Spring Recovery of Constructed Wetland Plants Affects Nutrient Removal From Nursery Runoff[1]

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Abstract

The nursery/greenhouse industry is the fastest growing segment of United States agriculture. Consumer demand for excellent product quality requires luxury applications of water and agricultural chemicals. These cultural practices tend to yield significant volumes of runoff rich in nutrients and pesticides. A capture and recycle system at the Nursery/Floral Crops Research and Education Center at the Texas A&M University was fitted with 12 sub-surface flow (SSF) and 12 free-surface flow (FSF) wetland cells. A single pass of runoff through constructed wetland cells provided substantial reduction of runoff nutrient concentrations, particularly NO_3-N, without increasing electrical conductivity (EC), an indicator of salinity. Nitrate-N concentration reductions were greater in the FSF cells than SSF cells, while the greatest reductions in ammonium and nitrites were obtained with SSF cells. Growth of *Iris pseudacorus* L. and *Canna* x *generalis* L.H. Bailey during spring growth was greater in the FSF wetland cells, while that of *Colocasia sp.* Fabr. was greater in the SSF wetland cells. *Equisetum hyemale* L. grew equally well in both cell types. Interactions among irrigation water sources and container media types for growth indices occurred for *Juniperus procumbens* (Endl.) Miq. 'Green Mound' and *Ilex vomitoria* Ait. 'Nana', but not for *Raphiolepis indica* L. 'Carmelita'.

Index words: water conservation, water reuse, irrigation, container nurseries, non-point source pollution, constructed wetlands.

Species used in this study: *Canna* x *generalis*, *Colocasia sp.*, *Equisetum hyemale*, *Ilex vomitoria* 'Nana', *Iris pseudacorus*, *Juniperus procumbens* 'Green Mound', *Raphiolepis indica* 'Carmelita'.

Significance to the Nursery Industry

Runoff collection, treatment, and reuse offers a combined benefit to nursery and greenhouse industries by reducing the volume of fresh water used for irrigation and limiting the release of nutrients and pesticides to the environment in discharged runoff water. Initial evaluations of wetland performance for treating collected runoff indicated that wetland cells substantially reduced nitrogen concentrations without increasing salinity using a single pass through wetland cells. Constructed wetlands may provide a viable, simple, low-technology method for reducing nutrient loads to comply with environmental standards for discharging nursery runoff. A part of the constructed wetlands cost might be recoverable by using the wetlands to produce bog and water garden plants for sale in the retail or wholesale market. Single pass wetland treated water did not induce salt toxicity symptoms when reapplied to container-grown *J. procumbens*, *I. vomitoria*, or *R. indica*. However, reduced nitrogen levels in the treated water may necessitate supplemental fertigation or addition of granular fertilizers to maintain growth similar to that of plants watered with fertilizer injected water or direct nursery runoff, particularly if the medium selected tends to decompose rapidly. The bark:kenaf medium decomposed more rapidly than the bark:sand medium regardless of the irrigation water source.

Introduction

The nursery and greenhouse industry is the fastest growing segment of United States agriculture (5, 11). Consumer demand requires a near-perfect product from the industry. Consequently, water and chemical requirements of these industries are among the highest for commercial agricultural crops. Containerized crops grown in artificial media typically require substantial applications of soluble fertilizers and significant leaching of potting media occurs (16). Nitrogen applications for some floral crops can be as high as 4,480 kg/ha (4,000 lb/A). In addition, a myriad of pesticides are used to maintain crop health in confined growing conditions. These cultural practices may result in runoff containing significant concentrations of nutrients and pesticides. High water usage in nurseries compounds problems associated with nutrient- and pesticide-rich runoff. Not only do high irrigation rates lead to greater runoff volumes, they may deplete local water supplies. In Texas, several large nurseries are located in regions facing water shortages where demand will likely exceed supply in the near future.

