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Irrigating Landscape Bedding Plants and Cut Flowers With Recycled Nursery Runoff and Constructed Wetland Treated Water

Michael A. Arnold1, Bruce J. Lesikar1, Garry V. McDonald1, Donita L. Bryan2, and Amit Gross4

Department of Horticultural Sciences, Texas A&M University
Mail Stop 2133, College Station, TX 77843

Abstract

Direct nursery runoff (runoff), wetland treated recycled nursery runoff (recycled), and a municipal water source (tap) with and without elevated salt (NaCl targeted injection to 3.0 dS·m⁻¹) levels were tested as potential drip irrigation sources for production of in-ground cut flower crops and landscape bedding plants. Two species of cut flowers, Helianthus annuus L. ‘Mammoth’ (sunflower) and Gladiolus x hortulanus L. ‘Tout À Toi’ (gladiolus), and two bedding plants, Catharanthus roseus G. Don ‘Pacifica Red’ (vinca) and Zinnia elegans N.J. von Jacquin ‘Lilliput Mixed Colors’ (zinnia), were established in trial beds irrigated with the four water treatments during the summer of 2001 as a warm season experiment. A second experiment was conducted from November 2001 to May 2002 to investigate growth and flowering responses of two species of cut flower crops [Consolida ambigua (L.) P. Ball & V. Heywood (larkspur) and Narcissus tazetta L. ‘Galilea’ (paperwhite narcissus)] and two bedding plants [Antirrhinum majus L. ‘Montego Mix’ (snapdragons) and Viola x wittrockiana H. Gams ‘Crown Mix’ (pansies)]. Marketable crops of sunflower, paperwhite narcissus, and larkspur were produced with all four water treatments. Direct nursery runoff, recycled wetland treated water, and NaCl spiked water that were high in soluble salts during the heated season reduced yield and inflorescence diameter with sunflowers, but only slightly reduced inflorescence quality and had no effect on yield of paperwhite narcissus. These three treatments also affected stand density, but not yield of cut larkspur inflorescences in the cool season. Irrigation with water containing elevated NaCl levels reduced flower counts on pansies and growth indices on pansies and snapdragons over much of the growing season, but reduced snapdragon flowering only in spring. Vinca was unaffected by the irrigation treatments. Zinnia survival and flowering were reduced or delayed by irrigation with recycled or elevated NaCl water.

Index words: fertility, nursery effluent, salinity.

Species used in this study: snapdragon (Antirrhinum majus L. ‘Montego Mix’); vinca (Catharanthus roseus G. Don ‘Pacifica Red’); canna (Canna x generalis L.H. Bailey); larkspur (Consolida ambigua (L.) P. Ball & V. Heywood); gladiolus (Gladiolus x hortulanus L. ‘Tout À Toi’); sunflower (Helianthus annuus L. ‘Mammoth’); iris (Iris L. x ‘Clyde Redmond’); paperwhite narcissus (Narcissus tazetta L. ‘Galilea’); pansy (Viola x wittrockiana H. Gams ‘Crown Mix’); zinnia (Zinnia elegans N.J. von Jacquin ‘Lilliput Mixed Colors’).

Significance to the Nursery Industry

Drip application of single pass recycled wetland effluent or direct nursery runoff were suitable for drip irrigating zinnia, vinca, pansies, and snapdragons in landscape settings. These same treatments were effective for drip irrigating larkspur and paperwhite narcissus as cut flower crops, but reduced the yield of sunflowers during the warm season. Irrigation of these cut flower crops suggest an alternative use for recycled or direct nursery runoff. A lack of substantially adverse effects on bedding plants irrigated with direct nursery runoff and wetland treated effluent suggest that retail operations should be able to utilize their captured runoff for drip irrigating landscape display plantings. Reductions in growth indices and flowering of pansies and snapdragons with sodium chloride injected irrigation water suggests that if soluble salt levels increased to the 3.0 dS/m level associated with this treatment, then salts will need to be diluted with less saline water or alternative uses for the water may need to be found.

Introduction

Water quality, water availability, and environmental issues associated with runoff have become a concern for floral and nursery producers throughout the United States (16, 17, 18). Greater emphasis on prevention of surface and ground water contamination, pesticide usage, solid waste disposal, and energy consumption have significantly influenced business and cultural practices. However, increased regulation of water consumption and quality is anticipated with increased public environmental concerns (16). 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 (16, 17). Capture, treatment, and reuse of runoff provides a potential solution. Retention of runoff water on-site reduces movement of nutrients and pesticides to local surface water resources. In addition, reuse of captured runoff water may greatly reduce fresh water consumption.

