Water Management Section

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Section Editor

Phosphorus Removal and Accumulation by Swiss chard (*Beta vulgaris*) Grown in Floating Treatment Wetlands

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Index Words: Phosphorous, Floating wetland, Hyper-eutrophication, remediation, Swiss chard, *Beta vulgaris*

Significance to Industry: Hyper-eutrophication occurs when surface waters are enriched with excessive nutrients and results in excessive primary production or algal and cyanobacteria blooms. The overabundance and decomposition of these organisms leads to decreased water clarity, hypoxic conditions, and fish kills. Phosphorous (P) availability typically limits the rate of eutrophication in freshwater systems. Some growers apply more P than is necessary to grow healthy crops. Irrigation and rain move excess P into surface water flows, where it may promote the rate of eutrophication. Phosphorus is essential to all life forms, and technologies that help prevent eutrophication and/or help recycle P are needed. We examined the potential of floating treatment wetlands established with *Beta vulgaris* (Swiss chard) to remediate P from simulated nursery runoff. Swiss chard displays low to moderate potential for P remediation. Yet if P accumulation can be paired with a saleable end product, use of FTW can reduce environmental impacts while enhancing grower profitability.

Nature of Work: Floating treatment wetlands are one option for remediating excess nutrients from water. In floating treatment wetlands, plants are placed directly into floating mats with roots extending directly into the water column. Floating treatment wetlands (FTWs) provide similar benefits as constructed and natural wetlands, namely filtration of particulates and removal of excess nutrients. However, FTWs are somewhat less costly than constructed wetlands and are more adaptable, as FTWs are not permanent installations, require no additional land, and plant choice is not restricted to aquatic macrophytes alone. Plants can be chosen for their nutrient removal characteristics, aesthetic quality, or even edibility.

Research by Glenn et al. (1) indicated that Golden Canna (*Canna flaccida*) grown in a FTW is capable of aiding P removal from simulated nursery runoff. The purpose of this study was to assess the potential for a common vegetable crop, Swiss chard (*Beta vulgaris*), to remove P from simulated nursery runoff by evaluating the influence of cultivar and nutrient load on plant growth, phosphorus uptake, and phosphorus removal.

Swiss chard plants used in this experiment were either started from seed or procured as mature plugs (*Beta vulgaris* 'Bright Lights') from Hi Cotton Greenhouses, (St. Matthews, SC). On 6 March 2013, all plants were of sufficient size to incorporate into the floating treatment wetlands and were individually placed in 5 cm diameter aerator cups, which were then seated within a 1 cm thick, solid core foam mat (60 cm x 60 cm) precut with 10 holes for each plant per experimental unit. Swiss chard plants were grown in the floating treatment wetlands for 9 weeks before they reached mature (edible size) and were harvested on 7 May 2013. Sampling was initiated 13 March 2013, and recurred on a weekly basis (for 8 weeks) until harvest.

The controlled experimental factors of fertilizer load (moderate and high) and species mix [*B. vulgaris* (SCS), *B. vulgaris* 'Bright Lights' (SCB), and a 50% SCS and 50% SCB mixed planting (SCM)] were subdivided among experimental units (EUs), which consisted of 16, 380-liter (100 gal.) Rubbermaid® tanks. Moderate (12.6 g) and high (24.6 g) fertilizer treatments were assigned across EUs (8 per level) using a 15-5-15 commercial grade soluble fertilizer (The Scotts Company LLC, Marysville, OH). Within the moderate treatment, 3 EUs were assigned to SCB, 4 to SCS, and 1 to SCM; within the high treatment 3 EUs were assign to SCB and SCS, with 2 EUs assigned to SCM.

The sixteen EUs were individually spiked with fertilizers, drained, refilled, and respiked on a weekly basis, to simulate a static system with a 7-day hydraulic retention time. Approximately 7-days after each spiking event, water samples were collected, and dissolved oxygen (DO, mg/L), pH, oxidation-reduction potential (ORP, mVolts), and temperature (ºC) measurements were recorded. Water samples were analyzed for dissolved anion and mineral content. Anions concentrations (NO_3-N, NO_2-N, NH_3-N, PO_4-P, and SO4-S) were determined using a Dionex AS50 ion chromatograph (Dionex Corp., Sunnyvale, CA), and mineral concentrations (total P, K, Ca, Mg, Zn, Cu, Mn, Fe, S, Na, B, Al) were analyzed via inductively coupled plasma emission spectrophotometer (ICP-ES, 61E Thermo Jarrell Ash, Franklin, MA).

Measurements of pH, ORP, and temperature were measured with a YSI Professional Plus meter, and DO was measured using a YSI Pro ODO meter (YSI Incorporated, Yellow Springs, OH). Shoot height (cm) and root length (cm) were measured on a weekly basis. On the first day of sampling, three plants from each EU were chosen for repeated measurement of plant growth over the duration of the experiment. On 7 May 2013, after final plant measures were made, three plants were harvested from each EU. The fresh weight (g) and dry weight (g) for the roots and shoots of each plant were recorded. Plants were submitted to the Clemson Agriculture Service laboratory for tissue analyses. Data were analyzed using the GLM procedure and when appropriate, means separated using the Students *t* –test ($\alpha = 0.05$) within JMP v10.0 (SAS Institute Inc. Cary, NC).

Results and Discussion: Swiss chard established in FTWs removed P from simulated nursery runoff (Figure 1). Effluent P concentrations were lower than influent levels for both high and moderate fertilizer loads (Figure 1). The concentration of P was greatest in shoot tissue for both high and moderate fertilizer loads ($P < 0.0001$; Table 1, Figure 2). Shoot tissue comprised the majority of total plant tissue mass, and so greater accumulation of P in shoot tissues was expected. Harvest of plant biomass from floating treatment wetlands may be an important aspect of their management, because removing nutrients from the internal cycle of the water body helps to reduce primary productivity. However, tissue allocations differ among plant species. White and Cousins 2013 (unpublished data) observed P and nitrogen fixation was greatest in the below-mat biomass of their two plants of study, *Canna flaccida* and *Juncus effusus*. Consequently, for effective nutrient remediation, harvesting the whole plant was recommended. These results, which differ from our current study, indicate that plant choice may dictate management of FTWs.

All three species mixes grew well over the 8 weeks of sampling (Figure 3). Static shoot growth during the first few weeks of the experiment, for all species mixes, may be an indication of a shift in resource allocation to root growth initially, as roots grew consistently over the first 3 weeks (Figure 4). During this time the plants were acclimating to their new environment, as consistent shoot growth was recorded over the remaining weeks. ‘Bright Lights’ (SCB) was significantly shorter than the straight species (SCS) or a mix of SCB and SCS over the experiment ($P < 0.0001$; Table 2). However, these differences in shoot height could be an artifact of the method used for measurement. Shoot growth was measured from the top of the aerator cup to the top of the tallest standing leaf. Shoots and leaves were not extended vertically for measurements of height. As leaf and stalk growth continued, some plants lost height as their leaves and stalks sagged from their own weight. When additional experiments are conducted with these species, or other plants with similar growth habits, plant leaves should be extended fully for measurement, as this will likely result in a more accurate measurement of shoot growth and correlate more accurately with mass allocation to either shoot or root biomass.

Root lengths were longer for species spiked with the moderate fertilizer load (Table 3). One explanation for this partitioning of metabolic energy towards root growth is that plants residing in nutrient rich environments have no need to expend energetic resources to extend their roots in search of nutrients, which are readily available to them. For example, canna exposed to low nutrient concentrations drive nutrient accumulation into root tissue, as metabolic resources are directed to these organs for growth (2). In a study which analyzed allocation of stem, leaf, and root biomass of twenty seven herbaceous clonal plants grown at either a high or low nutrient environment, Müller et al. (3) reported that the fraction of biomass in roots was typically greater for plants grown in the low nutrient environment. Future experiments may focus on exposing Swiss chard plants to nutrient poor environments and determining if partitioning patterns change to greater loading of P within root tissues rather than shoot tissues. Understanding these changes in partitioning in nutrient rich and nutrient poor environments could alter floating treatment wetland management for species that concentrate nutrients in shoot tissue. If such a perennial species were used in an environment where influent nutrient levels fluctuate seasonally from high to low concentrations, whole plant harvesting may be crucial for effective nutrient remediation, due to nutrient accumulation in root tissue during times of low influent nutrient levels.