Throughout the United States, environmental issues are rapidly becoming a focus for floral and nursery producers (13, 14, 15). Greater emphasis on prevention of surface and ground water contamination, pesticide usage, solid waste disposal, and energy consumption has significantly influenced business and cultural practices. Some regulations have already been imposed in a number of states (e.g., Texas, California, and Florida). However, increased regulation of water consumption and quality is anticipated with increased public environmental concern (14).

Water conservation practices, pollution prevention strategies, and alternative irrigation water supplies are needed to balance the drive for high-quality products with the need for environmental stewardship (13, 14). Capture, treatment, and

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reuse of runoff provides a potential solution. Retention of runoff water on-site reduces the movement of nutrients and pesticides to local surface water resources. In addition, reuse of captured runoff water may greatly reduce fresh water consumption.

Constructed wetlands may provide a viable low-technology method for reducing nutrient loads to comply with environmental standards for discharging nursery runoff or reducing organic contaminants, such as herbicides or pesticides, prior to reapplication to crops. Vegetation in constructed wetlands serves as a substrate for microbial growth. Transmission of oxygen from leaves to roots in SSF cells creates microsites favorable to microbial growth adjacent to the root zone (9).

Objectives of this experiment were to: 1) assess the effects of four wetland species' resumption of spring growth on the efficacy of constructed wetlands in which they reside to remove nutrients from nursery runoff, and 2) to compare the effects of wetland-treated water, direct nursery effluent, and conventional irrigation water on three evergreen shrub species grown in contrasting bark and kenaf based media.

Materials and Methods

Wetland plant regrowth and efficacy of nutrient removal. Between fall 1995 and summer 1996, 870 sq m (1041 sq yd) of container nursery production space at the Nursery/Floral Crops Research and Education Center at the Texas A&M University, College Station, TX, was equipped with a subsurface capture and recycle system as previously described (7). The system included the ability to store more than 35,200 liters (9,300 gal) of runoff in settling and storage tanks, in addition to that stored in the twenty-four 0.9 m × 0.6 m × 2.4 m (3 ft × 2 ft × 8 ft) galvanized steel open-top tanks used as wetland cells. An additional 7,570 liters (2,000 gal) can be stored after processing. Irrigation water for the nursery was injected with concentrated sulfuric acid (Scholle Corp., Northlake, IL) to lower water pH to 6.5 and with a 24N–3.5P–13.2K (24–8–16, 7.19 % ammonium nitrate, 7.21 % urea, and 9.60 % nitrate, The Scotts Corp., Marysville, OH) water soluble fertilizer to yield a concentration of 50 mg/liter (50 ppm) N. Runoff from the nursery where containerized plants were grown was applied to the cells at a rate of 40.8 liters/sq m/day (1 gal/sq ft/day), a rate used for numerous other wetland systems across North America (4, 6).

In August 1996, twelve 1.9 liter (2 qt) liners of *Canna* x *generalis*, *Colocasia sp*., *Equisetum hyemale*, or *Iris pseudacorus* (Hines Nursery Corp., Houston, TX) were established in each of 24 wetland cells, 3 FSF cells and 3 SSF cells per species. The FSF cells mimicked a natural wetland environment where the plants were planted in a 15.2 cm (6 in) layer of Silawa fine sandy loam (siliceous, thermic ultic haplustalfs, pH 6.6, 73" sand, 9 % clay, 18 % silt) covered by open water through which the wetland plants emerged. The SSF cells consisted of galvanized tanks filled to a depth of 45.7 cm (18 in) with 3.2 cm (1.25 in) diameter gravel in which the plants were planted. Water levels are maintained at approximately 2.5 cm (1 in) below the top of the gravel in the SSF cells. Wetland plants covered near 100 % of the cells by the first frost in fall 1996. Damaged plant tissues resulting from freeze injury were removed from cells in early January 1997. Beginning January 15, 1997, percent surface coverage by the foliage was estimated monthly using a ten-section grid, and the height of the tallest plant in each cell was measured. Concurrent with wetland plant measurements, 60 ml water samples were collected from each outlet pipe per cell, and three replicate samples each from the nursery runoff drain, runoff storage tank, irrigation water, and tap water prior to acid and fertilizer injection. Samples were immediately frozen until transported to the Texas A&M University Research and Extension Center in El Paso, TX, where samples

Table 1. Growth responses of *Iris pseudacorus* (Yellow Flag), *Equisetum hyemale* (Common Horsetail), *Colocasia sp*. (Elephant's Ear), and *Canna* x *generalis* (Canna) grown in free-surface flow or sub-surface flow wetland cells (2.4 m long × 0.9 m wide × 0.6 m deep) over time following over-wintering in College Station, Texas, USDA cold hardiness zone 8b.

