Foliar Damage, Spectral Reflectance, and Tissue Ion Concentrations of Trees Sprinkle Irrigated with Waters of Similar Salinity but Different Chemical Composition

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Abstract. We investigated foliar damage to five landscape species sprinkler irrigated with either reuse water or one of five synthesized saline waters that contained elevated single salts mixed with Colorado River water, all having similar electrical conductivities. The experiment allowed us to compare the impact of elevated concentrations of Na, Mg, Ca, Cl, and SO$_4$ on an index of visual damage (IVD), tissue ion concentrations, and spectral reflectance. Waters containing elevated concentrations of MgCl$_4$ or NaCl caused greater foliar damage than did MgSO$_4$, NaSO$_4$, CaSO$_4$, or reuse water, as recorded in higher IVD values ($p<0.05$). Privet and elm were damaged to a greater extent (higher IVD values) than were desert willow, guava and laurel ($p<0.05$). Higher IVD values were recorded for all species irrigated with the MgCl$_4$ waters, with mortality recorded in privet. Tissue nutrient concentrations were correlated with the IVD values. In the case of guava, 61% of the variability in the IVD could be accounted for based on N, P and K ($P<0.01$). On a treatment basis, the single salts added to the municipal water showed little correlation with the IVD values, except in the case of MgCl$_4$, where Mg was included in the regression equation ($r^2=0.82$, $P<0.01$, IVD $\propto$ SO$_4$, Mg and P$^+$$^+$$^+$$^+$. Eleven different spectral indices separated based on treatment and/or species ($P<0.05$). In elm, 70% of the variability in the IVD could be accounted for by including Red Edge, Normalized Difference Vegetation Index (NDVI) and Water Band Index (WBI)/NDVI. A mixed response was observed to a post 30-day irrigation rinse in an attempt to reduce IVD values. Based on our results, care should be given to monitoring not only the EC (and osmotic potential) but also the ionic composition when saline waters are blended with other water sources, with the aim of minimizing the concentration of Mg, Cl, and Na.

In arid regions where water resources are limiting and population growth outstrips water conservation efforts, greater consideration is being given to the use of lower quality waters. Reuse water (treated sewage effluent) in particular, has been adopted in most regions of the U.S. as acceptable water for landscape irrigation, especially large turf grass areas such as golf courses, parks and cemeteries (U.S. Golf Association, 1994). However, in a recent survey of superintendents in the southwestern U.S., 73% of the respondents who irrigated with reuse water indicated that reuse water had a negative impact on shrubs and trees growing on golf courses (Devitt et al., 2004).

The objective of this study was to investigate foliar damage to five ornamental landscape species sprinkler irrigated with waters containing different elevated concentrations of cations and anions. Reuse (tertiary treated sewage effluent) water and five synthesized waters of similar electrical conductivity but varying in specific ion composition were used as irrigation sources, so that a comparison could be made between the relative impacts of Na, Ca, Mg, Cl, and SO$_4$ on foliar damage, spectral reflectance and leaf tissue ion concentrations.

Materials and Methods

Research was conducted at the Clark County Sanitation District (CCSD) in Las Vegas, Nev., and involved five tree species (Table 1), and six qualities of water (irrigation plots) with each tree species replicated three times within each water quality treatment ($n=15$ for species per plot, $n=90$ for all trees in six plots). Irrigation plots were separated, with 15-m alleys to minimize drift to adjacent plots. The six irrigation treatments consisted of sprinkler-applied reuse water and five synthesized waters with similar electrical conductivities (ranging from 1.86 to 1.95, with no statistical difference between treatments) to the reuse water but different in ionic composition. Salts of CaSO$_4$$\cdot$7H$_2$O, MgSO$_4$$\cdot$7H$_2$O, MgCl$_2$$\cdot$6H$_2$O, NaCl and Na$_2$SO$_4$ were blended with potable water in separate storage containers to obtain electrical conductivities statistically similar to reuse water and distributed to irrigation plots. All waters used in this experiment originated from Colorado River water and were provided by CCSD. Samples of the water were collected after each batch preparation (3754 L) and analyzed for electrical conductivity with a conductivity bridge (model RC-20; Beckman Industrial, Cedar Grove, N.J.) and major cations and anions were quantified using atomic absorption spectrophotometry [model 200 A; Buck Scientific, East Norwalk, Conn. (Ca, Mg, Na and K)], spectrophotometry [model 200 A; Buck Scientific, East Norwalk, Conn. (Ca, Mg, Na and K)].