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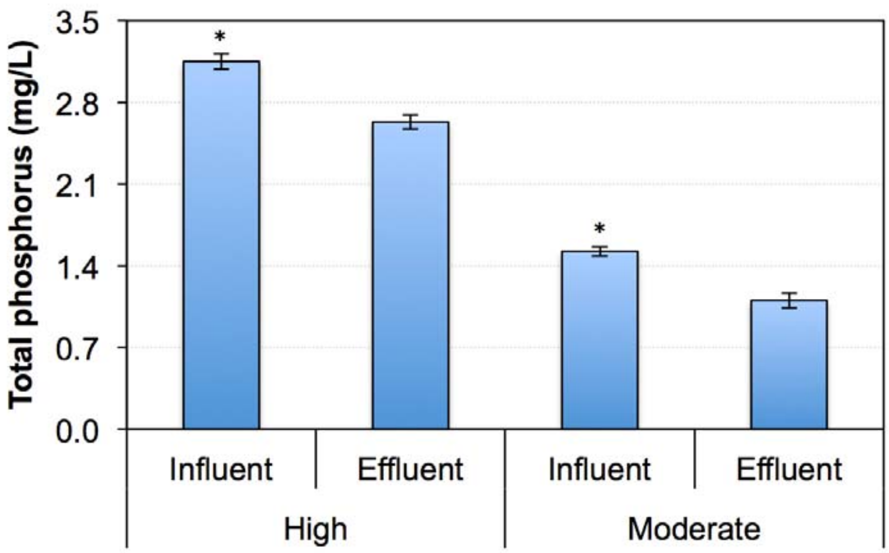

Figure 1: Change in total P concentration of influent and effluent as influenced by floating treatment wetlands established with Swiss chard (*Beta vulgaris*). High and Moderate fertilizer loads were refreshed weekly and the experiment was conducted over an 8 week period. Bars represent mean values for influent and effluent P concentration over time ± the standard error of the mean. The * designates a significant difference between influent and effluent values (p = < 0.0001) for both Moderate and High fertilizer treatments.

Table 1: Changes in P accumulation (g/m^2/8 weeks) and allocation within Swiss chard (*Beta vulgaris*), grown in floating treatment wetlands over an 8-week period, as influenced by fertilizer (2, high, moderate), species mix (3, *B. vulgaris* 'Bright Lights'; *B. vulgaris*; and an even mix of *B. vulgaris* and *B. vulgaris* 'Bright Lights'), and organ (2, shoot, root).

3-Way ANOVA	DF	*P > F*
Fertilizer	1	< 0.0001
Species mix	2	0.0624
Organ	1	< 0.0001
Fertilizer x species mix	2	0.2205
Fertilizer x organ	1	< 0.0001
Species mix x organ	2	0.1255
Fertilizer x species mix x organ	2	0.5439

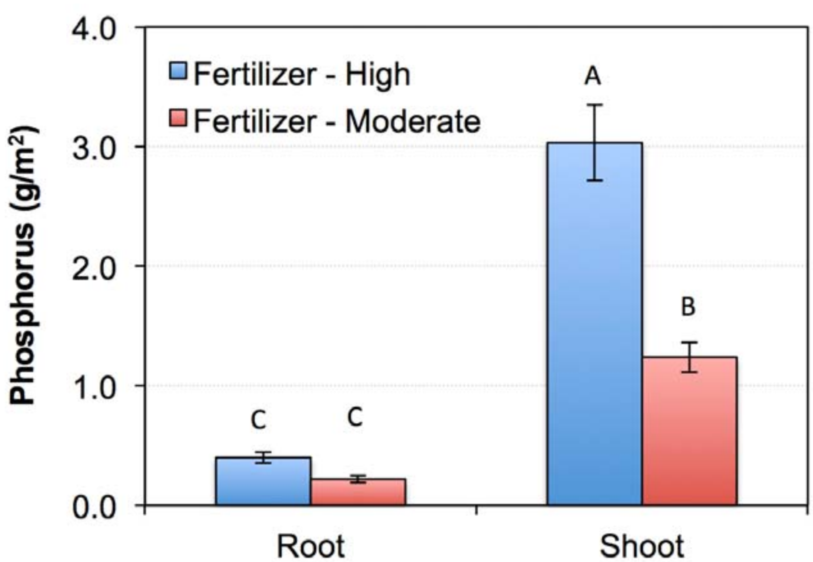

Figure 2: Total phosphorous content (mean ± standard error) of shoots and roots of Swiss chard (*Beta vulgaris*) grown in floating treatment wetlands and exposed to either high or moderate nutrient loads over an 8-week experimental period. Means with different letters are significantly different, students *t* test ($P \leq 0.05$).

Table 2: Shoot height of Swiss chard (*Beta vulgaris*) established in floating treatment wetlands for 8-weeks as impacted by fertilizer (high, moderate) and species mix (SCB = *B. vulgaris* 'Bright Lights'; SCS = *B. vulgaris*; and SCM = even mix of SCB and SCS). Means with the same letters are not significantly different, students *t* test (α ≤ 0.05).

2-Way ANOVA	DF	*P > F*
Species	2	< 0.0001
Fertilizer	1	0.2238
Species x fertilizer	2	0.3688

Species	LS Mean	
SCB	16.6	A
SCM	12.6	B
SCS	12.3	B

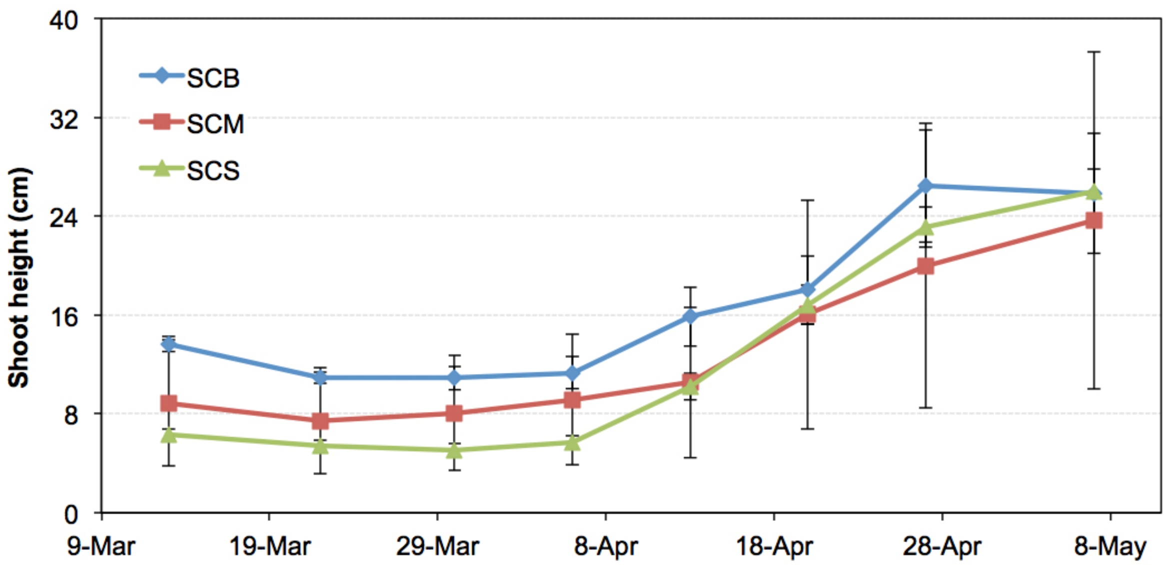

Figure 3: Shoot growth (mean ± standard error) of three species mixes (SCB = *B. vulgaris* 'Bright Lights'; SCS = *B. vulgaris*; and SCM = even mix of SCB and SCS) of *Beta vulgaris* (Swiss chard) established in floating treatment wetland over an 8-week experimental-period.

Table 3: Root length of Swiss chard (*Beta vulgaris*) established in floating treatment wetlands for 8-weeks as impacted by fertilizer (high, moderate) and species mix (SCB = *B. vulgaris* 'Bright Lights'; SCS = *B. vulgaris*; and SCM = even mix of SCB and SCS). Means with the same letters are not significantly different, students *t* test (α ≤ 0.05).

2-Way ANOVA	DF	*P > F*
Species	2	< 0.0001
Fertilizer	1	0.0003
Species x Fertilizer	2	0.2049

Species	LS Mean	
SCS	15.7	A
SCB	12.2	B
SCM	10.6	B

Fertilizer	LS Mean	
Moderate	14.3	A
High	11.3	B

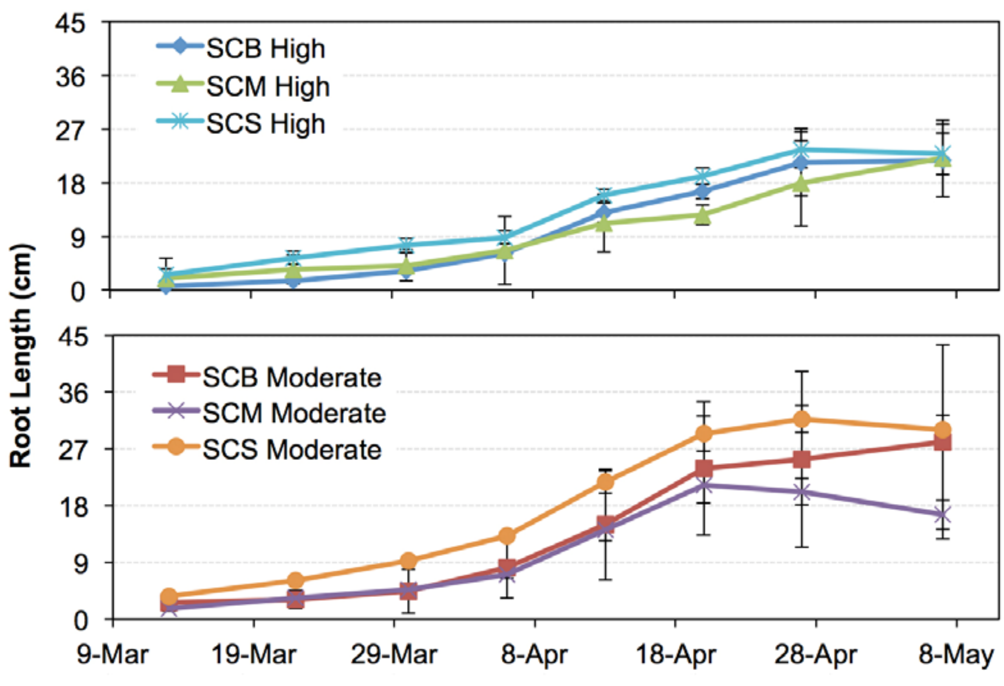

Figure 4: Root length (mean ± standard error) of *Beta vulgaris* (Swiss chard) grown in floating treatment wetlands over an 8-week period, exposed to two fertilizer levels (Moderate, High) and three species (SCB = *B. vulgaris* 'Bright Lights'; SCS = *B. vulgaris*; and SCM = even mix of SCB and SCS).