Cell type	Genus	Month	Surface coverage (%)	Maximum plant heights (cm)
Free-surface flow	*Iris*	February	53[z]	40
		March	63	40
		April	69	101
		May	92	83
		June	100	143
Sub-surface flow	*Iris*	February	17	30
		March	20	30
		April	23	83
		May	57	122
		June	63	131
Free-surface flow	*Equisetum*	February	35	37
		March	40	24
		April	40	40
		May	38	67
		June	40	52
Sub-surface flow	*Equisetum*	February	8	30
		March	10	30
		April	8	55
		May	31	82
		June	45	85
Free-surface flow	*Canna*	February	3	9
		March	10	21
		April	17	30
		May	38	52
		June	75	107
Sub-surface flow	*Canna*	February	0	0
		March	0	6
		April	1	9
		May	2	9
		June	2	24
Free-surface flow	*Colocasia*	February	0	0
		March	0	6
		April	4	15
		May	17	30
		June	31	37
Sub-surface flow	*Colocasia*	February	0	0
		March	0	0
		April	5	24
		May	37	55
		June	62	98
Statistical significance				
Cell type			**[y]	ns
Species			**	**
Cell type × species			**	**
Month			**	**
Cell type × month			ns	ns
Species × month			ns	**
Cell type × species × month			ns	**

[z]Values are means of three observations, percent data were transformed prior to statistical analysis.

[y]ns = non-significant at $P \leq 0.05$, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$.

were analyzed for pH, electrical conductivity, and concentrations of nitrates, nitrites, ammonium, and phosphates. Water measurements and wetland plant growth measures were subjected to analysis via the general linear models procedure in SAS (10) as a completely randomized factorial design containing two cell types × four wetland species × six sample dates with three replicates per combination. Percent data were transformed prior to analysis. Lower order interactions or main effects are presented only if higher order interactions were non-significant ($P = 0.05$).

Use of recycled water. In January 1997, to test the effectiveness of treated water for reuse, 60 liners each of *Ilex vomitoria* ‘Nana’, *Juniperus procumbens* ‘Green Mound’, and *Raphiolepis indica* ‘Carmelita’ were planted in 2.3-liter black plastic nursery containers (#1 trade containers, Lerio Corp., Mobile, AL) filled with one of two growth media. One growth medium consisted of 75% (by vol) composted pine bark and 25% coarse builders sand. The other medium contained 70% composted pine bark and 30% fresh ground kenaf stalk core (Kinney Bonded Warehouse, Donna, TX). Kenaf particle size distribution and media characteristics were described by Goyne (3). Both media were amended with 5.9 kg/cu m (10 lb/cu yd) 16N–3.1P–10.0K controlled release fertilizer (Southern Special, The Scotts Corp., Marysville, OH), 2.4 kg/cu m (4 lb/cu yd) dolomitic limestone (Vulcan Materials Co., Tarrant, AL), 2.4 kg/cu m (4 lb/cu yd) gypsum (Standard Gypsum Corp., Fredericksburg, TX), 0.30 kg/cu m (0.5 lb/cu yd) Aquagrow® granular (wetting agent), and 0.89 kg/cu m (1.5 lb/cu yd) micronutrients (Micromax®, The Scotts Corp.). Thirty plants of each species were planted in each medium. Plants were arranged, by species, on 0.25 m (10 in) spacings on a greenhouse bench in a completely randomized design.

