The use of reclaimed water as an irrigation source for nursery crops is of increasing importance because many nurseries are located near urban areas that have experienced rapid population growth. Population growth results in increased demand for water as well as increased production of potentially reclaimable sewage water. Reclaimed water could replace potable water used for irrigation. In addition, reclaimed water use by nurseries may provide an alternative to reclaimed water discharge to the environment.

The literature regarding ornamental plant responses to reclaimed water is mostly about evaluations of plants grown in landscapes rather than commercial container plant production. Southern Indian hybrid azaleas (Rhododendron L. spp.) irrigated overhead with reclaimed water in the landscape had smaller sizes than when reclaimed water was soil-applied, potable water was applied overhead, or potable water was applied to the soil (Robinson and Parnell, 1989).

The treatment that received overhead reclaimed water exhibited leaf burn, probably as a result of high levels of chloride (Cl) in reclaimed water. There was 300 mg L⁻¹ Cl in the reclaimed water compared with 6 mg L⁻¹ Cl in potable water. Overhead and soil-surface applications of reclaimed water resulted in 20% and 24% plant deaths, respectively, compared with similar applications of potable water. Dwarf azalea hybrids (Rhododendron L. spp.) irrigated with reclaimed water and those that received potable water applied overhead did not have different size indices (Robinson and Parnell, 1989); however, leaf burn was observed when irrigated overhead with reclaimed water. According to Wu et al. (1995), crops that have higher tissue levels of Cl are more sensitive to reclaimed water irrigation, although tissue Cl levels were not reported by Robinson and Parnell (1989). The dwarf azalea hybrids that received soil-surface-applied reclaimed water had the highest mortality (82%) as did the Southern Indian hybrids (Robinson and Parnell, 1989).

The impact of sprinkler-irrigating various landscape trees with reclaimed water was the subject of an investigation conducted in Nevada (Devitt et al., 2003) where oak (Quercus virginiana Mill. ‘Heritage’), desert willow (Chilopsis linearis Cav. Sweet), flowering plum (Prunus serrulata Ehrh ‘Atropurpurea’), and Chinese pistache (Pistacia chinensis Bunge) were evaluated for response to: 1) sprinkler application of reclaimed water followed by a post-irrigation rinse of fresh water; 2) acidified reclaimed water that was aerated and passed through a carbon filter; 3) 25% fresh water water dilution; and 4) 50% fresh water dilution. They concluded that no single treatment worked best for all species and that species selection at the time of landscape planning was an important strategy for avoiding negative impacts of reclaimed water irrigation.

Similar to landscape tree evaluations, reclamation water has been used for irrigation of citrus trees. Conserv II is a project in central Florida where high-quality reclaimed water is used primarily for citrus tree irrigation (Parsons et al., 1995). In one study, the effect of reclaimed water on visual evaluations of canopy appearance and leaf color of ‘Hamlin’ orange [Citrus sinensis (L.) Osb.], ‘Valencia’ [C. sinensis (L.) Osb.], and ‘Orlando tangelo’ (Citrus paradisi Macf. × C. reticulate Blanco) was compared with trees irrigated with well water. Overall, trees irrigated with Conserv II water had similar canopy appearance and leaf color as trees irrigated with well water (Zekri and Koo, 1994). No detrimental effects were found after 6 years of continuous applications of Conserv II water (Zekri and Koo, 1994) to Astatula fine sand. Zekri and Koo (1994) also determined that Conserv II water resulted in about twice the sodium, Cl, and boron (B) tissue concentrations compared with plants irrigated with well water. The precise amount by which Conserv II water can reduce the need for Cl and B should be studied more extensively. A different study with Conserv II water applied at different irrigation rates to ‘Hamlin’ orange [C. sinensis (L.) Osb.] and ‘Orlando’ tangelo (C. paradisi Macf. × C. reticulate Blanco) with a combination of the four rootstocks: Carrizo citrange [Citrus sinensis (L.) Osb. × Poncirus trifoliata (L.) Raf.], Cleopatra mandarin (C. reticulata Blanco), sour orange [C. aurantium (L.)], and Swingle citrumelo (C. paradisi × P. trifoliata) demonstrated other benefits of reclaimed water use (Parsons et al., 2001). At the high irrigation rate of 2500 mm/year compared with 400 mm/year, soluble solids concentrations in the juice were lower, whereas total soluble solids per hectare increased as a result of increased fruit production per hectare. The 2500 mm/year irrigation did not result in disease or flooding problems as expected as a result of excellent drainage of the sandy soil. This study shows that a high application rate of reclaimed water can be applied successfully to citrus on well-drained soils. In Spain, citrus [C. sinensis (L.) Osb.] trees flood-irrigated with reclaimed water and those irrigated with groundwater
for 3 years did not exhibit differences in tree height or trunk diameter (Reboll et al., 2000).