Passing water through constructed wetlands has been shown to effectively reduce nutrient, pesticide, and growth regulator contaminant levels in nursery runoff (2, 3, 4, 7, 9) and other industrial and agricultural water remediation efforts (8, 10). In previous studies, elevated salinity was not a concern with single pass water during spring months, but potential effects of concentration of salts with water recycled...
during summer droughts and with multi-pass water remain unanswered (2).

Disposal of excess nursery runoff is also an issue. In most instances, nurseries are required to capture runoff from all applied irrigation water plus the first half inch of rainfall per precipitation event (6). During times of frequent rainfall, management of mandated captured runoff may become more of an issue than conservation or remediation efforts. Thus, alternative uses for direct or treated runoff such as landscape application or production of compatible horticulture crops might represent viable solutions to disposal of this effluent. In-ground display beds at retail garden centers and nurseries are gaining in popularity as a marketing tool (13), but often require irrigation. Also the Texas Department of Agriculture has been advocating cut flower production as one alternative to conventional agronomic crops (5). These may represent opportunities to utilize excess direct nursery runoff or treated effluent. The objective of this study was to evaluate the efficacy of constructed wetlands remediated water and direct nursery runoff as reclaimed water sources for irrigation of landscape bedding plants and cut flowers under warm and cool season conditions.

Materials and Methods

Warm season experiment. On June 7, 2001, two species of cut flower crops (sunflower and gladiolus) and two bedding plants (vinca and zinnia) were established in trial beds irrigated with four water treatments. The 12.2 m (40 ft) long × 3.7 m (12 ft) wide raised trial beds were constructed using 10 cm (4 in) diameter exterior treated landscape timbers. Trial beds contained a Silawa fine sandy loam (siliceous, thermic ultic haplustalfs, 73% sand, 9% clay, 18% silt) soil and were crested from 30.5 cm (12 in) in the center to 15.3 cm (6 in) at the edges to ensure drainage. Beds were hand cultivated weekly to control weeds. Sunflowers (Producers Coop, Bryan, TX) and zinnias (Bentley Seeds, Cambridge, NY) were direct seeded, gladiolus were from corms (VanBloem Gardens, The Netherlands), and vinca were from transplants grown in 0.16 liter (9.6 cu in) six-cell packs (Hines Nursery Co., Houston, TX). Gladiolus corms were placed in cold [4.4°C (40°F)] storage until planted. Pre-irrigation soil samples were collected and analyzed for selected chemical characteristics (A&L Analytical Laboratories, Inc., Memphis, TN). A second set of soil samples were collected in September after the warm season experiment concluded. Plots were fertilized at treatment initiation and monthly thereafter with a 13N–5.7P–10.8K granular fertilizer (Pursell Industries, Inc., Sylacauga, AL) at the rate of 0.45 kg (1 lb) of actual N per 92.9 sq m (1000 sq ft) of bed surface.

The four treatments included direct nursery runoff (runoff), nursery runoff water treated via passage through constructed wetland cells [previously described by Arnold et al. (2) and Lesikar et al. (11)] containing Canna x generalis L.H. Bailey and Iris L. x ‘Clyde Redmond’ (recycled), a municipal water source (tap), and municipal water with elevated sodium [NaCl (Morton’s stock salt, Grand Saline, TX) targeted injection to 3.0 dS/m]. Trial beds were irrigated with drip tape (T-Tape®, T-Systems Intl. Inc., San Diego, CA) at 10 psi spaced on 46 cm (18 in) centers. Irrigation was applied when soil moisture tension reached ~20 kPa (Model 2725 Jet Fill Tensiometers, Santa Barbara, CA). All water sources were injected with concentrated sulfuric acid to a target pH of 6.5 prior to field application. At treatment initiation and biweekly thereafter, three replicate 60 ml (2.0 oz) water samples from each treatment were collected for analysis of pH (Accumet®, Model 20, pH/conductivity meter, Fisher Scientific, Pittsburgh, PA), electrical conductivity (EC, Twin Cond B-173, Spectrum Technologies, Plainfield, IL), nitrate (Cardy NO₃⁻ Nitrate Meter, Spectrum Technologies), and sodium (Cardy Sodium Na⁺ Meter, Spectrum Technologies) levels.