Ten plants of each species were watered with a typical nursery fertigation for regional nurseries, as determined using a modified Delphi technique (8), consisting of sulfuric acid injected water (pH 6.5) containing 50 mg/liter N (50 ppm) from a 24N–3.5P–13.2K water soluble fertilizer (The Scotts Corp.). Another 10 plants of each species received direct nursery runoff. The remaining 10 plants of each species received runoff water that was passed once through the constructed wetland cells (bulked sample from all cells). This resulted in a two media × three water source factorial arrangement with 10 single plant replications per combination for each species. Plants were hand watered with the three water sources as needed. Growth index ((height + widest width + narrowest width) / 3), presence or absence of foliar chlorosis, and market size ratings were determined in May 1997. Plants were determined to be marketable if the canopy was dense and regular in outline, covered the upper surface of the container, and the majority of foliage was dark to medium green in color as would be typical of the individual taxa.

Results and Discussion

Wetland plant regrowth and efficacy of nutrient removal. In the wetland cells, regrowth (surface coverage) of *I. pseudacorus* and *C.* x *generalis* was greater in the FSF cells, while that of *Colocasia sp*. was greater in the SSF cells; *Equisetum hyemale* grew similarly in both cell types (Table 1). In general, *I. psuedacorus* which is a vigorous grower during the cool season (1) exhibited earlier spring recovery from winter injury and recovered to a greater percent surface coverage by the end of the study than the warm season plants, *Colocasia sp*. and *C.* x *generalis* (Table 1). *Equisetum hyemale* had a more intermediate recovery rate and tends to be an evergreen perennial in most years in USDA cold hardiness zone 8 where the trials were conducted (1). *Canna* x *generalis* and *Colocasia sp*. typically dieback to the ground or water level each winter in USDA zone 8 (1). Recovery of *C.* x *generalis* from winter injury was severely inhibited in the SSF cells compared to the FSF cells (Table 1). This was likely because plant crowns were better insulated from temperature fluctuations by several inches of water flowing over them in FSF cells versus SSF cells where plant crowns were at the water surface. Height data was less consistently affected by the treatments, but indicated a generally similar pattern of growth responses as surface coverage (Table 1).

Table 2. Main effects of time, over species and cell type, on pH, EC, and NH_4-N of nursery runoff after passing through the constructed wetland cells.

Month	pH	EC (dS/m)	NH_4-N (mg/liter)
January	8.53[z] ± 0.07	0.357 ± 0.064	2.57 ± 1.10
February	7.98 ± 0.07	0.314 ± 0.064	0.93 ± 1.10
March	7.46 ± 0.07	0.508 ± 0.065	0.46 ± 1.12
April	7.57 ± 0.07	0.862 ± 0.066	1.40 ± 1.10
May	7.48 ± 0.07	1.367 ± 0.065	5.27 ± 1.12
June	7.57 ± 0.08	1.176 ± 0.068	2.21 ± 1.17

[z]Values are means (± standard errors) of 24 observations.

Mean pH and EC of tap water were pH 8.36 and 0.777 dS/m and pH 6.49 and 1.29 dS/m prior to and after acid and fertilizer injection, respectively. Nursery runoff pH averaged 7.95 after passing through the containers and underlying gravel on the container yard, and the water in the collection tank had an average 8.04 pH. Typical pH of media used in containers at the nursery from which the runoff was generated ranged from 5.5 to 7.0 (3), suggesting a possible elevation of runoff pH via gravel or soil contact. The pH of wetland cell effluent decreased from January to March and then remained fairly constant in the range of 7.46 to 7.57 (Table 2). Wetland species also influenced effluent pH, $P < 0.05$ (Table 3). *Canna* x *generalis* had little influence on the pH of the water passing through the cells, while the other three species tended to have a slight acidifying effect resulting in pHs 0.2 to 0.4 units lower than that of the inflow from the runoff storage tank.

Electrical conductivity and the concentration of all monitored nutrients were low in nursery runoff, the bulk storage tank, and wetland effluent during January and February 1997

Table 3. Main effects of wetland species, over time and cell type, on pH and electrical conductivity (EC) of nursery runoff after passing through the constructed wetland cells.

