 2. Relationship between photosynthetic rate and substrate moisture content for two dogwood species and their hybrid. Each species was fit with a sigmoidal three parameter equation.

*C. kousa* 'National' (red), $r^2 = 0.74$

*C. florida* 'Cherokee Princess' (blue), $r^2 = 0.70$

*C. x Constellation®* (orange), $r^2 = 0.74$
Table 1. Development of a photosynthesis-based irrigation model for three dogwood taxa.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Predicted Maximum Photosynthetic Rate (µmol CO₂ m⁻²·s⁻¹)</th>
<th>Substrate Moisture Content at Predicted Maximum Photosynthetic Rate (mV)</th>
<th>80% Predicted Maximum Photosynthetic Rate (µmol CO₂ m⁻²·s⁻¹)</th>
<th>Setpoint 80% Predicted Maximum Photosynthetic Rate (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CherokeePrincess</td>
<td>9.4</td>
<td>550</td>
<td>7.5</td>
<td>477a²</td>
</tr>
<tr>
<td>Constellation</td>
<td>13.1</td>
<td>548</td>
<td>10.5</td>
<td>469a</td>
</tr>
<tr>
<td>National</td>
<td>10.9</td>
<td>550</td>
<td>8.7</td>
<td>487a</td>
</tr>
</tbody>
</table>

ANOVA P value 0.6285

²Means followed by the same letter were not significantly different (Tukey's HSD alpha = 0.05).
Deployment of Wireless Sensor Networks for Irrigation and Nutrient Management in Nursery and Greenhouse Operations

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\textbf{Index Words:} field, soil, soilless, container, water, matric potential, Decagon, Ech\textsubscript{2}0

\textbf{Significance to the Industry:} Concerns over drought and water availability from groundwater or surface reservoirs, water quality, nutrient and chemical runoff, capture and recycling issues and various local, state and federal regulations all are focusing us in one way or another on the quantity and quality of water that will be available for ornamental plant production in the future. Almost all growers have some issues with water management, but oftentimes the most basic question is – do I need to irrigate today? While this question could seem trivial, plant water requirements vary by species, season and microclimate, and depend upon any number of environmental and plant developmental factors that need to be integrated on a day-to-day basis. Effective daily irrigation decisions take time and the irrigation manager often faces complex decisions about scheduling that require the integration of knowledge at many levels. Irrigation management is therefore one of the most complicated tasks in a nursery operation, particularly when water is limiting. Ideally, this should be combined with real-time sensing of nutrient concentrations in the root zone, by measuring electrical conductivity (EC). Our goal is to enable the automation of this task by using wide area networks of soil moisture and EC sensors.

\textbf{Nature of Work: Background:} There are many technologies that over the years have been touted to aid the irrigation decision process. Various soil moisture measurement devices from tensiometers, gypsum blocks, meters that directly sense soil moisture and weather station / satellite forecast data that integrate information with evapotranspiration models are all available, and yet the widespread adoption of any technology has not occurred, for good reasons. Firstly, many sensing technologies which were originally engineered for soil-based measurements have been applied to soilless substrates. They have failed, largely because these sensors did not perform well in highly porous substrates, as aeration is a physical property that is required for good root growth in container culture. Even when a technology was adapted successfully to container culture (e.g. low-tension tensiometers), the technology has often been too expensive for wide-scale adoption or there have been issues with precision, maintenance and
automation of the technology. Cost and ease of use are key aspects to adoption and use of any tool. Secondly, macro-scale weather or ET Pan factors are too gross a measure for accurate irrigation schedules at the micro-scale in nurseries, and Kc values for ornamental species are non-existent or imprecise. Most importantly, the technology has often not achieved any real economic benefit for the grower, in terms of water savings or improved plant growth. Very often the technology merely adds another ‘management layer’ that requires added expertise to interpret and use the data to make a decision. We therefore need to bear these considerations in mind when we develop any system that aims to “improve” upon current irrigation management techniques.