Runoff was collected from a 1,672 sq m (18,000 sq ft) research and teaching nursery, previously described in Arnold et al. (2) and Lesikar et al. (11), containing numerous species of plants primarily grown in containers filled with pine bark based substrates. Most of these container substrates contained 4.75 kg/cu m (8 lb/cu yd) controlled released fertilizer (23N–1.7P–6.6K High N Southern Formula, Scotts Co., Marysville, OH) incorporated at planting and the standard irrigation water used in the nursery was a municipal water source injected with concentrated sulfuric acid to a target pH of 6.5. Irrigation water in the nursery was injected with soluble fertilizer (24N–3.5P–13K, Scotts Co., Marysville, OH) at the rate of 50 mg/liter (ppm) N from February 15 through October 15 each year.

Growth and flowering data were gathered initially and at biweekly intervals for warm season bedding plants, including canopy height, canopy diameter parallel to and perpendicular to the row, and flower number. Growth indices were calculated as (height × parallel diameter × perpendicular diameter) / 3 to provide a canopy volume estimate. Survival of individual plants was recorded at each harvest date. Market/quality rating scales were developed for cut flowers by consultation with commercial florists. Sunflower inflorescences were counted and assigned a quality rating as they reached harvestable stages. Quality ratings for sunflower inflorescences were made using a 1 (poorest quality) to 5 (highest quality) scale where: 1 = plant dead or a very small plant with the inflorescence aborted, stunted, or insect damaged, not marketable; 2 = inflorescence with weak stalks, or inflorescence damaged or miss-shaped, not marketable; 3 = inflorescence slightly miss-shaped or of poor color intensity, but acceptable for non-premium markets; 4 = above average in overall quality, strong stalks, inflorescence symmetrical and of good color and form, marketable; 5 = superior product, large symmetrical inflorescence with excellent color and strong stalk; suitable for premium markets. Marketable inflorescences were considered to be those receiving a rating of three to five, while premium quality inflorescences were those receiving a four or five rating.

The statistical design for each species was analyzed as a nested factorial design, a modified split plot (12). Blocks were nested within the irrigation treatments in a factorial over time. Two replications of the main pots (water treatments) and three replicates of the subplot (blocks) were present. The number of harvest or observation times varied among the different characteristics that were measured. Each 0.9 m × 1.8 m (3 ft × 6 ft) block contained eighteen individual plant replicates. Growth, flowering, and survival measures were analyzed as a separate, but concurrent study for each species. Water and soil samples were analyzed as factorial designs (14) with four water treatments and three (for soil samples), six (warm season water samples), or seven (cool season water samples) sample times. For each measured characteristic, an analysis of variance was conducted to determine if interactions were present among the irrigation treatments over time (14). If
this interaction was not significant ($P \leq 0.05$), then data were pooled across either irrigation treatments or time to test the respective main effects. Only significant interactions or main effects not involved in significant interactions are presented. Percentage data were subjected to square root transformation prior to analysis to achieve a more normalized distribution.

**Cool season experiment.** During the first few days of November, 2001, two species of cut flower crops (larkspur and paperwhite narcissus) and two bedding plants (snapdragons and pansies) were established in trial beds irrigated with the four water treatments. The statistical design was the same as described for the warm season experiments. Larkspurs were established from seeds (Wildseed Farms, Fredericksburg, TX), paperwhite narcissus from bulbs (Abbott IPCO, Dallas, TX), and pansies and snapdragons from transplants grown in 0.16 liter (9.6 cu in) six-packs (Hines Nursery Co., Houston, TX). Growth and flowering data, as previously described for warm season bedding plants, were measured at planting and monthly intervals through April and May, respectively, for snapdragons and pansies.