Genus	pH	EC (dS/m)
Colocasia sp.	7.77[z] ± 0.06	0.695 ± 0.053
Iris pseudacorus	7.60 ± 0.06	0.922 ± 0.053
Equisetum hyemale	7.72 ± 0.06	0.762 ± 0.053
Canna x *generalis*	7.96 ± 0.06	0.647 ± 0.054

[z]Values are means (± standard errors) of 36 observations.

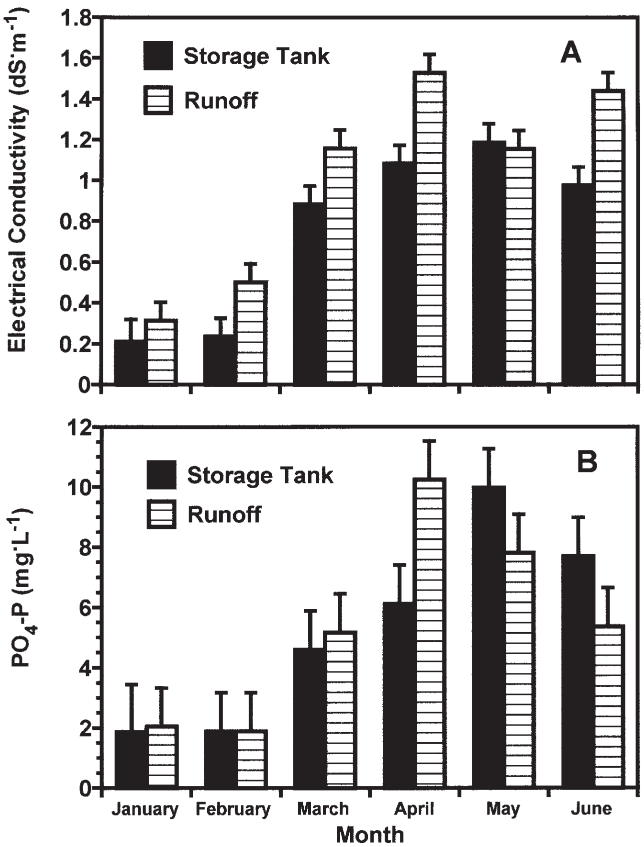

Fig. 1. **Mean (± standard errors) electrical conductivity (A) and PO_4-P concentration (B) during spring recovery for samples drawn directly from the nursery runoff stream and the bulk storage tank acting as an inflow source for the wetland cells, n = 3.**