Effects of Substrate and Estimated Matric Potential on Vinca Growth and Water Use

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Index Words: gravimetric irrigation control; substrate matric potential; moisture characteristic curve; water application efficiency

Significance to Industry: Greenhouse growers must use water more efficiently. One way to achieve this is to monitor substrate moisture content and decrease leaching. A gravimetric on-demand irrigation system was used to maintain Sunshine LB2 and Fafard 3B at matric potentials of -2 kPa and -10 kPa during production of Vinca. A moisture characteristic curve (MCC) was used to determine gravimetric water content, volumetric water content, and air-filled pore space at target matric potentials. Volumetric water content and air-filled pore space differed between substrates at similar matric potentials. Maintaining substrates at -2 kPa increased irrigation volume applied and evapotranspirated, plant size, leaf area, shoot and root dry weight, and flowers per plant. Fafard 3B had less air-filled pore space at target matric potentials. Plants grown in Fafard 3B had greater leaf area, shoot dry weight, and root dry weight. Closely managing substrate matric potential and air-filled pore space in addition to substrate water content can reduce irrigation and leachate volume while maintaining plant quality and reducing the environmental impacts of greenhouse crop production.

Nature of Work: Several methods for increasing irrigation application efficiency have been developed. Microirrigation and cyclic irrigation have proven to dramatically increase irrigation application efficiency resulting in decreased water consumption (3, 4, 5, 7), however irrigation of containerized horticulture crops is still typically applied on a set schedule. Previous research has shown that plant water demand can be met by measuring and maintaining substrate volumetric water content (VWC) at specified ranges (2, 6, 8, 9). Due to differences in substrate physical properties, the relationship between substrate water content and plant growth of a specific species will differ between substrates. To better understand plant response to irrigation management systems, the relationship between substrate moisture content, substrate physical properties, substrate matric potential, and plant growth needs to be determined. By developing a moisture characteristic curve (MCC), VWC, gravimetric water content (GWC), air-filled pore space, and matric potential can be estimated in real-time during production using either VWC or GWC measurements.

The objective of this study was to determine the effects of substrate and estimated substrate matric potential on vinca growth and irrigation volume applied, leached, and retained by substrates.

On 7 March 2012, forty-eight 5-inch plastic containers were filled with a uniform mass of either Sunshine LB2 (SLB2) or Fafard 3B (F3B) commercial potting mixes. SLB2 was composed of Canadian sphagnum peat moss, coarse perlite, and gypsum and was amended with dolomitic limestone and a wetting agent. F3B was composed of Canadian sphagnum peat moss, pine bark, perlite, and vermiculite and was amended with dolomitic limestone and a wetting agent. Neither substrate had starter nutrients. Substrate samples taken during container filling were used to determine an estimate of average substrate dry mass per container so that gravimetric water content (GWC) could be tracked using gravimetric data. Finished seedlings of *Catharanthus roseus* (L.) 'Cora Lavender' were transplanted from 288-cell plug flats one per container. Two days after transplanting, a topdress of Osmocote Plus 15-9-12, a 3-4 month controlled release fertilizer, was applied at a rate of 3 grams per container, and containers were drenched with Cleary 3336F at 0.1 oz/gal on 13 March 2012. Ten days after transplanting, four containers were placed within a tray on each of 15 electronic scales of a gravimetric on-demand irrigation system. Trays were elevated on one end so that leachate would drain through holes into a collection pan next to the scale. Scales were tared with a tray and four empty containers beforehand so that only the weight of the substrate and seedling were represented by gravimetric data. Moisture characteristic curves were developed for both substrates using the Modified Long Columns method (1) and used to determine GWC at matric potentials of -2 kPa and -10 kPa. Each substrate was maintained at the GWC at these matric potential values by the gravimetric on-demand irrigation system. Substrate weight was recorded every 15 minutes throughout the experiment. Irrigation was initiated when weight was 10% below target weight and terminated when target weight was reached.

The experiment was terminated 51 days after treatment initiation. Weight archives were used to calculate total irrigation volume retained by substrate over the course of the experiment. Leachate accumulation from each plot was collected and measured with a graduated cylinder every one to two days and totaled to calculate total irrigation volume leached by substrate over the course of the experiment.

Growth index [(height + width + width) ÷ 3] and number of flowers were recorded for all plants, and leaf area was measured on two randomly selected plants per plot. Shoots were harvested, dried, and weighed. Roots of three randomly selected plants per plot were harvested, washed free of substrate, dried, and weighed. Total plant water use efficiency (WUE), shoot WUE, and root WUE were calculated for all 60 plants by dividing the corresponding plant dry mass by the average liters of plant water use per plant (liters plant water use per plot divided by 4 plants per plot). The experimental design was a 2x2 factorial combination (2 substrates x 2 matric potential values) with three four-plant replications in a complete randomized block design. Data were analyzed using ANOVA within IBM SPSS Statistics software (Version 19, SPSS Inc., Chicago, IL).

Results and Discussion: A 4-parameter log-logistic function was found to most accurately fit data from the moisture characteristic curve and was used to estimate GWC at matric potentials of -2 kPa and -10 kPa (Fig. 1). Substrate total porosity was found to be 85.5% for SLB2 and 78.3% for FB3. Data from the Modified Long Column method was also used to estimate VWC based on GWC. A 3-parameter sigmoid function fit this data most accurately (Fig. 2). Air-filled pore space at matric potentials of -2 kPa and -10 kPa was calculated by subtracting estimated volumetric water content at these matric potential values according to the MCC from total porosity. At a matric potential of -2 kPa, SLB2 had 22% air-filled pore space, while F3B had 13% air-filled pore space. At a matric potential of -10 kPa, SLB2 had 50% air-filled pore space, while F3B had 43% air-filled pore space. Although GWC and VWC were similar between substrates at the same matric potential, air-filled pore space at these set points varied. For instance, although there was only a 3% difference in VWC between SLB2 and FB3 maintained at -2 kPa, air-filled pore space in SBL2 was 69% higher than that of F3B.

Substrate had no significant effect on irrigation volume applied, leached, or retained by substrates, but matric potential did affect irrigation volume applied and retained by substrates (Table 1). Irrigation retained per container averaged 3907 mL among containers maintained at 2 kPa and 2488 mL among containers maintained at -10 kPa. Total leachate volume per plant was low and similar among all treatments ranging from 313 mL to 137 mL over the 51 days of irrigation treatment.

Matric potential affected leaf area, shoot and root dry weight, and number of flowers per plant (Table 2). Maintaining substrates at -10 kPa decreased leaf area by 29%, shoot dry weight by 27%, root dry weight by 19%, and number of flowers by 30%. Average shoot and root dry weights of all plants grown in SLB2 were lower (5.02 g and 0.73 g, respectively) than plants grown in F3B (5.99 g and 0.90 g, respectively). Substrate affected shoot and root dry weight and leaf area. Average shoot dry weight of all plants grown in SLB2 was 5.02 g, while that of F3B was 5.99 g. Average root dry weight of all plants grown in SLB2 was 0.73 g, while that of F3B was 0.90 g. Growth index was affected by an interaction between substrate and matric potential. Matric potential had no affect on size of plants grown in F3B, but plants grown in SLB2 at -2 kPa were significantly larger than plants grown in SLB2 at -10 kPa. Although plants grown in SLB2 at -2 kPa were significantly larger than all other plants, plants grown in F3B at -2 kPa had the highest root dry weight. WUE was similar among all treatments. The absence of a treatment effect on WUE indicates that plants grown in substrates maintained at -10 kPa did not experience significant stress.

Substrate pH was affected by substrate but not by irrigation treatment (Table 3). Average SLB2 pH was higher than F3B pH at the end of the trial. Substrate EC levels were unaffected by treatments. A major concern often cited for growing plants with little or no leaching is excessive EC levels. In this experiment, EC levels at the end of the experiment did not exceed recommended levels.

Although maintaining a lower substrate matric potential significantly affected the size of plants grown in SLB2, plants grown in F3B were similar in size (growth index) and flower number despite maintained substrate matric potential. Maintaining F3B at -10 kPa resulted in a 35% reduction in irrigation volume applied and similar size plants compared to -2 kPa. Using a MCC in conjunction with GWC or VWC measurements would allow other substrate physical properties such as air-filled pore space and substrate matric potential to be managed in real time during production.