Initial harvests of paperwhite narcissus were begun at weekly intervals in December 2001 and continued through February 2002. Scapes (leafless flower stalks) were considered harvestable when a third of the florets were opened. Market/quality ratings, flower counts, and scape lengths were recorded for individual inflorescences on paperwhite narcissus. Quality ratings for paperwhite narcissus inflorescences were made using a 1 (poorest quality) to 5 (highest quality) scale: 1 = flowers aborted or ‘blasted’, or scape broken, not marketable; 2 = scapes very short (< 12 cm (< 4.7 in)) or few flower buds fully open (< 4), or scapes with weak necks (crooks in scape below flower cluster), not marketable; 3 = scapes greater than 12 cm (4.7 in) long, but flowers few in number (< 8) or unevenly opened or distributed in the cluster; marginally marketable, perhaps for mass merchants; 4 = stems greater than 12 cm (4.7 in), eight or more flowers, flowers uniform in size and appearance, and evenly distributed in the cluster, marketable; 5 = stems greater than 18 cm (7.1 in), flower buds greater than ten in number, and uniform in size and appearance, a superior product and marketable.

Harvests of larkspur began on April 15, 2002, and continued for approximately a month. Inflorescences were considered harvestable when a fourth of the florets were open. Market/quality ratings are recorded for individual inflorescences on larkspur with inflorescence quality assessed on the following 1 (poorest quality) to 5 (highest quality) scale: 1 = culls: no value or dead plants; 2 = not marketable, spikes < 30 cm (12 in) in length, florets few and low floret density, flowers damaged, weak stems; 3 = lower quality, but marketable; spikes < 30 cm (12 in) in length, florets acceptable, no damage to flowers, weak to moderate stem diameter with few flowering branches, variability present in flower cluster density; 4 = good quality, would meet market standards, spikes > 30 cm (12 in) long, florets of good quality, stems sturdy with some secondary flowering branches; tight clusters of flowers; 5 = superior quality, stem length > 45 cm (18 in), florets of superior quality, stems sturdy with many secondary branches of flowers, tight clusters of flowers.

Water samples were collected monthly from November 2001 through May 2002 as previously described. A third set of soil samples was taken in May to examine cool season effects of irrigation treatments on soil characteristics. A statistical analysis was conducted as previously described for warm season studies.

**Results and Discussion**

**Warm season soil and water characteristics.** Irrigation water for the elevated salt treatment consisted of dissolved NaCl injected to a target EC of 3.0 dS/m (measured 3.17 ± 0.09 dS/m) resulting in a mean Na concentration of 723 ± 5.5 mg/liter (ppm). The elevated salt irrigation water treatment was omitted from the analysis of other water treatments to avoid swamping differences among these treatments due to these very high imposed EC and Na levels, hence the elevated salt water irrigation treatment is not presented in the graphs in Fig. 1. Significant interactions ($P \leq 0.05$) occurred for EC, sodium, and nitrate concentrations among the other irrigation treatments over time (Fig. 1A–C). Soluble salts in runoff and recycled water increased as the summer progressed (Fig. 1A). A less pronounced increase in soluble salts was present for tap water where EC levels increased until early July and then stabilized. This may have been a result of drawing groundwater from progressively deeper, lower quality wells as the droughty summer season progressed. The local aquifer rests atop a geologic salt dome, hence the lower strata have elevated EC levels. Changes in total soluble salts in runoff and recycled water were due at least in part to elevated Na levels (Fig. 1B). Early in summer, runoff had lower EC than tap or recycled water due to diluting effects of rainfall on nursery runoff. Later in the season an increase in Na concentration of nursery runoff occurred, likely due to evaporative concentration of captured water relative to applied irrigation (Fig. 1B). This process was even more evident in recycled water in which salts were further concentrated as evapotranspiration occurred during processing in the wetlands (Fig. 1B). Nitrates increased in both nursery runoff and recycled water as the season progressed and fertilization of the nursery continued (Fig. 1C). This increased concentration was likely an effect of evaporative concentration of captured runoff from applied irrigation water. The decrease in nitrate concentration of runoff on August 14, 2001, was a result of a major tropical rainfall event that diluted runoff just prior to sample collection. A single pass through wetland cells reduced the amount of nitrate in the water during the warm season, however the concentration was still above 10 mg/liter (ppm) (Fig. 1C).