A study conducted in Egypt using navel orange trees provided information on the effects of long-term irrigation with sewage water (Omran et al., 1988). Five soil sites irrigated with sewage water for 10, 20, 30, 40, and 60 years were chosen to study the effects of long-term irrigation on heavy metal accumulation. Overall, leaves were shown to contain the highest heavy metal concentrations and juice contained the lowest concentration. Concentrations tended to become greater with longer sewage application times, but heavy metal levels always remained within permissible limits and below toxic levels for humans and plants.

The effects of reclaimed water on the growth of young apple trees in British Columbia, Canada, were investigated using ‘Macspur McIntosh’ (Malus ×domestica Borkh.) and ‘Redchief Delicious’ apple varieties on a M.7a rootstock. Either reclaimed water or well water was applied to these cultivars from 1983 to 1987 along with three different rates of surface nitrogen (N) fertilization (0, 200, 400 g NH₄NO₃/tree/year). Reclaimed water irrigation resulted in increased trunk diameter for all years and increased fruit number in the nursery to 1987 along with three different rates of water was applied to these cultivars from 1983 and ‘Redchief Delicious’ apple varieties on a 2.5-L container. Reclaimed water had been successfully used on many horticultural crops.

The objective of our research was to evaluate the plant growth response of container-grown ornamentals to reclaimed water as an alternative irrigation source for nursery production.

**MATERIALS AND METHODS**

**General procedures**

The following research used reclaimed water as defined in Part III of Chapter 62-610 F.A.C. (Florida Administrative Code, 2007), which outlines the criteria for high-quality reclaimed water deemed suitable for land application. Reclaimed water was obtained as needed from the Kanapaha Wastewater Treatment Facility in Gainesville, FL, for irrigation of ornamental crops that included: vinca [Catharanthus roseus (L.) G. Don], salvia (Salvia splendens F. Sellow ex Roem. and Schult.), Dwarf Yaupon holly (Ilex vomitoria Ait. ‘Nana’), and ‘Helleri’ holly (I. crenata Thunb. ‘Helleri’). These plants were chosen because of their varying levels of salt tolerance and varying durations to maturity or marketable size. Vinca (Tija and Rose, 1987) and Dwarf Yaupon holly (Black, 2003; Watkins and Sheehan, 1988) are accepted as more salt-tolerant than salvia (Black, 1994) and ‘Helleri’ holly (Watkins and Sheehan, 1988). Vinca and salvia are annuals typically grown in the nursery for 6 to 8 weeks, whereas Dwarf Yaupon holly and ‘Helleri’ holly are woody perennials grown for 6 to 8 months in the nursery to produce a plant in a 2.3-L container.