**Deployed Sensor Networks:** Our group has previously reported on the calibration of sensors for soilless substrates (1, 2, 3) as well as the development and deployment of specific wireless networks (5, 6, 7). In this paper, we report on the deployment and performance of two wireless sensor networks, the current challenges and benefits associated with each network and our future research directions. Briefly, we are comparing the use and operation of two sensor networks in three different production environments. One network (Fig. 1) is commercially available from Decagon Devices, Inc. (Pullman, WA); the other (Fig. 2) is a non-commercial research network developed by the Carnegie Mellon Robotics Institute (Pittsburg, PA). Each sensor network consists of a system of radio-powered “nodes” that are deployed in a plant production area, to which a number of environmental sensors are connected. Any combination of soil moisture and electrical conductivity sensors, soil and air temperature, relative humidity, tipping rain gauge and light (photosynthetically-active radiation) sensors can be connected to the radio nodes, according to the specific sensing requirements of the grower. The nodes log data on a per minute basis, and log the average data every 15 minutes, to conserve battery life and memory. The accumulated data is then transmitted at 900 MHz or 2.4 GHz using a battery operated radio card to a ‘base radio station’ whenever it is required. The base station is connected to a computer, which uses custom software to plot and display the information from each of the nodes. With the CMU network, this information is relayed over the internet (Fig. 3) to provide the information to anyone, in any place and at any time. In this way, a grower can develop a network of sensors that allows for the monitoring of environmental data in the nursery, in real time. The advantages of these networks are obvious – they provide information at the “micro-scale” which can be expanded to any resolution for a specific operation, for specific needs.

Both networks have good basic sensor network capabilities, but the CMU system has a few distinct advantages. Firstly, the CMU nodes have a “mesh networking” capability (i.e. the nodes communicate with each other, which has advantages for large-scale deployment or in hilly terrain). Secondly, the CMU node has a local control capability, which means that the software in an individual node can average data from a number of moisture sensors, which is then used to actuate a solenoid for automated irrigation scheduling in blocks, independent of the main (central) computer system. Thirdly, the CMU node can accept 10 sensor inputs (compared to only five with the Decagon Devices node), which further maximize data transmission cost and the cost-effectiveness of any individual node in the field.
On the other hand, the Decagon Devices EM50R node (Fig. 1) is extremely robust and well-engineered, has a more powerful radio card (necessary for connecting over large distances to the ‘base’ radio station) relative to the present CMU system, and has excellent power conservation capabilities (more than 9 months on 5 ‘AA’ batteries) when data are collected every 15 minutes from the attached sensors. The Decagon Devices network has performed very well on a tree farm during 2008, with data gathered from a variety of sensors in the field, including the EC-5 and 10-HS soil moisture sensors. The sensors and nodes have had very few issues either in deployment or operation. Custom soil calibrations did provide more precise data than the factory set calibrations, as would be expected. The EchoTrac™ graphic user interface software (Fig. 4), which graphs the data from each individual node is simple and easy to use, and has provided the grower with information that has only been available from much more expensive research sensor systems, until now. We monitored irrigation practices and environmental conditions from two blocks of indicator trees during 2008, to establish baseline irrigation management data.

We are using a CMU sensor network in a container-production research site at the Wye Research and Education Center near Queenstown, MD (Fig. 2) to automatically monitor and control irrigation events in small (2 gallon) containers. This is possible using custom calibration data for the pine bark substrate, based on the matric potential (plant-available water content) of the substrate. Irrigation set points are at a matric potential of approximately -10kPa (ON) and -2kPa (OFF) to minimize leaching events. A micro-pulse routine was written into the sensor node software, to irrigate in 1 second pulses. Using this technique, enough time (a few seconds) elapses between micro-pulses for the sensors to then measure the new substrate matric potential, before additional micro-pulses are applied. In this way, leaching volumes can be precisely controlled to minimize nutrient leaching. We are currently quantifying water applications and nutrient runoff with current best management practices (cyclic time irrigation events) compared to sensor-controlled irrigation method in a replicated experiment using four plant species. We have also deployed the CMU sensor network in a greenhouse operation during 2008. This greenhouse is a closed-system hydroponic (perlite) system that grows Antirrhinum (snapdragon) species year round. All water and nutrients are continuously recycled. The primary production objectives are to automatically schedule water (based upon matric potential) and nutrient solution (based on substrate EC) applications up to 20 times per day, ultimately to increase the percentage of #1 cut flower stems during the summer months. This will require the same network capabilities as we are currently testing in container culture, but in a more demanding environment with rapid temporal changes.