**Warm season bedding plants.** Significant interactions ($P \leq 0.05$) occurred for growth indices and flowering of both vinca (Fig. 2A, B) and zinnia (Fig. 2C, D) among irrigation treatments over time, while only main effects of time (data not presented) and irrigation treatments (Fig. 2E) were significant for survival with both species. Flowering and growth of surviving vinca were unaffected from June 14 through July 30 (Fig. 2A, B). However, on August 14 and September 10 flowering and growth of vinca was reduced by recycled, runoff, and salt treatments compared to tap water (Fig. 2A, B). This corresponded with the time period in which the Na and EC of recycled and runoff irrigation sources were greater than tap water (Fig. 1A, B). Flowering and growth of zinnia were similar among water treatments on most dates (Fig. 2C, D), except an unexplained spike in number of flowers of plants irrigated with elevated salt levels on September 10, 2001, and some reductions during late July and August in
growth of salt water irrigated zinnia. This may represent a delaying effect of salts on flowering, or perhaps it was due to a leaching of salts as it occurred shortly after the rainfall event that diluted the nursery runoff on August 14, 2001 (Fig. 1C). Survival (Fig. 2E) was much lower with zinnia than with vinca (Fig. 2F), partly due to poor germination of zinnia in high salt treatments and loss of plants in recycled, runoff and salt treatments. Elevated salt water reduced zinnia survival compared to other irrigation treatments (Fig. 2E). Survival of runoff and recycled irrigated zinnias were inter-

Fig. 1. Changes in electrical conductivity (A, D), sodium (B, E), and nitrate nitrogen (C, F) content (mean ± standard error) of irrigation water from a tap water source, direct container nursery runoff, or single pass recycled water from a constructed wetland, during warm (A–C) or cool (D–F) season experiments, n = 3.
mediate between those irrigated with salt or tap water (Fig. 2E). Survival did no appear to be related to soluble salts concentration of irrigation treatments for vinca and was generally high regardless of irrigation treatment (Fig. 2F). Zinnia plants were established via seeding, while vinca were established from transplants. Variability in survival among treatments with vinca may be the result of late season losses due to cooler temperatures and moister conditions as fall rains began rather than long term responses to irrigation treatments.

Warm season cut flowers. More cut sunflowers were produced with the tap water (79 stems), than with runoff (50

Fig. 2. Interactions of flowering (A, C) and growth index (B, D) responses (mean ± standard error, n = 6) of vinca (A, B) and zinnia (C, D) to irrigation with a tap water source, direct nursery runoff, recycled water from a constructed wetland, or water with an elevated salt content over time. Main effect of survival of vinca and zinnia in response to these same irrigation treatments (E). Columns within a species with the same letter are not different at $P \leq 0.05$ using least squares means procedures, n = 36 (E).
Table 1. Initial and ending selected chemical characteristics of field plots treated for three months in summer 2001 (warm) and six months in the fall
2001–spring 2002 with irrigation water from a municipal water source (tap), direct container nursery runoff (runoff), single pass recycled
water from a constructed wetland (recycled), or water with an elevated sodium content (salt).

<table>
<thead>
<tr>
<th>Season treatment</th>
<th>pH</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>B</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Na (%)</th>
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<tbody>
<tr>
<td>Initial None</td>
<td>6.5</td>
<td>59</td>
<td>116</td>
<td>1166</td>
<td>90</td>
<td>18</td>
<td>0.7</td>
<td>1.6</td>
<td>207</td>
<td>46</td>
<td>4.0</td>
<td>164</td>
</tr>
<tr>
<td>End warm Tap</td>
<td>6.6</td>
<td>77</td>
<td>127</td>
<td>1350</td>
<td>98</td>
<td>29</td>
<td>0.7</td>
<td>1.8</td>
<td>171</td>
<td>40</td>
<td>4.7</td>
<td>269</td>
</tr>
<tr>
<td>Recycled</td>
<td>6.5</td>
<td>51</td>
<td>136</td>
<td>489</td>
<td>64</td>
<td>46</td>
<td>0.5</td>
<td>0.8</td>
<td>136</td>
<td>36</td>
<td>2.0</td>
<td>268</td>
</tr>
<tr>
<td>Runoff</td>
<td>6.9</td>
<td>83</td>
<td>115</td>
<td>1478</td>
<td>97</td>
<td>37</td>
<td>0.8</td>
<td>2.2</td>
<td>197</td>
<td>45</td>
<td>5.4</td>
<td>247</td>
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<tr>
<td>Salt</td>
<td>6.6</td>
<td>53</td>
<td>114</td>
<td>430</td>
<td>52</td>
<td>32</td>
<td>0.5</td>
<td>0.8</td>
<td>145</td>
<td>41</td>
<td>1.8</td>
<td>304</td>
</tr>
<tr>
<td>End cool Tap</td>
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<td>88</td>
<td>144</td>
<td>1011</td>
<td>96</td>
<td>8</td>
<td>0.8</td>
<td>1.0</td>
<td>157</td>
<td>35</td>
<td>4.0</td>
<td>192</td>
</tr>
<tr>
<td>Recycled</td>
<td>6.4</td>
<td>71</td>
<td>152</td>
<td>558</td>
<td>73</td>
<td>18</td>
<td>0.6</td>
<td>0.7</td>
<td>128</td>
<td>36</td>
<td>2.3</td>
<td>188</td>
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<tr>
<td>Runoff</td>
<td>6.6</td>
<td>48</td>
<td>120</td>
<td>459</td>
<td>66</td>
<td>9</td>
<td>0.6</td>
<td>0.7</td>
<td>101</td>
<td>31</td>
<td>2.1</td>
<td>157</td>
</tr>
<tr>
<td>Salt</td>
<td>6.5</td>
<td>72</td>
<td>147</td>
<td>458</td>
<td>51</td>
<td>10</td>
<td>0.7</td>
<td>0.8</td>
<td>147</td>
<td>55</td>
<td>1.8</td>
<td>211</td>
</tr>
</tbody>
</table>