Table 1. Ornamental landscape species used in the foliar study.

| Common name          | Species                                      |
|----------------------|----------------------------------------------|
| Desert Willow        | Chilopsis linearis (Cav.) Sweet              |
| Japanese Privet      | Ligustrum japonicum Thum.                    |
| Drake Elm            | Ulmus parvifolia Jacq. "Drake"              |
| Guava                | Fjoeia sellowiana (O. Berg) O. Berg          |
| Laurel               | Sophora secundiflora (Ortega) Lag. ex DC    |
Table 2. Average chemical composition of treatment waters used in the foliar study.

| Parameter | Municipal | Reuse | CaSO₄ | MgSO₄ | MgCl₂ | NaCl | Na₂SO₄ |
|-----------|-----------|-------|-------|-------|-------|------|--------|
| EC (dS·m⁻¹) | 0.86 | 1.94 | 1.90 | 1.86 | 1.95 | 1.93 | 1.94 |
| Na (mg·L⁻¹) | 3.31 | 10.03 | 4.93 | 5.42 | 5.11 | 12.03 | 13.33 |
| K (mg·L⁻¹) | 0.02 | 0.90 | 0.28 | 0.27 | 0.30 | 0.29 | 0.26 |
| Ca (mg·L⁻¹) | 3.32 | 6.20 | 15.76 | 4.33 | 4.21 | 4.09 | 4.24 |
| Mg (mg·L⁻¹) | 3.12 | 3.05 | 1.94 | 8.78 | 7.73 | 1.82 | 1.84 |
| Cl (mg·L⁻¹) | 2.66 | 7.33 | 3.29 | 2.71 | 12.06 | 10.31 | 2.52 |
| SO₄ (mg·L⁻¹) | 4.60 | 8.81 | 18.58 | 17.70 | 5.24 | 5.20 | 15.15 |
| pH | 8.00 | 7.84 | 7.87 | 7.97 | 7.94 | 7.90 | 7.99 |
| OP* (MPa) | --- | -0.113 | -0.098 | -0.113 | -0.110 | -0.108 | -0.105 |

*OP* = osmotic potential; measured at 25% evaporation.

Table 3. Summary of vegetation indices used to assess treatment effects [R = reflectance at a specified wavelength (nm)]. Sources: Field et al., 1994; Gamon and Surius, 1999; Gamon et al., 1997; Peñuelas et al., 1993a, 1993b, 1995; Peñuelas and Filella, 1998; Serrano et al., 2000.

| Index | Description | Wavelengths (nm) |
|-------|-------------|------------------|
| PRI | Photochemical reflectance index | (R₄₁₅ + R₅₄₁₅ + R₆₇₉₃ + R₇₃₀₅)/(R₄₁₅ + R₅₄₁₅ + R₆₇₉₃) |
| SR | Simple ratio | (R₃₅₄₆)/(R₄₇₅₄) |
| Chl | Chlorophyll index | (R₆₄₅₇ – R₅₄₅₇)/(R₇₃₀₉ + R₅₄₅₇) |
| NDPI | Normalized total pigment to chlorophyll a index | (R₄₃₃₉ – R₄₃₃₉)/(R₆₇₉₃ + R₄₃₃₉) |
| SPI | Structure insensitive pigment index | (R₆₄₅₇ – R₅₄₅₇)/(R₄₇₅₉ + R₄₃₃₉) |
| WBI | Water band index | (R₄₄₂₉ + R₄₃₃₉) |
| NDVI | Normalized difference vegetation index | (R₄₃₃₉ – R₇₃₀₉)/(R₄₃₃₉ + R₇₃₀₉) |
| NPP | Normalized phaeophytinization index | (R₄₃₃₉ – R₄₃₃₉)/(R₄₃₃₉ + R₇₃₀₉) |
| λₑ | Red edge (wavelength of maximum slope) | (between 680 and 740 nm) |
| R:FR | Red to far red index | R₆₄₅₇/R₃₅₄₆ |
| WBI:NDVI | Water band index to NDVI | WBI/NDVI |

UV-120-02; Shimadzu Corp., Columbia, Md. (SO₄); chloride titration [digital chloride meter, model 4425; Haake Buchler Instruments, Paramus, N.J. (Cl)] and titration (HCO₃⁻/CO₃²⁻) (Table 2).