To date, we have shown that the measurement of soil or substrate moisture can provide precise information to schedule irrigation events in both soil and soilless substrates. Both sensor networks perform well in production environments, although some networking challenges remain with remote sites (line of site transmissions greater than 1 mile), as could be expected in large operations. A higher power radio card in the CMU nodes is being tested to overcome this limitation, which would slightly increase the
cost of this node. However, the cost per node for the CMU network should still be considerably below the current cost of the Decagon EM50R. In our estimation the cost structure of the sensors is less of a factor compared to the cost of the nodes. The solenoid actuation capability of the CMU node is a vital control function which many nursery growers agree is necessary for maximum utility and labor savings.

**Future Directions:** There are many areas where we need additional research and development to provide the maximum cost benefit of these networks for growers. We need a more robust database management system that would provide the backbone to the graphic user interface, able to handle networks of more than 10 nodes (50-100 sensors). This database must be able to manage rapid computations and statistical analysis, for example, similar to GPS and business systems that are used to track packages in real time. These systems also need to be web-enabled, so that employees can access sensor data with hand-held devices in the field, using the same wireless networks that transmit the data to the office computer (server). Most importantly, we need to connect our capability for precision water applications with a knowledge of real-time plant water use. We need to improve our ability to predict plant water use in real-time using various technologies. We think that modeling plant water use for indicator species (4, 8) is essential to providing a prediction capability for large-scale implementation of sensor-derived data from indicator species. In conclusion, we are making some rapid progress in our ability to accurately monitor and control irrigation scheduling in nursery and greenhouse environments.

**Acknowledgements:**
We gratefully acknowledge funding from the Chesapeake Bay Trust, the Horticultural Research Institute (ANLA-HRI) and the University of Maryland Agricultural Experiment Station for their support of this research.

**Literature Cited**


Fig. 1. A Decagon Devices EM50R node connected to a tipping rain gauge, light (PAR) sensor and three soil moisture sensors (not visible) in the field.
Fig. 2. The Carnegie Mellon University (CMU) network at the Wye Research and Education Center, near Queenstown, MD, showing sensor nodes (at left and centre), communication node and antenna (at right).

Fig. 3. A schematic of the CMU sensor network, which utilizes the internet for real-time monitoring and control of irrigation scheduling.
Fig. 4. A computer screenshot of the Decagon Devices, Inc. EchoTrac™ software, showing soil moisture data from EC-5 sensors at 6” (black), 12” (green) and 18” (purple) with rainfall and irrigation amounts from a sensor node in an *Acer rubrum* block in September, 2008.
NCDC216: A New Multistate Group for Water Management and Quality for Ornamental Crop Production and Health

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Significance to Industry: We have established a USDA multistate development committee (NCDC216) to create a project focused on water management and quality for ornamental crop production and health. Irrigation is essential or beneficial for production of ornamental plants. The quantity and quality of water available for irrigation has major consequences on the productivity and profitability of this important sector of agriculture. The record 2006-2008 drought in the eastern US has had a severe negative impact on the nursery industry in that region. The Great Lakes region is implementing water use policies in order to comply with the recently ratified Great Lakes-St. Lawrence River Basin Water Resource Compact. Drought and water conservation are not new issues to the western states where availability has long been a limitation but demographic changes are increasing competition between users. The quality of water leaving agricultural facilities is an issue of increasing public concern. Demand from industry, homeowners and agriculture is increasing in almost all areas of the US. Water is no longer an issue restricted to certain areas of the country with insufficient water quantity and/or quality but is a national and global issue. Increased regulation and competition for water resources, therefore, calls for improved water management techniques with respect to application and runoff water quantity and quality in all regions. This national
effort to address water resource challenges will ensure a more efficient and coordinated utilization of assets to provide research and extension programs to address this critical issue.