The experiments were conducted in Gainesville, FL (long. 82.35° W, lat. 29.69° N) during 2001 to 2003 in a glass greenhouse with temperature set points of 28 °C day/18 °C night with radiation averaging 695 and 865 µmol·m⁻²·s⁻¹ during fall/winter and spring/summer, respectively. The treatments applied consisted of a combination of varying percentages of reclaimed water and deionized water: 1) 100% deionized water; 2) 25% reclaimed water:75% deionized water; 3) 50% reclaimed water:50% deionized water; 4) 75% reclaimed water:25% deionized water; and 5) 100% reclaimed water. Each irrigation treatment was 460 mL applied to the substrate surface of each container. Treatments 6 to 10 were the same as Treatments 1 to 5, respectively, except that 50 to 70 mL of the corresponding substrate-applied irrigation water was applied by overhead spray to each plant with a handheld sprayer that delivered a fan pattern for 10 s. Irrigation treatments were applied every other day and then daily when needed as determined by visually observing substrate. Reclaimed water (Part III) was obtained from Gainesville Regional Utilities Kanapaha Wastewater Treatment Facility. Elemental composition of reclaimed water at initiation of each experiment is given in Table 1. The plants were on benches in a randomized complete block design containing eight blocks with one plant per treatment per block. Measurements from the substrate surface to the top of each plant (plant height), the plant width at the widest point, and the plant width perpendicular to the widest point were recorded for all plants and growth indices (height/average width) were determined. Additionally, the leachate resulting from pouring 100 mL of deionized water onto the surface of the substrate was collected, and EC and nutrient concentrations (NO₃-N, P, and K) were determined according to standard procedures (Analytical Research Laboratory, 2008) for Blocks 1 to 4. At experiment termination, visual appearances were observed and roots were washed of substrate and stems cut above the uppermost root. Shoots and roots were dried in a forced-air oven at 70 °C. Shoot and root dry weights were recorded for all plants.

**Table 1.** Reclaimed water analyses for a sample taken at beginning of each experiment conducted in Gainesville from 2001 to 2003 to evaluate the growth response of C. roseus (vinca), S. splendens, I. vomitoria ‘Nana’, and I. crenata ‘Helleri’ to various percentages of reclaimed:deionized water (0:100, 25:75, 50:50, 75:25, and 100:0) applied at each irrigation.

<table>
<thead>
<tr>
<th>Plant</th>
<th>NO₃-N (mg L⁻¹)</th>
<th>Phosphorus (mg L⁻¹)</th>
<th>Potassium (mg L⁻¹)</th>
<th>Calcium (mg L⁻¹)</th>
<th>Magnesium (mg L⁻¹)</th>
<th>Zinc (mg L⁻¹)</th>
<th>Manganese (mg L⁻¹)</th>
<th>Copper (mg L⁻¹)</th>
<th>Iron (mg L⁻¹)</th>
<th>Sodium (mg L⁻¹)</th>
<th>Chloride (mg L⁻¹)</th>
<th>pH</th>
<th>Electrical conductivity (dS m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. roseus</td>
<td>3.8</td>
<td>0.2</td>
<td>20</td>
<td>39</td>
<td>20</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td>0</td>
<td>72</td>
<td>88</td>
<td>7.8</td>
<td>0.7</td>
</tr>
<tr>
<td>S. splendens</td>
<td>3.8</td>
<td>0.1</td>
<td>16</td>
<td>16</td>
<td>62</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td>0</td>
<td>52</td>
<td>90</td>
<td>7.9</td>
<td>0.5</td>
</tr>
<tr>
<td>I. vomitoria</td>
<td>3.1</td>
<td>0.1</td>
<td>12</td>
<td>31</td>
<td>16</td>
<td>0.06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>90</td>
<td>7.9</td>
<td>0.5</td>
</tr>
<tr>
<td>I. crenata</td>
<td>1.0</td>
<td>0.3</td>
<td>15</td>
<td>36</td>
<td>21</td>
<td>0.06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>75</td>
<td>95</td>
<td>7.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*Reclaimed water was obtained from Gainesville Regional Utilities Kanapaha Wastewater Treatment Facility, Gainesville, FL.*

**Statistical analyses.** Shoot and root dry weights were analyzed using two-way factorial and regression analyses. Waller-Duncan
k-ratio t tests were used to determine the presence of significant differences between treatment means.

RESULTS AND DISCUSSION

Expt. 1. There were no interactions between the main effects of irrigation method and percentage of reclaimed municipal water applied for vincia shoot and root dry weights. Shoot dry weights were not different for irrigation method ($P \leq 0.086$) (averaged over percentage reclaimed applied), but shoots exhibited a positive linear response to increased percentage of reclaimed water applied (Fig. 1). Shoot growth indices were not different 4 or 8 weeks after experiment initiation for irrigation method or percentage of reclaimed water applied, and visual observations did not reveal foliar aberrances at 8 weeks (data not shown).