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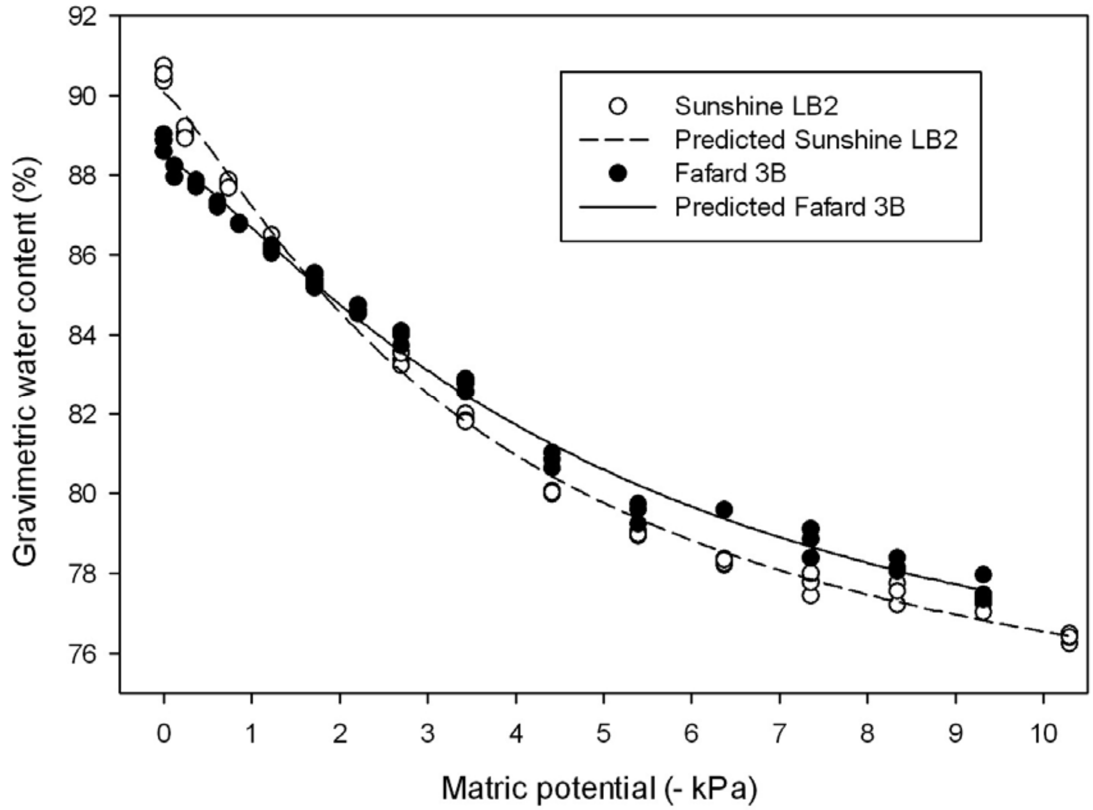

Figure 1. Moisture characteristic curves of Sunshine LB2 and Fafard 3B generated by the modified long column method. Data were fit to a log-logistic 4-parameter function [$F(x) = ((a-d)/(1+((x/c)^b))) + d$; Sunshine LB2, $R^2 = 0.995$; Fafard 3B, $R^2 = 0.993$].

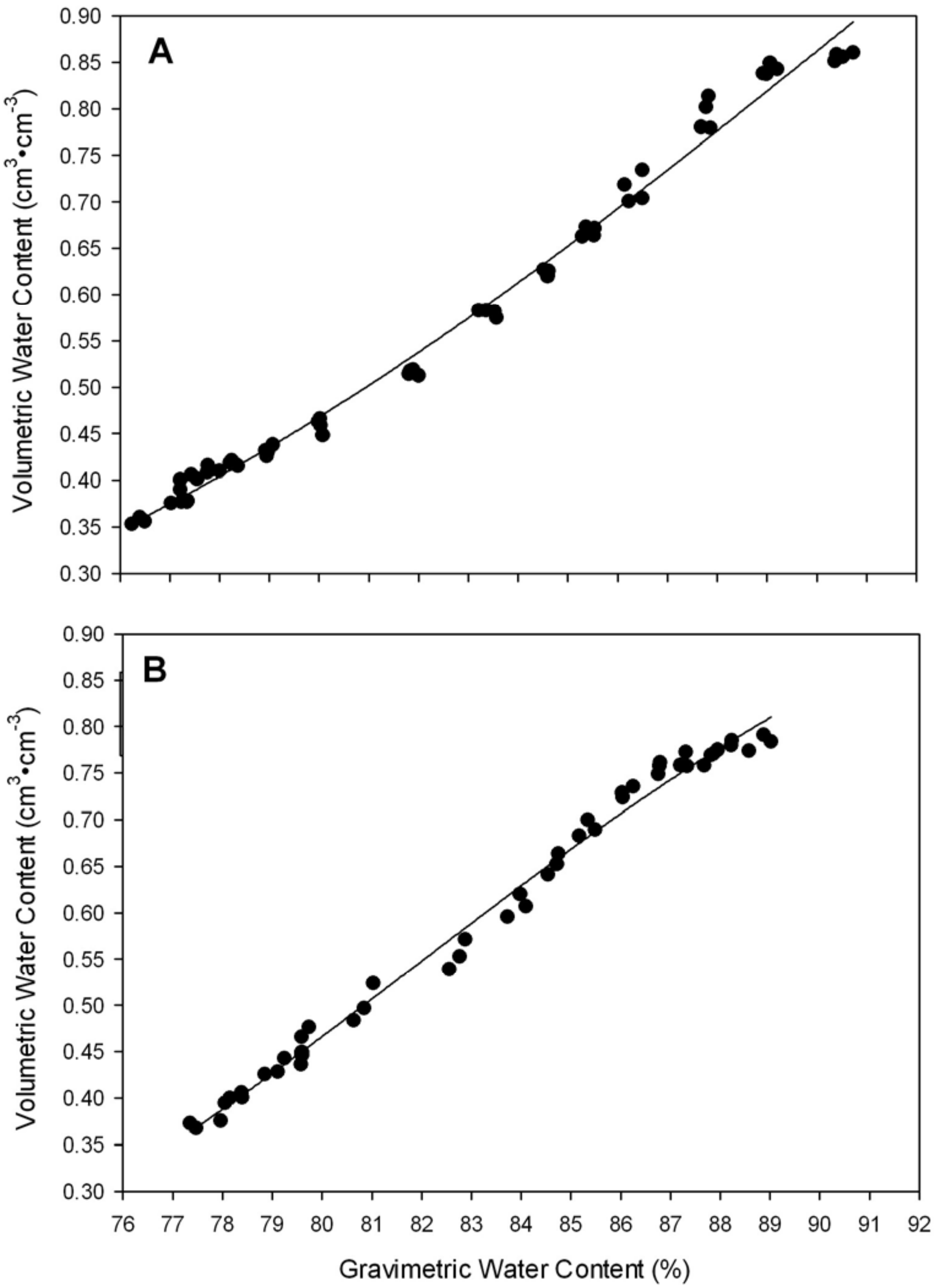

Figure 2. Relationship of gravimetric water content and volumetric water content (VWC) in order to estimate VWC using substrate weight. Data were fit to a sigmoidal 3-parameter function ($y = a/1+e^{-((x-b)/c)}$) with R^2 = 0.992 for Sunshine LB2 (A) and R^2 = 0.991 for Fafard 3B (B).

Table 1. Effects of substrate and substrate matric potential on irrigation volumes and WAE on *Catharanthus roseus* (L.) 'Cora Lavender' growing in 13 cm pots.

Treatment combination		Irrigation (mL)			
Substrate	Target matric potential (kPa)[Z]	Applied[Y]	Leached[X]	Retained[W]	WAE (%)[V]
Sunshine LB2	-2	4021 a[U]	313 a	3708 a	91.9 a
	-10	2432 b	153 a	2279 b	93.6 a
Fafard 3B	-2	4341 a	236 a	4105 a	94.9 a
	-10	2834 b	137 a	2696 b	95.0 a
Effects (*P* values)	Substrate	0.230	0.613	0.185	0.357
	Tension	0.001	0.181	0.001	0.709
	Substrate*Tension	0.887	0.738	0.972	0.736

[Z]Substrates maintained at estimated matric potential tensions of 2 kPa or 10 kPa.
[Y]Total irrigation volume in mL applied per plant.
[X]Total irrigation volume leached in mL per plant.
[W]Total irrigation volume in mL not leached and retained by substrate per plant.
[V]Water application efficiency as a percentage estimated by dividing irrigation volume retained by irrigation volume applied and mulitplying by 100.
[U]Means within a column with different letters are significantly different according to Duncan's multiple range tests ($P \leq 0.05$).

Table 2. Effects of substrate and target matric potential on growth of *Catharanthus roseus* (L.) 'Cora Lavender' growing in 13 cm pots.