**Background:** The nursery/greenhouse industry ranks 5th (>$14.6 billion) in US agriculture commodities and is in the top 5 commodities for 26 states (USDA, 2004). Water issues, specifically irrigation scheduling, surface and groundwater water management, and water quality are quickly becoming topics of major concern to the ornamental plant industry even in what are thought of as water-rich states. Drought, urban competition for surface and groundwater water reserves, salinity and runoff water quality, and increasing legislation at state and county levels are all increasing the need for ornamental crop producers to manage water more effectively. Legislation regarding water use and/or quality has been implemented in California, Delaware, Florida, Maryland, Michigan, North Carolina, Oregon, and Texas.

Most field (in soil) producers of ornamental stock use irrigation water at some point during production because the cost-benefit ratio of maximizing plant growth is apparent. Many field producers use low-volume (drip) irrigation, and many also use this system to deliver soluble fertilizers during the growing season. While supplemental irrigation is beneficial in field production it is essential for container production of ornamental plants. Container substrates need to be well drained and container volume limits the amount of water that can be stored. This results in frequent irrigation applications and large amounts of water used. In a recent survey, over 75% of nursery crops in 17 states (AL, CA, CT, FL, GA, IL, MI, NJ, NY, NC, OH, OR, PA, TN, TX, VA, WA) were grown in containers and require irrigation, often daily (USDA, 2007). In Florida, container nurseries annually apply 56 to 120 inches per acre per year in addition to the 40 to 60 inches of average annual rainfall. Container nurseries in Alabama were estimated to have used 9.8 to 13 billion gallons of water in 1985 (Fare et al., 1992) and container nursery production in Alabama has almost tripled since 1987 (USDA, 1992, 2002).

Frequent irrigation in combination with high fertilizer and pesticide use can lead to significant losses of agricultural chemicals in runoff water that transports agricultural chemicals to containment structures and/or off-site into groundwater or surface water (Briggs et al., 1998, 2002; Cabrera, 2005; Camper et al., 1994). Irrigation water management is the key to nutrient management in ornamental crop production and reducing the impact of runoff water on local water resources (Tyler et al, 1996; Lea-Cox et al, 2001; Ross et al, 2001; Ullah and Zinati, 2006). Increasing anion and cation exchange capacity, for example through the use of aluminium or various clay materials can help to reduce leaching of nutrients from soilless substrates (Owen et al, 2008; Williams and Nelson, 1996). Recycling of water includes another set of issues for growers, primarily in the form of disease (Hong and Moorman, 2005) and salinity management. Emerging constraints on water use and quality means that the ornamental industry needs to find ways to manage water without detracting from production schedules and crop quality. Therefore, we need to tackle the issue of water management through a multi-disciplinary approach on a national level, because few states have the personnel to individually integrate all these issues.
**Nature of Work:** The goals of this national group are to provide a forum for representatives from all land-grant and other institutions to develop multidisciplinary approaches to 1) improve water use efficiency and crop productivity in the industry while minimizing the risk of nutrient- and chemical-rich irrigation runoff water releasing into natural waterways, 2) de-couple crop health risk with recycling irrigation to promote water resource conservation and protection through understanding aquatic ecology and water treatment innovation, 3) investigate alternative water sources such as treated municipal waste water, and 4) to develop soilless substrates with better physical and chemical characteristics to improve water and nutrient availability while reducing leaching of fertilizers. Several active research programs around the US are currently investigating ways to improve water management and quality for greenhouse and nursery production to achieve these objectives. This multi-state effort will allow for better coordination of research and extension efforts to more efficiently address these multidisciplinary issues. Projects can be replicated at different participant sites when necessary and, conversely avoid unnecessary duplication of effort. Data can be shared among participants to help test and refine models. Interaction among a national group of researchers and stakeholder groups will also provide a forum to discuss and determine future research needs and priorities. A strong extension and outreach component will be built into the project to insure the transfer of information to stakeholders.

**Summary and Discussion:** The intent of this project is to bring together a multidisciplinary team to include colleagues in horticulture, plant pathology, entomology, weed management, engineering and other fields interested in addressing water use issues. The primary subject areas the group intends to focus on are 1) irrigation management during production including irrigation systems, scheduling, and cultural practices to increase efficiency; 2) source water quality, including current and alternate sources and their natural and introduced biotic and abiotic contaminants, how they affect intended uses, and water treatment to improve quality; 3) runoff water management and quality, including production effects on water quality, effects on the surrounding environment, effects on reapplication to a crop, runoff water treatment, and modeling; and 4) pest/crop health management, including the impact of recycled or reused water on plant production and worker safety and pest movement and control in recycled, reused and runoff water.