Nutrients [mg/liter (ppm)]

<table>
<thead>
<tr>
<th>Season</th>
<th>Water treatment</th>
<th>N</th>
<th>Organic matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>None</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>End warm</td>
<td>Tap</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Recycled</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Runoff</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Salt</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

# Cool season soil and irrigation water characteristics.

Background EC of tap water remained constant during the course of the experiment, rising slightly in late spring as water is drawn from deeper wells that are the source of the tap water (Fig. 1D). Aside from an elevation in January, EC of recycled and runoff water remained similar to that of tap water. The reason for this brief spike in recycled and runoff EC is unknown, but it does not correspond to an increase in either nitrate runoff or sodium buildup (Fig. 1E). Sodium levels remained fairly constant in tap water during the course of the study (Fig. 1E) and were similar to the warm season study (Fig. 1B). Nursery runoff contained less Na than tap water on most dates (Fig. 1E), likely due to dilution of water by rainfall events. Recycled water had greater Na concentrations than nursery runoff on some dates (Fig. 1E), probably due to concentration via evapotranspiration in wetlands, but it was still lower than tap water on most dates. Nitrate levels were not statistically different from November through February (Fig. 1F). Nitrate levels in both nursery runoff and recycled wetland treated water began to rise (Fig. 1F) with resumption of fertigation and slow release fertilizer applications to containers in the nursery beginning March 1, 2002. A much smaller rise in background nitrate levels, above what is a typical action level of 10 mg/liter (ppm), was measured in tap water in late spring (Fig. 1F). In general, nitrate levels of tap water were greater than that reported in previous studies conducted at the site (2). The source of increased nitrate level appears to be from outside the water processing system on the site as levels in the tap water remained essentially constant in samples taken between October 15, 2001, and February 15, 2002, when no fertilizer was being injected in the nursery.

Interestingly, wetland cells were relatively ineffective at nitrate removal during the cool season study (Fig. 1F), while they averaged about a 50% reduction in nitrate nitrogen during passage through wetland cells in the warm season experiment (Fig. 1C). Perhaps the warm season wetland species, *Canna × generalis*, was more effective at affecting nitrate removal or nitrification than the cool season *Iris sp*. This is consistent with Holt et al. (9) findings for warm season nutrient removal, but this is in contrast to earlier results of effective nitrate removal during spring regrowth of wetland cells containing these species (2).

Reduced levels of fertilization in the nursery were likely responsible for the reduction in levels of Ca, S, Cu, and Zn in soils of cool season plots irrigated with nursery runoff compared to levels present at the end of the warm season study (Table 1). Return of S levels to those similar to the initiation of the warm season study across treatments might be attributable to a reduced volume of sulfuric acid injected irrigation water used in the cool season and greater leaching due to precipitation. Two dramatic changes in soil characteristics from the end of the warm season to the end of the cool season are the return of the direct nursery runoff plots to similar levels of Na as prior to the initiation of the study and a sub-

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Table 1. Initial and ending selected chemical characteristics of field plots treated for three months in summer 2001 (warm) and six months in the fall 2001–spring 2002 with irrigation water from a municipal water source (tap), direct container nursery runoff (runoff), single pass recycled water from a constructed wetland (recycled), or water with an elevated sodium content (salt).