Treatment combination							
Substrate	Target matric potential (kPa)[Z]	Growth index[Y]	Leaf area (cm^2)	Shoot dry weight (g)	Root dry weight (g)	WUE (g/L)[X]	Flowers per plant
Sunshine LB2	-2	24.6 a[W]	654 ab	6.02 a	0.80 b	2.34 a	20 a
	-10	18.1 c	440 c	4.01 c	0.65 c	2.18 a	11 b
Fafard 3B	-2	22.2 b	747 a	6.73 a	0.99 a	2.09 a	20 a
	-10	21.3 b	554 bc	5.25 b	0.81 b	2.44 a	17 a
Effects (*P* values)	Substrate	0.610	0.047	0.001	<0.001	0.951	0.074
	Tension	<0.001	<0.001	0.000	0.001	0.528	0.001
	Substrate*Tension	0.001	0.827	0.318	0.700	0.098	0.068

[Z]Substrates maintained at estimated matric potential tensions of 2 kPa or 10 kPa.
[Y]Growth index calculated as the sum of height and two widths divided 3.
[X]Total plant water use efficiency calculated as grams of shoot and root dry weight divided by liters plant water use
[W]Means within a column with different letters are significantly different according to Duncan's multiple range tests ($P \leq 0.05$).

Table 3. Effects of substrate and irrigation treatments on substrate pH and EC at end of trial.

Treatment combination			
Substrate	Target matric potential (kPa)[Z]	pH	EC ($mS \cdot cm^{-1}$)
Sunshine LB2	-2	6.6 a[Y]	1.04 a
	-10	6.3 ab	1.06 a
Fafard 3B	-2	6.0 bc	1.26 a
	-10	5.7 c	0.91 a
Effects (*P* values)	Substrate	0.004	0.827
	Tension	0.100	0.314
	Substrate*Tension	0.812	0.247

[Z]Substrates maintained at estimated matric potential tensions of 2 kPa or 10 kPa.

[Y]Means within a column with different letters are significantly different according to Duncan's multiple range tests ($P \leq 0.05$).

Evaluating Irrigation Scheduling Based on Daily Evapo-transpiration or Plant Demand of Container Grown Woody Plants

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Index Words: Daily water use, set point, irrigation, nursery crop

Significance to the Industry: Container nursery production depends on irrigation usually in the form of overhead sprinklers. Irrigation water management is a key consideration in ornamental crop production and for reducing the impact of fertilizer and pesticide runoff on local water resources. Irrigation scheduling based on daily water use (DWU) improved water use efficiency for nursery crops compared to scheduling with timers (1). A recently proposed plant demand-based irrigation system uses photosynthetic rate as a sensitive indicator of plant water status to schedule irrigation (2). It assumes that growth would not be compromised when an irrigation set point was used based on the substrate water content where photosynthesis begins to decline due to water stress. Using *Boxwood* (*Buxus microphylla* ‘Green Ice’) it was found that overall water use as well as water use efficiency (WUE) was improved using either the DWU or demand-based scheduling system without reducing plant biomass and plant quality under outdoor nursery conditions.

Nature of Work: The study was conducted at the University of Kentucky Horticulture Research Farm in Lexington in conjunction with Tennessee in 2012. *Buxus microphylla* ‘Green Ice’ plants were obtained as 4-inch liners from Spring Meadow Nursery (Grand, Haven, MI). Plants were potted into 1-gal containers with 85% pine bark: 15% peatmoss (vol:vol) (Renewed Earth, Inc., Kalamazoo, MI). After transplanting, plants were fertilized with 19.0N–2.2P–7.5K controlled release fertilizer with micronutrients (HFI Topdress Special; Harrell’s Inc.) at the medium rate (8 g per container). Irrigation zones were 10 square feet with 18 plants per replicate. There were three replicate zones per treatment. Each treatment replicate was controlled by a Rain Bird 13DE04K solenoid valve (Rain Bird Corporation). Irrigation was applied through four overlapping Toro 570 Shrub Spray Sprinklers (The Toro Co., Riverside, CA) per irrigation zone. Emitters were mounted on 1.3-cm diameter risers at a height of 66 cm. The pH and electrical conductivity of leachate was monitored during the study. Volumetric water content was measured using Echo-5 probes (Decagon Devices, Pullman, WA) inserted into two containers per irrigation zone. Daily water use (1) was calculated based on the average soil moisture readings of the two ECHO-5 probes per plot and irrigation was applied daily at 9 am. The demand-based irrigation system (2) was based on substrate moisture set point selected at the point photosynthetic rate declined by 90% of maximum. The system was designed to apply irrigation to return the moisture to container capacity (0.53 cm^3) after substrate moisture set point (0.28 cm^3) has been reached (Figure 1). Acquisition and control were monitored using a data logger (CR 1000, Campbell Scientific, Logan, UT). Total WUE was estimated by dividing total dry weight at the time of harvest by total water volume applied (irrigation plus precipitation; L per container). Year 2012 was one of the hottest and driest in the weather history of Lexington. Plant growth index was calculated [(height+width1+width2 perpendicular to width1)/3] to determine plant performance under the different irrigation regimes.

Results and Discussion : The average growth index and average plant dry weight at the end of study were not statistically different between plants grown in DWU or demand-based irrigation treatments. Plant physiological parameters such as leaf water potential, photosynthetic rate, transpiration rate and stomatal conductance were also not significantly different between plants in both the treatments. Total irrigation water applied was significantly (35%) more for the DWU based treatment than the on-demand irrigation treatment. Plants under on-demand treatment significantly increased total WUE by 47% compared to plants in the DWU treatment. The pH and electrical conductivity of leachate were similar between the treatments and were within the acceptable range during the study. Both the DWU and demand-based systems applied less water that would be applied using a conventional timer-based system. However, these results suggest that irrigation based on plant physiological parameters can further reduce water use compared to using DWU based methods. In addition, for woody plants with lower water use requirements such as boxwood, DWU methods may significantly increase water usage by irrigating every day compared to a plant demand-based water application, because of the inherent inefficiencies of overhead sprinkler irrigation (*i.e*. non-target water application).

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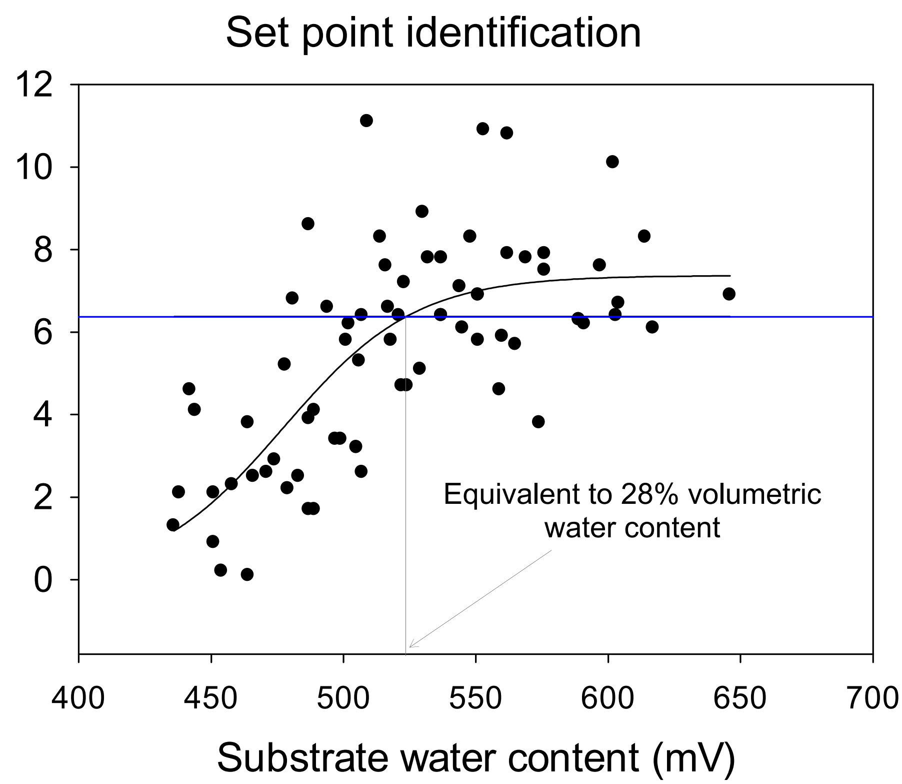

Figure 1: Relationship between photosynthesis rate and substrate water content of *Boxwood* (*Buxus microphylla* ‘Green Ice’). Blue line represents the chosen set point.

Phosphorus Removal and Accumulation by Sweet Basil (*Ocimum basilicum*) Grown in Floating Treatment Wetlands

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Index words: Floating treatment wetlands, Alternative cropping system, Irrigation runoff water, Nutrient remediation

Significance to Industry: Floating treatment wetlands (FTWs) are a useful tool for removing excess nutrients and pollutants from production runoff water at ornamental nurseries. This plant-based treatment system is relatively low maintenance, and when performing optimally, reduces prevalence of nuisance aquatic weeds without the use of chemicals. When FTWs are successful, our surface water resources are protected from increased nutrient pollution, nutrients are removed from the internal cycle of the pond, biomass is harvested for use as a compost material, or plant material is grown for profit while cleaning water. The selection of proper plant species is essential for optimal water filtration. Sweet basil (*Ocimum basilicum*) was screened for its potential to cleanse water and to concentrate nutrients. Potentially FTWs could grow a marketable crop as an alternative marketing system, while recycling nutrients otherwise lost to runoff.