**Expected Impacts:** Improving water management and quality for ornamental plant production and health in the United States will have several important impacts: 1) reduction in total water use through more efficient practices; 2) improved technology for irrigation scheduling; 3) improved crop production through increased water and nutrient use efficiency, 4) reduced runoff and potential off-site pollution from fertilizers and other agricultural chemicals and 5) enhanced crop health and consumer confidence stemming from more sustainable practices.
Literature Cited


Nutrient Remediation Using Vegetated Floating Mats

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Index Words: Nitrogen, phosphorus, water quality, vegetated channels, polishing, agrichemical runoff

Significance to Industry: The green industry is often perceived as a waste contributor rather than as an industry that is capable of providing “green” solutions for environmental problems. It is critical to promote the “real green industry” by focusing on sustainable production practices. Included in this mix is the promotion and implementation of various remediation approaches for removal of agrichemical contaminants from water for both onsite reuse and offsite release. This research presents an effective method for cleansing low-level nutrient contaminants from runoff in agricultural ditches, channels, and retention ponds. Floating mat technology is easy to implement, adaptable to a wide variety of plant species, and has broad application potential in a variety of settings not limited to the green industry alone, but also to homeowners and municipalities.

Nature of Work: Constructed wetlands, both surface and subsurface flow, are often used to remediate nutrient-rich waters (1-4), but the large land area required for installation sometimes limits their applicability. Floating mat treatment systems (FMS) are potential alternatives to constructed wetland systems and could be established in drainage ditches or retention ponds. Once established, FMS provide nutrient-processing functions similar to wetlands. The large root surface area in the water column provides habitat for microbes, matrices for direct filtration, and plant nutrient uptake. An additional benefit is easier harvest of shoot and root biomass for additional nutrient removal. Ease of harvest is not typically considered when constructed wetlands are designed; rather, they are designed for specific remediation functions. Floating mat systems could be adapted to many such functions while facilitating quick installation, rapid establishment, and simpler harvest. Any nutrients fixed in plant roots or shoots are easily removed from the aquatic system as plants are harvested. This harvested tissue may then be used as a media amendment or nutrient source if properly composted.

The goal of this research was to assess the potential of FMS for remediating agrichemicals in runoff prior to entry into water bodies. The experiment was divided into two treatment classes, the first consisted of small-scale (one 88 ft\textsuperscript{3} and two 51 ft\textsuperscript{3} units) channels, and the second consisted of large-scale (one 500 ft\textsuperscript{3} and one 918 ft\textsuperscript{3}) ponds (Figure 1). Plants from each species examined were seated in floating mats and placed...
in the flow-through channels and ponds on April 14, 2008. Fertilizer treatments started May 2, 2008. The vegetated channels were established with *Canna flaccida* and *Juncus effusus*. *Canna flaccida, J. effusus, Eleocharis montana*, and *Agrostis* sp. were established in floating mats in the pond treatments. Each of the ponds and vegetated channels was sampled weekly, beginning 3 days after initiation of fertilizer addition. One water sample was collected on each sampling date.