Root dry weights were different (surface-applied = 3.0 g, surface-applied plus overhead = 3.3 g) for each irrigation method ($P \leq 0.008$) and percentage of reclaimed water applied ($P \leq 0.039$). Root dry weight for surface irrigation method increased as percentage of reclaimed water increased (Fig. 2).

Leachate NO$_3$-N, P, and K concentrations declined throughout the experiment regardless of irrigation method (Fig. 3A–C). However, K leachate concentrations were above the 10 to 20 mg L$^{-1}$ optimum for container plants (Yeager et al., 2007) at 8 weeks. Leachate EC ranged from 0.6 to 1.9 dS m$^{-1}$ during the experiment (Fig. 3D). The highest ECs, although not excessive, were observed at 8 weeks for plants that received the surface-applied plus overhead application of reclaimed water. Reclaimed water NO$_3$-N, P, and K concentrations at the beginning of the experiment were 3.8, 0.2, and 20 mg L$^{-1}$, respectively, and EC was 0.7 dS m$^{-1}$ (Table 1).

Data from this experiment indicated that reclaimed water can be used for irrigation of vincia. These results concur with the findings of Maurer and Davies (1993). They found in a study with reclaimed water irrigation of 'Redblush' grapefruit trees (Citrus paradisi Macf.) on a Swingle citrumelo rootstock [Citrus paradisi (L.) Osb. × Poncirus trifoliata (L.) Raf.] that tree heights were enhanced by irrigation with simulated reclaimed water compared with well water for trees that received fertilization. A possible explanation for the increased shoot biomass with increased percentages of reclaimed water in our experiment is the contribution of nutrients in the reclaimed water, although this was not investigated. This is further substantiated by the larger root biomass at higher percentages of reclaimed water when plants received a substrate surface application of reclaimed water.

Expt. 2. Salvia exhibited no interactions between the main effects of irrigation method and percentage of reclaimed water applied for shoot or root dry weights. Root dry weights of plants irrigated with surface-applied (5.0 g) irrigation were larger than plants that received surface-applied plus overhead (4.3 g) irrigation ($P \leq 0.020$); additionally, root dry weights

![Fig. 1. Shoot dry weights of C. roseus grown for 8 weeks in 2.3-L containers with Metro Mix® 500 substrate and irrigated with various percentage combinations of reclaimed and deionized water either applied to the substrate surface plus overhead to the plant canopy. Shoot dry weight = 0.032 (%) + 22.8 ($P \leq 0.001$).](image1)

![Fig. 2. Root dry weights of C. roseus grown for 8 weeks in 2.3-L containers with Metro Mix® 500 substrate and irrigated with various percentage combinations of reclaimed and deionized water applied to substrate surface plus overhead to the plant canopy (●) or applied to the substrate surface (●). Surface + overhead irrigation = 0.003 (%) + 3.15 ($P \leq 0.143$); surface-applied irrigation = 0.005 (%) + 2.77 ($P \leq 0.011$).](image2)

![Fig. 3. (A–D) Leachate NO$_3$-N, phosphorus (P), potassium (K), and electrical conductivity (EC) for C. roseus grown for 8 weeks in 2.3-L containers with Metro Mix® 500 substrate and irrigated with 0:100% (*), 25:75% (○), 50:50% (△), 75:25% (▪), or 100:0% (*) reclaimed/deionized water applied to the substrate surface (S) or applied to substrate surface plus overhead (SO) to the plant canopy.](image3)
decreased as percentage of reclaimed water applied increased (Fig. 4).

Shoot dry weights were not different for irrigation method \( (P \leq 0.489) \) or percentage of reclaimed water applied \( (P \leq 0.433) \); however, the first growth index determination (Week 1) was larger \( (P \leq 0.006) \) for surface-applied (47) compared with overhead plus surface-applied irrigation (44) (data not shown). The second growth index determination (Week 4) was not different and visual observations at 8 weeks did not reveal any foliar aberrance (data not shown).