Nature of Work: Runoff from ornamental nurseries typically contains high amounts of phosphorous and nitrogen, which can cause eutrophication in the surrounding bodies of water (1,2). Eutrophication can lead to algal blooms and subsequent declines of water body dissolved oxygen, creating an anoxic environment in which aquatic animals cannot survive (3). Floating treatment wetlands can be deployed in waters too deep for aquatic plants to survive and can adapt to changing water levels (3, 4). Microbial populations colonizing the root systems of plants within FTWs and uptake of nutrients into tissues are two methods by which FTWs facilitate removal of phosphorous, nitrogen, and other fine suspended solids from water (1, 2, 5). Both aquatic and terrestrial plants can be used in FTWs (1). Some plant species can accumulate higher concentrations of nutrients within tissues, thus when selecting plants for inclusion within FTWs, a plants' ultimate capacity to both fix nutrients and facilitate their removal from water are important factors. We evaluated the capacity of sweet basil (*Ocimum basilicum*) established in experimental FTWs, exposed to moderate and high nutrient loading rates, to fix nutrients within tissues and to stimulate remediation of nutrients from aqueous solution.

Eight experimental units (EUs) were established with a mixture of *O. basilicum* 'Genovese' and *O. basilicum* 'Nuphar.' Each EU consisted of a 100 gal Rubbermaid® stock tank, filled with 90 gallons of water on which a 2' x 2' solid core foam buoyant mat with 10 precut holes was floated (50% surface cover). Ten basil liners (5 of each cultivar), roots washed and wrapped with ½" thick coir pressed fiber to stabilize the plant, were placed individually into a 5 cm diameter aerator cup and seated within the foam mat. The leaves of each basil plant were held above the water surface, while the root system was completely submerged.

The moderate (5.22 ± 1.12 mg/L N and 1.15 ± 0.09 mg/L P) and high (14.2 ± 2.36 mg/L N and 2.70 ± 0.17 mg/L P) nutrient loading rates were imposed using a 15-5-15 water soluble fertilizer (The Scotts Company LLC, Marysville, OH) supplied to respective EUs at a 7-day hydraulic retention. Water quality parameters were monitored on a weekly basis and included total nitrogen (TN), total organic carbon (TOC), minerals, pH, dissolved oxygen, and temperature (°C). Total N and TOC were determined via TOC/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 mineral concentrations (P, K, Ca, Mg, Zn, Cu, Mn, Fe, S, Na, B, and Al) were quantified via inductively coupled plasma emission spectrophotometer (ICP-ES, 61E Thermo Jarrell Ash, Franklin, MA). Plant height and root length (cm) were measured every seven days. After six weeks, three representative plants were harvested from each EU, weighed, dried, reweighed, and separate root and shoot tissues submitted to the Clemson University Agricultural Service Lab for tissue analysis. We discuss results from both water and plant tissue analysis for total P only, as P is typically the nutrient limiting eutrophication in fresh water systems.

Changes in concentration from influent to effluent as impacted by the presence of FTWs established with *O. basilicum* were quantified, and the influence of fertilizer treatment on the growth of (root length and shoot height) and P accumulation by *O. basilicum* in FTWs were evaluated. Treatment impacts on the above factors were quantified using analysis of variance ($\alpha > 0.05$) and means were separated using Tukey's LSD. Data were analyzed using JMP v10.0 (SAS Institute, Cary, NC).

Results and Discussion: Floating treatment wetlands established with sweet basil facilitated removal of P from simulated production runoff (Fig. 1). Phosphorus export from EUs with the moderate fertilizer treatment was reduced by 64% from influent levels; while P export from High fertilizer treatment was reduced by 36%. Though these reductions were significant ($P < 0.0001$), P concentrations in effluent of both moderate and high treatments were still excessive and could contribute to increased rates of eutrophication, as eutrophication can be stimulated with soluble reactive P concentrations as low as 50 ppb.

Basil plants exposed to both the high and moderate treatments grew over time (Figure 2). Maximum shoot height (harvestable size) was attained between weeks 5 and 6 (Figure 2A). The basil plants exposed to high fertilizer treatments grew more than those plants exposed to moderate fertilizer treatments (Table 1A). Root growth of basil was variable over time for both treatments, with the roots of basil plants exposed to the high treatment growing slightly longer than those of the moderate (Table 1B). We recorded a decline in root length between 27 July and 7 August (Fig. 2B). This senescence of root tissues may have been caused by either temperature stress as water temperatures increased by 3C over that 10 day period (from 27 to 30 C) or by decreased oxygen saturation (2.1 mg/L to 1.7 mg/L) around the root systems associated with higher water temperature during that same time period (6).

The mass of P removed per unit area of FTWs (g/m^2) when basil plants were harvested differed between the high and moderate treatments (*Fertilizer,* Table 2). The mass of P fixed in the shoot system of the basil plants was much greater than the P fixed in the plant root systems (*Organ,* Table 2, Fig. 3). More P was fixed in the shoots of basil plants exposed to the high fertilizer treatment than plants exposed to the moderate fertilizer treatment, while a similar mass of P was fixed by the root systems, without regard to fertilizer treatment.

When considering plant harvest as a means to facilitate complete removal of nutrients from aquatic systems, it is important to differentiate how plants partition nutrients. Because basil plants fixed the majority of absorbed P in their shoot systems, plant harvest within these FTWs could involve successive shoot harvest and continued regrowth from the root system. Despite the greater mass of P fixed in the shoot system of the basil plants exposed to the high fertilizer treatment, only 36% of the loaded P was removed, the effluent P concentration could still induce deleterious environmental effects associated with eutrophication. Two options could enhance the rate of P removal and include additional retention time within the pond system before water release and/or additional surface area coverage with planted FTWs.

Acknowledgements:
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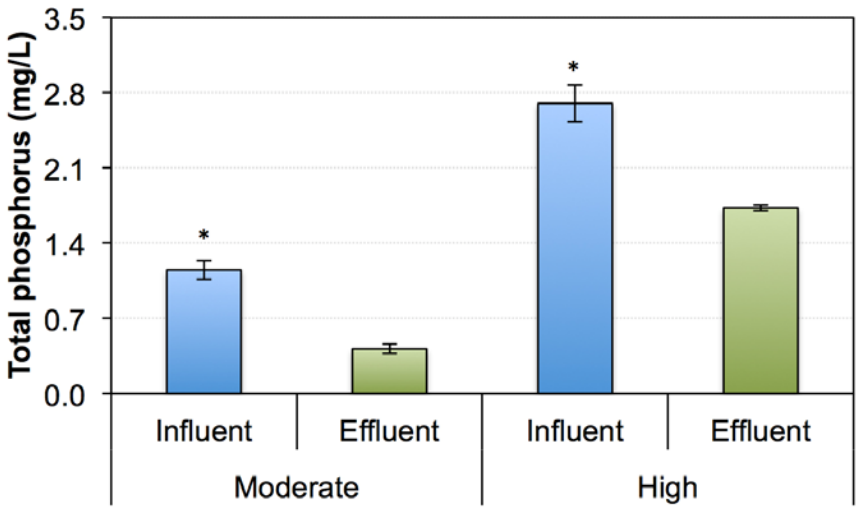

Figure 1. Change in total P concentration of influent and effluent as influenced by floating treatment wetlands established with Sweet basil (*Ocimum basilicum*). High and moderate fertilizer loads were refreshed weekly and the experiment was conducted over a 6 week period. Bars represent mean values for influent and effluent P concentration over time ± the standard error of the mean. The * designates a significant difference between influent and effluent values ($P < 0.0001$) for both moderate and high fertilizer treatments.

Table 1: Shoot height (A) and root length (B) of Sweet basil (*Ocimum basilicum*) established in floating treatment wetlands for 6-weeks as impacted by fertilizer (high, moderate). Means with the same letters are not significantly different, Student's t test ($\alpha \leq 0.05$).

		2-Way ANOVA	DF	*P > F*
A	Shoot	Week	1	< 0.0001
		Fertilizer	1	< 0.0001
		Week x Fertilizer	1	0.0478
		Level	*LS Mean*	
		High	36.8 A	
		Moderate	29.0 B	
B	Root	Week	1	0.0067
		Fertilizer	1	0.0050
		Week x Fertilizer	1	0.7661
		Level	*LS Mean*	
		High	18.0 A	
		Moderate	15.4 B	

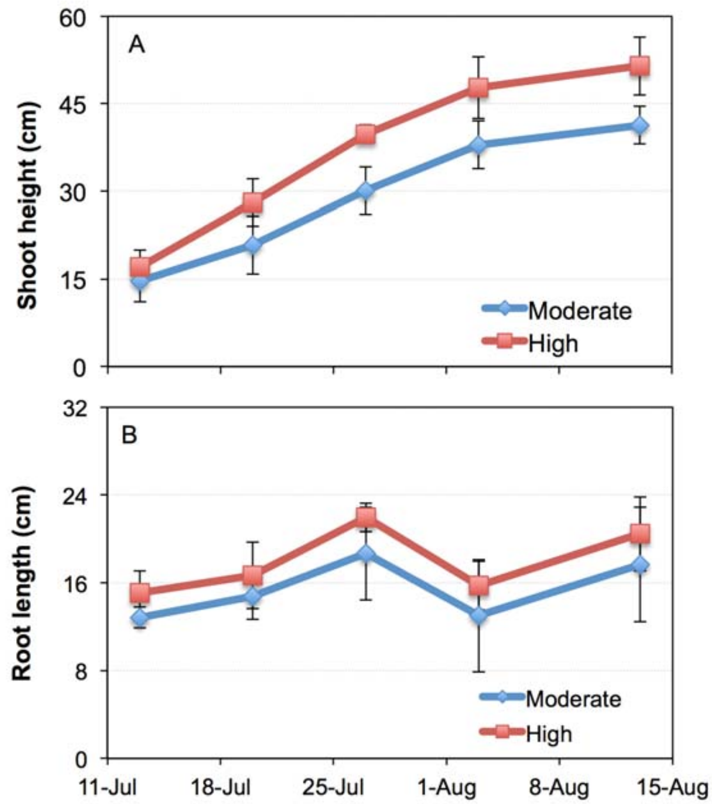

Figure 2. Shoot (A) and root (B) growth (mean ± standard error) of Sweet Basil (*Ocimum basilicum*) established in floating treatment wetland over a 6-week period after exposure to 2 fertilizer loading rates (moderate and high).