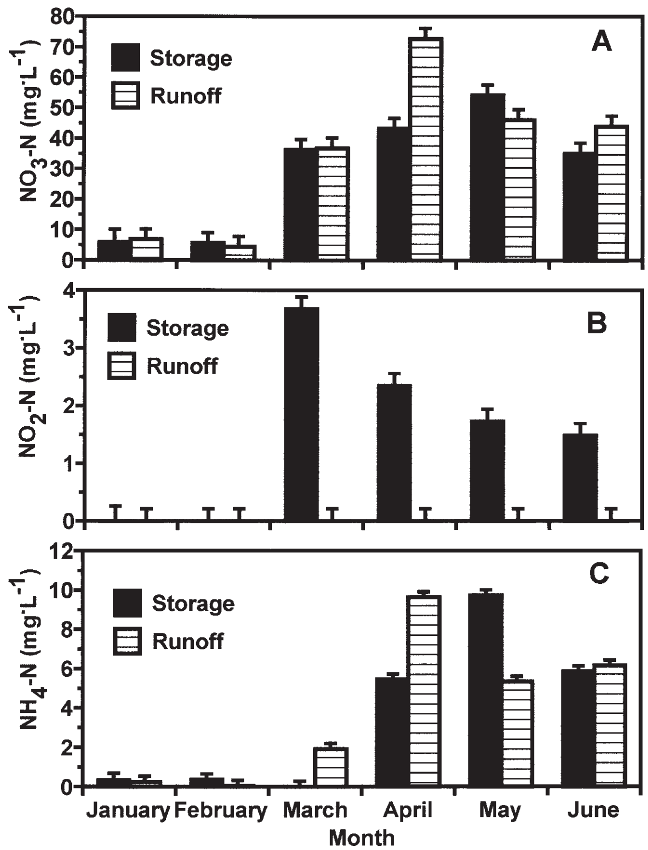

Fig. 2. **Mean (± standard errors) NO_3-N (A), NO_2-N (B), and NH_4-N (C) concentrations during spring recovery for samples drawn directly from the nursery runoff stream and the bulk storage tank acting as an inflow source for the wetland cells, n = 3.**

(Fig. 1, 2, and 3; Table 2). In late February, surface applications of controlled release fertilizers were made to existing containers in the nursery. This time period also coincided with addition of newly planted containers to the nursery at the beginning of the growing season containing fresh media which included controlled release fertilizers. In early March, just prior to or as budbreak began to occur on most species in the nursery, fertigation applications in the nursery were resumed. These combined factors resulted in a substantial increase in NH_4-N, NO_3-N, and PO_4-P concentrations and EC in the nursery runoff (Fig. 1 and 2). Nutrient concentrations in the direct runoff stream from the nursery tended to fluctuate more than that in the bulk storage tank from which the wetland cells were filled (Fig. 1 and 2). The exception was with NO_2-N which was essentially non-detectable in the nursery runoff stream, but was present at low levels in the bulk collection tank from March through June (Fig. 2B), suggesting that some denitrification may have begun in the storage tanks. Nitrate-N levels in direct runoff were somewhat higher than those reported by Tilt et al. (12), but runoff concentrations in our holding tanks were considerably greater than those reported in holding ponds on commercial nurseries (12). Differences may have been due in part to the more limited holding capacity in our tanks relative to the holding ponds in commercial nurseries. Alternatively, our holding tanks were covered and opaque preventing algae growth, while the open holding ponds in most commercial nurseries would be more conducive to growth of algae and other plant materials that may remove NO_3-N from the runoff during storage.

The EC of effluent was greatest for cells containing *I. pseudacorus*, intermediate for *E. hyemale* and lowest for *C.* x *generalis* and *Colocasia sp*. (Table 3). This appears to be a

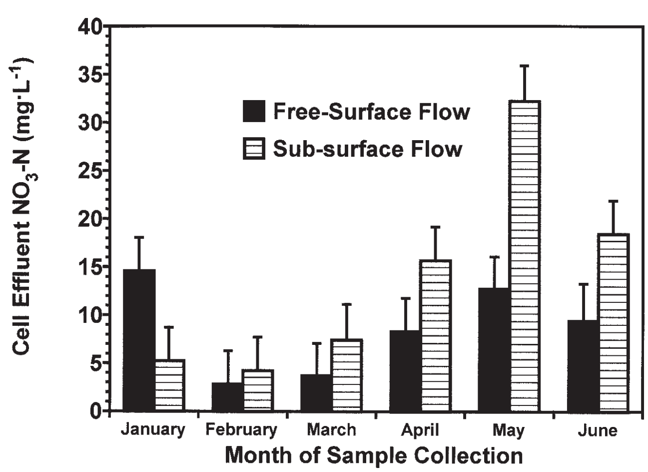

Fig. 3. **Interactions (means ± standard errors) between free-surface flow and sub-surface flow cells with time during spring recovery of wetland cells on NO_3-N concentration in the cell effluent, n = 12.**

positive correlation with the percent coverage rankings for the four species (Table 1). One explanation may be that the greater plant density resulted in greater water use by the plants, concentrating the salts present in effluent. While EC levels present in this study are within ranges of minimal concern for plant production (15), continued concentration of soluble salts with multiple passes of irrigation water through the system could present a potential problem.