Leachate \( \text{NO}_3^-\text{N}, \text{P}, \text{and K} \) concentrations declined from Weeks 1 to 4 regardless of irrigation method and then increased at 8 weeks to about the concentrations determined at 1 week (Fig. 5A–C). Potassium concentrations at 8 weeks were high to excessive, ranging from 130 to 190 mg L\(^{-1}\) (Eakes et al., 1991). Leachate EC ranged from 0.4 to 1.6 dS m\(^{-1}\) during the experiment and EC tended to be higher with higher percentages of reclaimed water applied (Fig. 5D). Reclaimed water \( \text{NO}_3^-\text{N}, \text{P}, \text{and K} \) concentrations at the beginning of the experiment were 3.8, 0.1, and 16 mg L\(^{-1}\), respectively, and EC was 0.7 dS m\(^{-1}\) (Table 1).

Salvia shoot dry weights were not different as a result of irrigation application method or percentage of reclaimed water applied; however, the differences in root dry weights could be indicative of salvia’s salt sensitivity (Black, 1994) and attributable to increased EC levels associated with increased percentages of reclaimed water applied. Despite the reduction in root dry weight, these data indicate that reclaimed water can be used for irrigation of salvia based on shoot growth response.

Expt. 3. Dwarf Yaupon holly did not have an interaction for root dry weight \( (P \leq 0.098) \) but there was an interaction between the main effects of irrigation method and percentage of reclaimed municipal water applied for shoot dry weight \( (P \leq 0.039) \). Waller-Duncan K-ratio \( t \) test for shoot dry weights (Table 2) revealed that surface-applied plus overhead irrigation without reclaimed water (46 g) resulted in greater shoot dry weights than 0%, 50%, or 100% reclaimed water surface-applied only (36, 38, and 34 g, respectively). Shoot dry weights were not different as a result of irrigation application method for each treatment that contained reclaimed water. Growth indices were not different at each determination for irrigation application method or percentage of reclaimed water applied, and visual observation at 8 months did not reveal foliar aberrances (data not shown). Root dry weights were larger for plants with surface-applied plus overhead irrigation (41 g) than root dry weights (37 g) for surface-applied irrigation only \( (P \leq 0.042) \). Percentage reclaimed water applied did not result in different root dry weights.

Leachate \( \text{NO}_3^-\text{N}, \text{P}, \text{and K} \) (Fig. 6A–C) concentrations were high regardless of irrigation application method at 2.5 months and then tended to decline until end of the experiment at 8 months when it appeared that nutrients supplied by the fertilizer were limited. Leachate \( \text{NO}_3^-\text{N}, \text{P}, \text{and K} \) concentrations at 2.5 and 4 months exceeded optimal substrate concentrations (Yeager et al., 2007). Leachate EC (Fig. 6D) followed a similar pattern except for the surface-applied plus overhead application of 100% reclaimed water at 8 months, in which an excessive EC of 2.9 dS m\(^{-1}\) was recorded (Yeager et al., 2007).

Table 2. Mean shoot dry weights for \( I. \text{vomitoria} \) grown in a 2 pine bark:1 Canadian peat:1 sand (by volume) substrate in 2.3-L containers and irrigated for 8 months with various percentage combinations of reclaimed and deionized water applied to the substrate surface or applied to substrate surface plus applied overhead to the plant canopy.

<table>
<thead>
<tr>
<th>Reclaimed:</th>
<th>Surface</th>
<th>Surface + Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:100%</td>
<td>36</td>
<td>46</td>
</tr>
<tr>
<td>25:75%</td>
<td>39</td>
<td>43</td>
</tr>
<tr>
<td>50:50%</td>
<td>38</td>
<td>43</td>
</tr>
<tr>
<td>75:25%</td>
<td>44</td>
<td>39</td>
</tr>
<tr>
<td>100:0%</td>
<td>34</td>
<td>39</td>
</tr>
</tbody>
</table>

Means separated by Waller-Duncan K-ratio \( t \) test. Minimum significant difference = 7 g.
Reclaimed water NO$_3$-N, P, and K concentrations at the beginning of the experiment were 3.1, 0.1, and 12 mg L$^{-1}$, respectively, and EC was 0.5 dS m$^{-1}$ (Table 1).