Table 2: Changes in phosphorus accumulation (g/m^2/6 weeks) and allocation within Sweet basil (*Ocimum basilicum*), grown in floating treatment wetlands over a 6-week period, as influenced by fertilizer (moderate and high), and organ (shoot and root).

2-Way ANOVA	DF	*P > F*
Fertilizer	1	< 0.0001
Organ	1	< 0.0001
Fertilizer x organ	1	< 0.0001

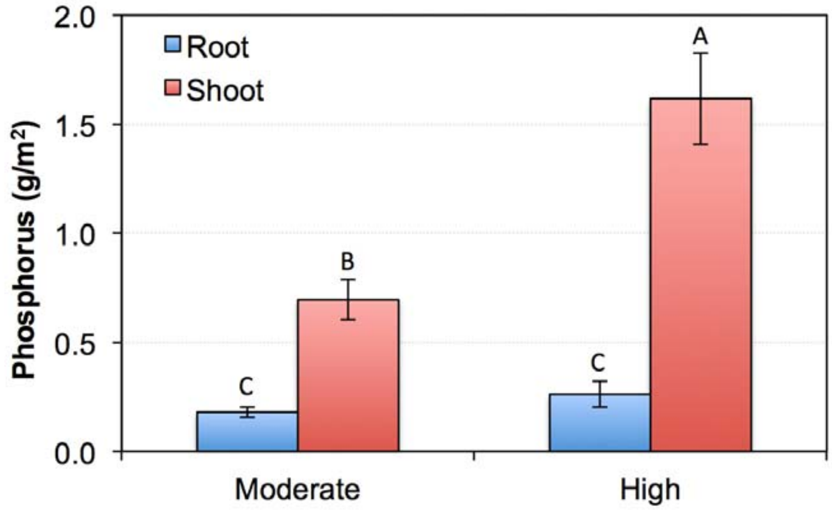

Figure 3. Total phosphorous content (mean ± standard error) of shoots and roots of Sweet basil (*Ocimum basilicum*) grown in floating treatment wetlands and exposed to either moderate or high nutrient loads over an 6-week experimental period. Means with different letters are significantly different, Student's *t* test ($\alpha \leq 0.05$).

Grower Identified Priorities for Water Research in Ornamental Crops

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Index Words: fertility, irrigation, treatment, remediation, leachate, container-grown, field-grown, survey, listening session

Significance to the Industry: Grower priorities in water research need to be regularly identified. The most recent strategic outlook on water management was reported by Beeson et al. (1). While many previous concerns remain, their priority has changed with the inclusion of emerging issues. This publication provides a synopsis of a nationwide survey and grower listening sessions to identify and validate the ornamental producers' current and future needs in water research.

Nature of Work: Nursery, floriculture, and propagation production accounted for 81% ($9.48 billion) of 2009 specialty crop production in the United States (USA). Access to high quality water sources for irrigating these economically significant crops is increasingly limited. There are many production-related, environmental, and economic issues associated with the use of water, including recycled, reclaimed, surface, and ground water. It is critical to develop sustainable runoff, containment, and remediation technologies and to identify alternative sources of water. A team of research and extension specialists facilitated by a Specialty Crops Research Initiative Planning Grant (NIFA Project # 2011-51181-30633) distilled the results from a survey and round-table discussions to ascertain specific research and extension related priorities identified by growers as necessary to achieve conservation-based water use and management practices. Our objective is to address the concerns and priorities identified by specialty crop producers while addressing gaps with current and future research.

Materials and Methods: To better understand current practices and future water-related needs as perceived by grower stakeholders, we conducted a national survey, in cooperation with the USDA-SCRI research project "Managing Irrigation and Nutrition via Distributed Sensing (MINDS)", collecting information from 152 industry stakeholders (44% completion rate). Baseline data related to current production practices, which included irrigation, fertilization, and best management practices, was collected from growers producing ornamental crops in greenhouses, container nurseries, and field operations. In addition, five in depth round-table discussion sessions were conducted at the Mid-Atlantic Nursery Trade Show, Gulf States Horticultural Expo, California Grown Show, OFA Short Course, and the Farwest Show with a total of 36 industry participants.

Results and Discussion:

National Survey. Of the 152 respondents; 96 identified themselves as a greenhouse, 83 as container nursery and 59 as a field nursery operation applying 11.8, 80.3 and 31.4 million gallons (MG), respectively, of water annually. The primary source of water for ornamental operations was well water (65%), surface water (25%) or collected rainfall or retention pond (43%). The majority of respondents (49%) identified state government agencies as controlling their water, while 25% indicated that a local water board or government controls their water.

Of the operation surveyed, 86% stated they have adequate water flow for day-to-day irrigation. However, operational water restrictions do occur as a result of daily pumping capacity requiring water storage, therefore 40 of surveyed operations store excess water using ponds (68%) or tanks and cisterns (36%) to ensure they have adequate volume to irrigate during times of water shortage such as a drought. Recycled water collected from greenhouse and nursery operation is primarily utilized to irrigate container production. Alternative, off-site water is cost prohibitive or municipal water has been restricted. Regardless, 50% of respondents stated the irrigation might not always be applied as needed due to limited capacity on hot days or during a drought. This is dealt with primarily by reducing irrigation frequency on crops that can tolerate short term-water deficit. To overcome water shortage issues, growers indicated they would prefer to drill additional wells and construct new containment ponds that can be used to collect rainwater and recycle runoff.

Best Management Practices that include vegetative buffer strips, sediment basin and riprap have been implemented on 60% of ornamental nursery greenhouse operations surveyed. However, the majority of ornamental operations do not treat runoff water before it leaves the operation, with 40% of respondents indicating that no treatment was required. Of the operations that treat water before leaving the site, 83% utilize vegetated buffer strips and 17% have constructed wetlands. Operations filter (39%) or chemical treat (i.e. chlorination) (26%) and blend (50%) recaptured water before using it to irrigate crops. In addition, approximately 60% of operations utilize aquatic vegetation or vegetative buffers to maintain recycling collection/recapture ponds.

Round-table Discussions. The dominant “challenges” related to water in ornamental crops were identified as pathogen contaminants, future water availability, and implications of water runoff from production facilities. Growers attending the listening sessions identified cost savings and having increased water capacity as primary reasons to collect runoff or storm water. In addition, growers stated that more information is needed on acceptable water quality measures, cost of effective water treatment to mitigate potential spread of disease, and sizing water retention ponds for given ornamental producers to minimize land use.

The participants’ top “concerns” were water quantity or availability (i.e. permitting, droughts) and future government or environmental regulation. If it becomes a necessity to stretch their existing water supply or seek greater quantities of water, ornamental producers identified altering existing irrigation infrastructure to low-volume application technology or utilizing reclaimed water (i.e. tertiary treated wastewater) as an alternative water source. However, growers identified the many challenges to utilizing reclaimed water that included availability, cost and quality. Growers indicated that reliability and longevity are their primary concerns when implementing new technology to assist in on-site water management, however, they stated the cost (amount and if justifiable) as a function of return on investment must be considered.

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Effect of Spacing on Evapotranspiration Rate of Container-grown Ornamentals

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Index words daily water use, irrigation, percent plant canopy cover, water

Significance to the Industry Plant spacing has a significant effect on the water use and, therefore, the irrigation requirement of container-grown ornamentals. Our research provides details regarding the relationship between container spacing and water use that can be used to predict changes in water demand that would be expected as container-grown plants are spaced in different arrangements during production. In general, spaced plants (e.g. 20-30% canopy cover) used up to 50% more water than the same plants grown under close spacings (90-100% canopy cover). Linear relationships established between percent plant cover and daily water use can be used to estimate daily water loss and improve irrigation management in container nurseries.