<table>
<thead>
<tr>
<th>Season</th>
<th>Water treatment</th>
<th>Nutrients [mg/liter (ppm)]</th>
<th>Organic matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>None</td>
<td>pH</td>
<td>P</td>
</tr>
<tr>
<td>End warm</td>
<td>Tap</td>
<td>6.6</td>
<td>77</td>
</tr>
<tr>
<td>Recycled</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Runoff</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Salt</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

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Values for each treatment are a mean of two blocks with composite samples drawn from 16 individual cores for initial measurements and 16 cores from each block for the end of warm and cool seasons.

Statistical significance of the main effects of and interactions among season and water treatments on warm and cool season ending soil characteristics, ns = not significant, * = significant at P ≤ 0.05, ** = significant at P ≤ 0.01.
stantial breakdown in the organic matter in all plots (Table 1). Sodium concentrations in soils of plots irrigated with tap water and recycled water remained slightly elevated, while that of elevated salt water irrigation plots remained moderately elevated (Table 1). Potassium concentrations were not significantly \((P \leq 0.05)\) affected by water treatments (data not presented).

**Cool season bedding plants.** With pansies, a significant \((P \leq 0.05)\) interaction occurred between irrigation treatments and time in the landscape for growth index and flower number, but no interaction was found for pansy survival. Survival of pansy plants was slightly greater \((P \leq 0.05)\) in plots irrigated with recycled (14.2 out of 18 plants) and nursery runoff (14.4) compared to plots irrigated with elevated salt water (12.3) or tap water (12.6). Pansy growth indices increased at a fairly modest rate from November through March, and then increased rapidly in April prior to suffering dieback and decline with the hot temperatures of May (Fig. 3A). The magnitude of differences among recycled, runoff, and tap water treatments were small, but elevated salt levels reduced plant indices, particularly in later winter and early spring when more frequent irrigation was required (Table 1). Potassium concentrations were not significantly \((P \leq 0.05)\) affected by water treatments (data not presented).

**Cool season cut flowers.** Significant interactions \((P \leq 0.05)\) were found between the effects of the water treatments and harvest date for paperwhite narcissus scape length (stem length on an inflorescence) (Fig. 4A), the number of flowers on a scape (Fig. 4B), and the number of plants receiving a four
(Fig. 4C) or a five (Fig. 4D) quality rating, and the total number of marketable scapes (Fig. 4E). No significant interactions were found for the total number of paperwhite narcissus inflorescences produced per treatment, nor the number of inflorescences rated low to moderate quality (1–3 rating) or total non-marketable inflorescences. Main effects of harvest date were the only significant effects ($P \leq 0.05$) for the total number of paperwhite narcissus inflorescences, and the number of those rated one, two, or three in quality (Fig. 4F).

Scape lengths were shorter than would be commercially desirable on the initial harvest date, but quickly reach more acceptable lengths by early January (Fig. 4A). Scape lengths...
were produced (Fig. 4F). A much greater number of four- and five-rated inflorescences were produced on paperwhite narcissus from the recycled water treatment on the first two harvest dates than the other treatments (Fig. 4C, D), but recycled water treatment yields were less than or equal to other treatments on later harvest dates. Number of four-rated scapes for plants irrigated with nursery runoff and tap water were greater than that of plants irrigated with recycled water or water with elevated salts on the January 15 harvest date (Fig. 4C). Paperwhite narcissus irrigated with elevated salt and tap water had slightly more five-rated inflorescences on the last January harvest (Fig. 4D). The total number of marketable scapes (Fig. 4E) followed a similar pattern of response as the four-rated inflorescences (Fig. 4C).