Water samples were analyzed for 1) anions (Cl, NO₂, NO₃, PO₄, and SO₄) via ion chromatography with a Dionex AS10 IC ion chromatograph (Dionex Corp., Sunnyvale, CA), 2) total organic carbon (dissolved carbon from organic sources that is available for microbial metabolic functions) via NPOC/TN analysis using a Shimadzu TOC-V CPH total organic carbon analyzer with TNM-1 total nitrogen measuring unit (Shimadzu Scientific Instruments, Kyoto, Japan), and 3) total P, K, Ca, Mg, Zn, Cu, Mn, Fe, S, Na, B, and Al were analyzed via inductively coupled plasma emission spectrophotometer (ICP-ES, 61E Thermo Jarrell Ash, Franklin, MA). Final water samples and harvest of selected plant tissues occurred September 18, 2008. Roots and shoots of each species were dried at 80 °C, weighed, and ground in a Wiley mill (Swedesboro, NJ) to pass through a 40-mesh (0.425-mm) screen. Nitrogen concentration was determined using 100 mg of tissue and assayed using an Elementar Vario Macro Nitrogen combustion analyzer (Mt. Laurel, NJ), and P was assayed by wet acid digestion procedure using the nitric acid and hydrogen peroxide method (5). Phosphorus, K, Ca, Mg, Zn, Cu, Mn, Fe, S, Na, B, and Al concentrations in plant tissues were determined by ICP-ES. Only data concerning effluent nutrient concentrations will be presented. Data were analyzed, when appropriate, using SAS PROC GLM procedure with a MEANS statement (SAS Institute Inc. Cary, NC).

**Results and Discussion:** The FMS reduced both nitrogen and phosphorus effluent concentrations (Figure 2). Nitrogen removal was consistent in both the pond and vegetated channel treatments (Figure 2A). Average nitrogen removal efficiency in a variety of constructed wetland systems ranged from 0 to 84.2%, with average influent concentrations ranging from 0.7 to 55.0 mg/L NO₃-N (4). Nitrogen loading rates for this experiment were at the very low end of that range (0.73 ± 0.17 mg/L N), and average nitrogen removal (82.2%, 0.13 ± 0.03 mg/L N) was similar to the most efficient constructed wetland systems examined by Vymazal (4).

Phosphorus removal was also consistent over the five months of sampling (Figure 2A). Effluent concentrations averaged 0.03 ± 0.01 mg/L total P for both the pond and vegetated channel treatments. Phosphorus concentrations entering constructed wetland treatment systems ranged from 0.7 to 10.5 mg/L PO₄-P and Pₚ (2, 4), with average effluent concentrations ranging from 0.02 to 5.15 mg/L PO₄-P and Pₚ. Previous research in our lab has indicated that constructed wetland systems are not effective at remediating phosphorus when inflow concentrations are below 1 mg/L (6). Loading concentrations of Pₚ in the pond and vegetated channel treatments averaged 0.08 ± 0.02, and effluent concentrations were consistently reduced by ~ 67% to 0.02 ± 0.003 mg/L Pₚ (Figure 2B). Other researchers have found much greater variability in phosphorus remediation, both with effluent concentrations achieved and seasonality (2,
These results indicate that FMS may have great potential when used to “polish” nutrient-rich water. Further work with FMS may reinforce their usefulness in these low nutrient environments where desired effluent P concentrations are < 50 ppb. The FMS were easy to install, maintain, and harvest, and they may prove to be an economically feasible treatment technology for polishing water quality to very low P effluent concentrations.

**Acknowledgement:** Financial support for this project was provided by Beeman’s Nursery.

**Literature Cited:**


Figure 1. Floating mat treatment systems tested in both small-scale (A) vegetated trough systems and (B) large-scale pond treatment systems.
Figure 2. Influent and effluent nitrogen (A, NO₂ + NO₃) and phosphorus (B, P₄) concentration changes over five months, as influenced by floating mat treatment in small-scale vegetated troughs\textsuperscript{a} and large-scale ponds\textsuperscript{b}.

\textsuperscript{a} Effluent values are the average of 3 replicates ± standard error of the mean.

\textsuperscript{b} Effluent values are the average of 2 replicates ± standard error of the mean.
Know Your Creek: A Look at the Water Quality of Two Creeks at the Collins River Sub-watershed

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Index Words: nursery, runoff, nutrient, pollutants, water quality