Currently, nitrate-N levels are mandated by the US Environmental Protection Agency (EPA) to be less than 10 mg/liter (ppm) in any discharged water (2). The NO_3-N concentration in FSF effluent was near or below the EPA mandated limit on most sample dates, but that of SSF cells was above the EPA mandated limits on several sampling dates (Fig. 3). A significant interaction ($P \leq 0.05$) existed for the NO_3-N removal between the cell type and the species of plant in the cells (Fig. 4). *Colocasia sp*. and *C*. x *generalis* were much more effective at NO_3-N removal in the FSF cells than in the SSF cells, while *E. hyemale* was more effective in the SSF cells. *Iris pseudacorus* was equally effective in NO_3-N removal in both cell types. No significant differences ($P \leq 0.05$) were present for NO_2-N, NH_4-N, and PO_4-P among species (data not presented).

Mean NH_4-N concentration was less in effluent from SSF cells than from FSF cells, 0.62 mg/liter (ppm) versus 2.70 mg/liter (ppm). Nitrite-N concentrations were non-detectable in effluent from SSF cells (data not presented). In FSF cell effluent, NO_2-N concentrations were detectable only in March and May and were less than 0.40 mg/liter (ppm). This suggests that most of the reduction in NO_3-N levels were evolved as N_2 or incorporated into wetland plant tissues.

Use of recycled water. Irrigation with nursery runoff resulted in reduced plant indices and the number of *Ilex vomitoria* 'Nana' reaching marketable size (12 of 20 versus 20 of 20 for fertigation and 19 of 20 with wetland treated water) in 2.3-liter nursery containers during the study (Table 4). No significant ($P < 0.05$) differences in market ratings were determined for *Juniperus procumbens* 'Green Mound' or *Raphiolepis indica* 'Carmelita' (data not presented). Significant ($P = 0.05$) interactions among irrigation water sources and media for growth indices occurred for *I. vomitoria* 'Nana' (Table 4) and *J. procumbens* 'Green Mound' (Table 5), but not for *R. indica* 'Carmelita' (Table 6). Interactions for growth indices were somewhat inconsistent with the greatest growth index for *J. procumbens* for the bark:kenaf medium watered with direct nursery runoff (Table 5), while growth of *I. vomitoria* (Table 4) was greatest with bark:kenaf medium and fertigation, and there was little effect of media or water source on the growth indices of *R. indica* (Table 6).

Generally, pine bark:kenaf media had greater shrinkage than pine bark:sand media (Tables 4, 5, and 6), consistent with previous reports using fertigation (3). Differential effects of water sources on plant growth were most apparent in the pine bark:kenaf medium compared to that of the pine bark:sand medium (Tables 4 and 5). Goyne (3) reported as

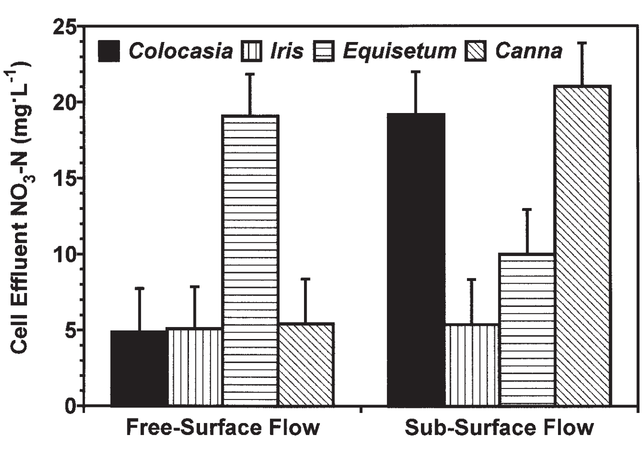

Fig. 4. **Interactions (means ± standard errors) between free-surface flow and sub-surface flow cells with wetland species during spring recovery of wetland cells on NO_3-N concentration in the cell effluent, n = 18.**

Table 4. **Growth responses of *Ilex vomitoria* 'Nana' to 50 mg/liter of N fertigation, nursery runoff, or treated water from wetland cells when grown in 2.3-liter black plastic containers filled with an 80% composted pine bark:20% coarse builders sand (by vol) or 70% composted pine bark:30% kenaf stalk core media.**

Medium	Water source	Growth index (cm)	Medium volume (cm^3)
Bark:sand	50 mg/liter N	23.5[z]	2098
	Nursery runoff	22.3	2186
	Wetland treated	21.0	2236
Bark:kenaf	50 mg/liter N	29.1	2023
	Nursery runoff	23.3	2111
	Wetland treated	26.2	1998
Statistical significance			
Media		**[y]	**
Water source		**	ns
Media × water source		*	ns

[z]n = 10.