Dwarf Yaupon holly was selected as a result of its perceived salt tolerance (Black, 2003; Watkins and Sheehan, 1988). However, shoot dry weights of plants that received 100% reclaimed water applied to the substrate surface were smaller than when 0% reclaimed water was surface-applied plus overhead applied. This may be related to the fact that 100% reclaimed, regardless of application method, resulted in the highest EC at 6 and 8 months. Root dry weights were not different in relation to percent of reclaimed water applied but were larger for overhead plus surface irrigation than for surface irrigation alone. There does not seem to be a logical explanation for this based on substrate nutrition. However, these data indicate that reclaimed water can be successfully used for the irrigation of Dwarf Yaupon holly.

Expt. 4. ‘Helleri’ holly exhibited an interaction between the main effects of irrigation method and percentage of reclaimed water applied for shoot dry weights ($P \leq 0.012$) and root dry weights ($P \leq 0.040$). The Waller-Duncan K-ratio $t$ test for shoot dry weights and root dry weights revealed no differences between treatments (Tables 3 and 4). The mean shoot and root dry weights for all treatments were 68 g (SD ±10) and 30 g (SD ±10), respectively.

6A

6B

6C

6D

Table 3. Mean shoot dry weights for I. crenata

Table 4. Mean root dry weights for I. crenata

CONCLUSIONS

Reclaimed water was a viable source of irrigation for the container plants grown in these experiments, either when applied to substrate surface or applied to the plant canopy and substrate surface. A key component of crop management when using reclaimed water irrigation is the monitoring and regulation of EC levels of the substrate within a range most appropriate for the plant species grown. Additionally, producers should monitor EC of irrigation water. Routine monitoring of substrate and irrigation water EC are best management practices (Yeager et al., 2007) and growth index and, although not statistically different, also in root growth of plants that received 100% reclaimed water surface-applied. EC peaked at 2.4 dS m$^{-1}$ at the experimental midpoint (4.5 months) for 100% reclaimed water surface-applied and growth index was a low of 76 at 8.5 months. One hundred percent reclaimed water surface-applied plus overhead irrigation resulted in the highest growth index (91) at 8.5 months and the lowest EC (1.93 dS m$^{-1}$) at the experimental midpoint (4.5 months). Previous experimentation with ‘Helleri’ holly (unpublished observation) indicated that an EC above 2.0 dS m$^{-1}$ was detrimental to root growth. These findings suggest that monitoring and control of EC are important during production of ‘Helleri’ holly when reclaimed water is used.

Reclaimed water NO$_3$-N, P, and K concentrations were excessive at 4.5 months (Yeager et al., 2007), but decreased at 8.5 months to approximately initial concentrations regardless of irrigation method (Fig. 7A–C). However, P and K concentrations were approximately two to five times, respectively, optimal concentrations (Yeager et al., 2007), possibly as a result of P and K in the reclaimed water. Leachate EC exhibited a similar pattern and ranged from 0.7 to 2.4 dS m$^{-1}$ during the experiment (Fig. 7D). Reclaimed water NO$_3$-N, P, and K concentrations at the beginning of the experiment were 1.0, 0.3, and 15 mg L$^{-1}$, respectively, and EC was 0.7 dS m$^{-1}$ (Table 1).

7A

7B

7C

7D

‘Helleri’ holly was selected as a result of its nontolerance of salt (Watkins and Sheehan, 1988). The salt sensitivity was reflected in the
thus should not be new production strategies for growers changing from ground or surface water to reclaimed water sources. In other plant evaluations we have conducted, the EC of reclaimed water processed according to Part III guidelines ranged from 0.5 to 0.7 dS m⁻¹ during 2004 to 2007 (unpublished data). Furthermore, survey responses of container plant growers and owners (unpublished data) indicated a willingness to use reclaimed water for irrigation with a few notable contingencies. Primary concerns were costs, availability, water quality, and politics. Thus, results of these experiments suggest that if low-cost/high-quality reclaimed water was consistently available with freedom from political barriers, container plant producers should embrace the opportunity to use this valuable irrigation resource.

**Literature Cited**