Significance to Industry: The protection of surface water (rivers, creeks, streams and lakes) from agricultural pollutants continues to pose a major challenge to growers and researchers. Since agricultural production contributes to non-point source pollution, many states are concerned about the impact of non-point source pollution on the quality of surface water in their watershed(s). The majority of ornamental plants in Tennessee are in-field grown; thus plowing, liming and fertilization of nursery fields can result in the runoff of tons of soil and essential crop nutrients on a watershed scale. Phosphorus (P) and nitrogen (N) are essential nutrients for crop production. However, they are also the primary factors that enhance eutrophication (1, 5). The US-EPA identified eutrophication as the most widespread water quality impairment in the United States; and agriculture as a major source of nutrient loading to surface water. In middle Tennessee, especially in Warren, Dekalb and Grundy counties, large concentrations of nursery crop production operations exist and the Collins River watershed spans these counties. Therefore, the potential for nutrient loading by overland and subsurface flow to creeks and streams exist. There is a dearth of research on the impact of nursery crop production systems on surface water quality. Subsequently, growers are not aware of the impact of their fertilizer and lime management on surface water; especially when many of the nursery fields lack nutrient management plans. Improved nutrient management strategies for individual nursery fields could be an effective component of improved watershed nutrient management that enhances water quality and Total Maximum Daily Loads (TMDL) goals.

Nature of Work: Two creeks, Hills Creek and Mountain Creek in Warren County Tennessee, were sampled in the fall of 2008. The creeks are tributaries of the Collins River. Land use in the study area is predominantly agricultural, being comprised of nursery crops primarily. Rainfall supplies nearly all the nursery crops water demand in this region. Grab water samples were collected with weighted bailers from corresponding bridges weekly for eight weeks. The water samples were collected mostly during base flow and in few instances after rainstorm events at three different locations (up stream, middle stream and down stream) in the creeks. During each creek visit, 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 (2). In order to determine other water quality parameters of interest (dissolved oxygen, total dissolved solids, specific conductance, turbidity, temperature and pH), Eureka Manta™ DataSondes or data logger units (Eureka Corp Austin TX), interfaced with the applicable sensors were 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. Each Manta was dedicated to each creek but was cleaned before taken to subsequent site(s) for data logging. While sampling, 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). Some of the cations determined are important because they are present in agricultural liming materials (i.e. calcium and magnesium) widely used by farmers. Both creeks have relatively low concentrations of the nutrients monitored 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. Nitrate concentration in Mountain Creek (0.02-1.3 ppm) and Hills Creek (0.04-0.3 ppm) is very low considering that some investigators (3, 4) have reported nitrate concentrations in nursery runoff water to range from 1.6 ppm to 304 ppm. Additionally, in determining surface water quality, certain aquatic habitats are indicative of polluted or non-polluted water. During the fall 2008 sampling, river otters, Lontra canadensis (Figure 1) were observed swimming in Mountain Creek, Warren County. River otters are usually found in non-polluted rivers, creeks and lakes (http://www.conservewildlife.org/animals/riverotter2.html). They breed in late fall or in early spring. Healthy populations of periwinkles, Littorina littorea, were also observed in the creek. The occurrence of periwinkles is not only a good water quality indicator but also a source of food for the otters. Otter populations have been reduced in many areas of the United States due to human encroachment, overharvest and habitat destruction. River otters are not a federally endangered species, although some states still consider them endangered and have restoration programs in place. Tennessee has embarked on restoration projects which have been considered successful. The disappearance of river otters from some water bodies may be due to factors associated with increased acidity of the ground water (originating from previous mining operations) that recharges them. Mountain Creek, where the river otters were spotted, had the following field-measured water quality parameters: pH = 7.5-7.8; turbidity = 0.8-32.4 NTU; specific conductance 152-263 micro Siemens/centimeters; dissolved oxygen 3.1-11.3 ppm and total dissolved solids = 98-200 grams/L. Conversely, in Hills creek, the pH ranged from 5.4-7.4; turbidity 0.75-29 NTU; specific conductance 417-1077 micro Siemens/centimeters; dissolved oxygen 5.8-11.1 ppm and total dissolved solids = 267-690 grams/L. Certainly, Mountain Creek has better water quality characteristics than Hills Creek. Knowledge of data such as those discussed here are invaluable in establishing baselines by which we can measure the impact of nursery production.
systems on local water quality. More importantly, data such as these can signal times when alteration of practices are needed due to negative impacts on water quality. It is important that we know our creek(s) and that we all do our best to maintain the environmental integrity of such bodies of water.

**Literature Cited:**


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Figure 1. River Otters (*Lontra Canadensis*) in Mountain Creek