Nature of Work Daily water use of container plants is due to evapotranspiration (ET), the combined evaporative loss of water from substrate and plant leaf surfaces. Daily water use can be measured by weighing containers early in the day after irrigation and subtracting the weight of same containers at dusk. Daily water use (g/container) can be converted to volume of water (cm^3/container) because the density of water is 1 g/cm^3. Two ET parameters can be calculated based on volume of water lost per container: ETc and ET. Container ET (ETc) is the equivalent depth of water (cm) that would need to be applied over the container to supply the volume of water lost from the container. ETc is calculated by dividing the volume of water lost (cm^3/container) by the top area of the container (cm^2/container). The parameter ET is the equivalent depth of water (cm) lost over the production area and is calculated by dividing the volume of water lost from the container (cm^3/container) by the area allotted the container (cm^2/container). The area allotted each container (cm^2/container) is the product of multiplying the average distance from the center of one plant to another within the row by the distance between adjacent rows. For example, if plants in a square arrangement are 40 cm center-to-center within the row and adjacent rows are 40 cm apart, then the allotted area would be 1600 cm^2/container. If the same plants were in an equidistant, offset pattern the distance between adjacent rows would decrease to 34.6 cm (0.866*40 cm) and the allotted area per plant would be 1386 cm^2 (40 cm*34.6 cm).

ET is dependent on plant canopy coverage and can be predicted using weather data. With full plant canopy coverage, essentially all incoming solar radiation is intercepted and little passes through to be absorbed by the substrate or production and/or container surfaces. In this case, ET is at a maximum rate and is affected primarily by weather (solar radiation, temperature, humidity, wind). In a nursery, as plant canopies grow and interact with neighboring plants, containers are typically spaced. This results in partial plant canopy coverage of the production area so that less solar radiation is intercepted on a production area basis (lower ET rates). Partial plant cover has two effects besides decreased ET. One effect is an increase in the temperature of the plant canopy due to heat generated by dark-colored container and production surfaces absorbing the un-intercepted solar radiation. A second effect of partial plant cover is that while total solar radiation interception decreases in the allotted area, the amount intercepted by each plant increases as light is intercepted by the sides of the canopy that were previously blocked from this radiation in a more dense planting. The net effect of spacing containers is lower ET rates (lower canopy cover) but higher ETc (higher temperatures and greater solar radiation interception per plant). The objective of this research was to evaluate the relationship between container spacing, canopy cover, ET and ETc so that we can better predict the irrigation requirement of container-grown plants.

We conducted four experiments to investigate the relationship between container spacing, plant canopy cover, ETc and ET (Table 1). Prior to each experiment, we measured the daily water loss of 28 test plants (same day and same spacing arrangement) and used the results to place the 28 plants into four treatment groups so that each group of seven test plants would have the same average water use. Each treatment group was assigned one of four spacings to be evaluated. Because of the equidistant, offset spacing arrangement used for each spacing treatment, the seven test plants were arranged in a 2-3-2 hexagonal shape with 19 border plants placed at the perimeter of the hexagon in the same arrangement as the test plants. Daily water loss of each container was measured on four separate days with the spacing treatments randomly reassigned to each of the four groups prior to each daily ET measurement. ETc and ET were calculated from water loss data as described previously.

Digital photographs were taken above each spacing treatment and percent canopy cover was estimated using free image analysis software (GIMP; http://www.gimp.org/). After opening the photo and cropping it as needed, we used the circle selection tool to circle and then delete all dense canopy cover in the image. Deleting turns colored pixels to white pixels. A histogram set at a threshold of 255 was then used to determine the proportion of white pixels, which we used as an estimate of percent canopy cover.

Each experiment was analyzed statistically as a randomized block design with four blocks (days), four treatments (spacings), and seven replications (plants). The relationship between percent canopy cover and ET was based on grouping data from all four experiments after normalizing ET so that ET of the full canopy treatment of each experiment was 1.

As the spacing between containers increased, ETc increased for all experiments (Table 2). Increases in observed ETc at the widest spacings relative to the ‘pot-to-pot’ (0 inch) spacing, were 24%, 52%, 35%, and 41% for Expts. 1, 2, 3, and 4, respectively. Conversely, ET decreased as plant coverage decreased from full to partial cover. If data from all experiments were combined, a good linear relationship between percent plant cover and normalized ET was observed (Fig. 1). If we can predict the potential ET of a full plant canopy, the linear relationship in Fig. 1 can help us to estimate the actual ET from which we can calculate ETc and, thus, the irrigation requirement.

In summary, similar-sized plants were observed to lose up to 50% more water when spaced than when placed in a close arrangement. The increase in water use of spaced plants could be predicted based upon changes in percent canopy coverage. We are working with nurseries to determine the most effective means for monitoring percent cover to guide irrigation.

Acknowledgements This project was made possible through grant support from the Southwest Florida Water Management District.

Table 1. Experiments used to evaluate the effect of plant spacing on daily water use of container-grown ornamentals grown in trade #3 containers.

	Expt 1	Expt 2	Expt 3	Expt 4
Plant species	*Viburnum odoratissimum*	*Viburnum odoratissimum*	*Ligustrum japonicum*	*Ligustrum japonicum*
Container top area (cm^2)	616	616	548	578
Spacing treatments (inch)[z]	0, 3, 6, 9	0, 5.5, 11, 16.5	0, 3, 6, 9	0, 2, 4, 6
Plant height, width (inch)	13, 17	14, 18	17, 16	16, 15
Dates measured (2013) [y]	Mar 5-13	Mar 15-26	June 12-25	July 10-16
Solar radiation ($W/m^2/hr$)[x]	179 (138-211)	227 (204-249)	256 (185-337)	267 (181-332)
Min daily temp (^oF)	54 (49-61)	52 (46-58)	73 (70-76)	74 (73-75)
Max daily temp (^oF)	83 (82-85)	86 (83-87)	94 (90-95)	91 (85-95)

[z] Distance between top edges of adjacent containers in an equidistant, offset arrangement
[y] ET measured on four days without rain within the range of dates
[x] Multiply watts per square meter per hour by 0.0863929 to get equivalent units of megajoules per square meter per day

Table 2. Effect of container spacing on allotted area per plant (At), percent plant canopy cover (PC), container ET (ETc), and ET.

Spacing[z] (inch)	At (cm^2)	PC (%)	ETc (cm)	ET (cm)
		Experiment 1		
0	680	95	0.63	0.58
3	1100	59	0.69	0.39
6	1620	40	0.74	0.28
9	2240	29	0.78	0.21
$HSD_{0.05}$[y]			*0.06*	*0.03*
		Experiment 2		
0	680	95	0.65	0.59
5.5	1530	52	0.84	0.34
11	2710	25	0.92	0.21
16.5	4230	16	0.99	0.14
$HSD_{0.05}$			*0.05*	*0.05*
		Experiment 3		
0	560	88	0.75	0.72
3	920	68	0.85	0.50
6	1380	49	0.91	0.39
9	1930	35	1.01	0.29
$HSD_{0.05}$			0.08	0.04
		Experiment 4		
0	640	95	0.81	0.73
2	900	84	0.97	0.63
4	1200	70	1.06	0.51
6	1540	64	1.14	0.43
$HSD_{0.05}$			0.08	0.04

[z] Distance between top edges of adjacent containers in an equidistant, offset arrangement

[y] Spacing effect was significant for all four experiments (*P*<0.001); $HSD_{0.05}$=Tukey's Honest Significant Difference; means are the average of 28 observations.

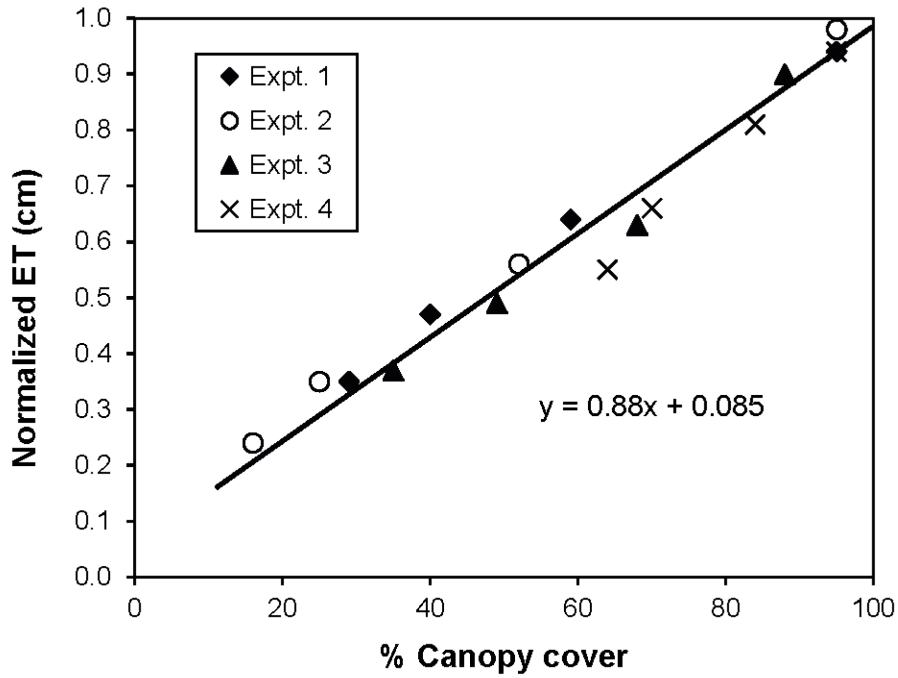

Fig. 1. Relationship between percent canopy cover and normalized evapotranspiration rate (ET) for four experiments. ET was normalized (100% canopy = 1) so that the effect of canopy coverage could be compared for all four experiments.