No significant interactions among irrigation treatments and harvest dates ($P \leq 0.05$) were found for quality (number in a given quality category) or yield (total number) of larkspur inflorescences, however there were significant main effects of harvest date for both yield and quality (Fig. 5A, B) and for the effects of irrigation treatments on quality and stand density (Fig. 5, Table 2). Although total yield was greatest at the final harvest date, the number of marketable inflorescences was similar at the second and last harvests (Fig. 5B). The first three harvest dates yielded a greater proportion of marketable (Fig. 5B) and higher quality (four- and five-rated) inflorescences (Fig. 5A), compared to the last harvest date. Many inflorescences harvested on the last harvest date were of poorer quality (Fig. 5A, B) regardless of the irrigation water source. This reflected the declining health of larkspur plants as higher temperatures began to occur in late spring. Tap water doubled the number of the highest quality inflorescences produced compared to other treatments (Table 2), but this represented a very small proportion of the total yield (Fig. 5B). The only adverse effects of the elevated salt water treatment seen with larkspur was a reduction in direct seeded stand density (Table 2). This appeared to be due to an effect on germination or emergence of larkspur as once seedlings became established, few were lost over the course of the study. Establishing plants as liners might overcome this limitation in higher salt environments.

In general, only those irrigation water treatments with high EC or Na levels caused reductions in cut flower yield or quality, or bedding plant growth or flowering. Aside from the treatment with NaCl added, these conditions principally occurred in warm weather when greater irrigation requirements resulted in the application of more salts to the soil. Greater reductions in yield or quality of some cut flowers, and growth or flowering of some bedding plants, occurred with the el-

remained fairly constant until the last three harvest dates when they began to increase. Increases in scape lengths on later harvest dates were also associated with increased variability and represented relatively few of the total harvested flower scapes (Fig. 4F). Although late fall and early winter blooming of paperwhite narcissus is a liability in Texas when they are planted for a spring flowering effect in landscapes (1), this tendency for premature flowering in fall and winter after planting might allow growers a window for cut flowers prior to the spring peak in north temperate regions. While paperwhite narcissus are generally well adapted to Texas (1), the economics of replanting each fall versus allowing bulbs to become perennials would need to be investigated.

Although water treatments did not significantly affect the total number of paperwhite narcissus inflorescences produced, water treatments did affect the quality of inflorescences (Fig. 4C, D). While total number of non-marketable scapes (those rated one or two) were not affected by the irrigation treatments (Fig. 4F), elevated salts in irrigation water decreased the number of high quality, four- and five-rated inflorescences (Fig. 4C, D), harvested during early and mid-January. This was when the bulk of the total inflorescences were produced (Fig. 4F). A much greater number of four- and five-rated inflorescences were produced on paperwhite narcissus from the recycled water treatment on the first two harvest dates than the other treatments (Fig. 4C, D), but recycled water treatment yields were less than or equal to other treatments on later harvest dates. Number of four-rated scapes for plants irrigated with nursery runoff and tap water were greater than that of plants irrigated with recycled water or water with elevated salts on the January 15 harvest date (Fig. 4C). Paperwhite narcissus irrigated with elevated salt and tap water had slightly more five-rated inflorescences on the last January harvest (Fig. 4D). The total number of marketable scapes (Fig. 4E) followed a similar pattern of response as the four-rated inflorescences (Fig. 4C).

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Table 2. Main effects of irrigation with tap water, nursery runoff, recycled water from constructed wetlands, or water with an elevated salt content on the mean number of larkspur inflorescences with the highest (five) quality rating across harvest dates ($n = 24$) and mean stand density per plot ($n = 6$).

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Inflorescences rating a five (#/plot date)</th>
<th>Stand density (plants/plot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff</td>
<td>1.3b</td>
<td>53.3a</td>
</tr>
<tr>
<td>Recycled</td>
<td>1.0b</td>
<td>37.3a</td>
</tr>
<tr>
<td>Salt</td>
<td>1.2b</td>
<td>29.3b</td>
</tr>
<tr>
<td>Tap</td>
<td>2.9a</td>
<td>44.2ab</td>
</tr>
</tbody>
</table>

*Means within a column followed by the same letter are not significantly different ($P \leq 0.05$) using least squares means analysis.
evated NaCl water treatment than with other irrigation treatments. This suggests that the 3.17 dS/m EC and approximately 723 mg/liter (ppm) Na concentrations of this treatment might represent maximum thresholds for utilizing drip applied irrigation water for similar uses. This is consistent with results of Schuch and Mahato (15) which indicated that 2.5 dS/m EC water generated with a 1:3 ratio of calcium chloride to sodium chloride was damaging, but not lethal, to several species of southwestern landscape plants. Testing of runoff and recycled water as an irrigation water source on additional cut flower species and a detailed economic analysis of using the runoff or recycled water is needed before widespread implementation of cut flower irrigation from these sources is recommended.

**Literature Cited**