[y]ns = non-significant at $P \leq 0.05$, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$.

Table 5. **Growth responses of *Juniperus procumbens* 'Green Mound' to 50 mg/liter of N fertigation, nursery runoff, or treated water from wetland cells when grown in 2.3-liter black plastic containers filled with an 80% composted pine bark:20% coarse builders sand (by vol) or 70% composted pine bark:30% kenaf stalk core media.**

Medium	Water source	Growth index (cm)	Medium volume (cm^3)
Bark:sand	50 mg/liter N	17.3[z]	2158
	Nursery runoff	17.3	2077
	Wetland treated	16.8	2118
Bark:kenaf	50 mg/liter N	15.9	1839
	Nursery runoff	18.2	1797
	Wetland treated	14.7	1660
Statistical significance			
Media		ns[y]	**
Water source		*	*
Media × water source		*	ns

[z]n = 10.

[y]ns = non-significant at $P \leq 0.05$, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$.

Table 6. **Growth responses of *Raphiolepis indica* 'Carmelita' to 50 mg/liter of N fertigation, nursery runoff, or treated water from wetland cells when grown in 2.3-liter black plastic containers filled with an 80% composted pine bark:20% coarse builders sand (by vol) or 70% composted pine bark:30% kenaf stalk core media.**

Medium	Water source	Growth index (cm)	Medium volume (cm^3)
Bark:sand	50 mg/liter N	15.7[z]	2189
	Nursery runoff	14.3	2078
	Wetland treated	14.3	2028
Bark:kenaf	50 mg/liter N	14.6	1676
	Nursery runoff	13.0	1777
	Wetland treated	14.0	1736
Statistical significance			
Media		ns[y]	**
Water source		ns	ns
Media × water source		ns	**

[z]n = 10.

[y]ns = non-significant at $P \leq 0.05$, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$.

much as a 40% reduction in medium volume with 70% (by vol) fresh ground kenaf, altering water holding capacities and medium aeration. Chlorosis symptoms consistent with those of N deficiency were present on 4 of 30 *I. vomitoria*, 24 of 30 *J. procumbens*, and 6 of 30 *R. indica* plants grown in bark:kenaf medium, while none of the three species exhibited foliar chlorosis when grown in the pine bark:sand medium. This may have been associated with the more rapid decomposition of the bark:kenaf medium compared to the bark:sand medium as indiced by the significant reductions in bark:kenaf media volume (Tables 4, 5, and 6).

Runoff collection, treatment, and reuse offers a combined benefit to nursery and greenhouse industries by reducing the volume of fresh water used for irrigation and limiting the loss of nutrients and pesticides with discharged runoff (13, 14, 15). Initial evaluation of wetland performance for treating collected runoff indicated that wetland cells effectively reduced nitrate concentrations without substantially increasing salinity in this study. This does not preclude the potential for increasing salinity with multiple passes of recycled water through the wetland cells. Results presented herein are based on the single flow rate (1 gal/sq ft/day) that was tested in this study. Determination of the potential interactions among flow rates, contaminant concentrations in inflow water, and wetland species removal efficacy would be necessary before confidently extending the results to commercial settings. Nitrite and ammonium concentrations were lower in SSF wetland cells than in FSF cells, while nitrates were lower in effluent from FSF cells than from SSF cells. Efficacy of nitrate removal during spring recovery varied among species, with cool season species reducing nitrate levels more so than warm season species. Species efficacy may well vary with season suggesting further testing is needed before species recommendations can be finalized.

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