Trees were not planted in the ground because the soil at the research site adjacent to the sewage treatment plant was highly saline with a shallow water table (≈180 cm). Each tree was left in its original #15 standard nursery container (57.0 L). To moderate container soil temperatures and promote drainage, containers with trees were placed in a second, in-ground, #15 container (pot in pot), containing a 10-cm layer of pea gravel, which prevented the containers from lodging. Exposed soil surfaces in each pot were mulched with a 5-cm layer of pine bark and covered with shade cloth to minimize evaporative water loss. Exposed container surfaces were painted white and wrapped in plastic-covered R-19 insulation to help modulate temperature extremes. Soil samples were taken to a depth of 30 cm in all containers before the experiment and at the end of the experiment. Soil salinity was measured using the saturation extract technique (U.S. Salinity laboratory, 1954). Electrical conductivity was measured with a conductivity bridge with all measurements adjusted to 25 °C.

The site was equipped with an automated weather station (Campbell Scientific, Logan Utah). Meteorological variables monitored included relative humidity, temperature, wind run, solar radiation and rainfall. The modified Penman combination equation was used to estimate potential evapotranspiration (ET). The yearly ET for August 2002 to July 2003 was 188 cm, with an average temperature of 29 ± 5 °C, average wind speed of 3.4 ± 2.9 m·s⁻¹ and an average relative humidity of 28% ± 17%.

Each plot received its irrigation treatment via nine sprinkler heads (model 200; Hunter Industries) mounted on 183 cm risers, operating within manufacturers specifications. Amounts of applied irrigation were measured by time (10 min per application), which wetted leaf surfaces beyond the point of runoff. Sprinkler irrigation events (190 total) occurred between the start up date of 4 Aug. 2002 and the last irrigation on 15 Sept. 2003. Sprinkler irrigations paralleled overhead irrigations in local mixed landscapes occurring four to five times per week during daylight hours in the summer months and reduced to as low as twice per week during the months of December and January. Tensiometers (model 2710; Soil Moisture Equipment Corp., Santa Barbara, Calif.) were used to measure soil moisture potential. Soil moisture potential was determined on a 1 to 9 scale (where 1 = 10% and 9 = 90% moisture, respectively). Amounts of irrigation were adjusted down 25%, 45%, 75%, and 95% based on the response to post irrigation rinse treatments, only guava and elm were tissue sampled for ion analysis at the end of the rinse period. Briefly, leaves were rinsed with distilled water and dried at 70 °C for 48 h and then ground to a fine powder with a stainless steel mill. The ground tissue samples were sent to a commercial laboratory (A&L Laboratory, Modesto, Calif.) for major cation and anion analysis.

Monthly visual evaluations were completed on one tree of each species in each treatment (same tree). Four times a season, complete visual evaluations were done on all 90 trees (minus those that died). All of the privets in the reuse plot died due to breakage during a high windstorm 2 weeks before the end of the experiment. Evaluations for the privets in the reuse plot, taken in the prior month were used in the final evaluation. Complete visual evaluations were also done at the end of the 30-d post rinse period. Assessments were based on six visual parameters; absence of crown dieback, overall canopy discoloration, presence of dead leaves, presence of deformed leaves, discolored leaves and tip damage. Except for absence of crown dieback, each parameter was evaluated on a 1 to 9 scale (where 1 = 10% and 9 = 90% damage, respectively). Absence of crown dieback was indirectly assessed with a chlorophyll meter (Spad 502; Minolta Corp., Japan). Tissue ion concentrations were measured at the end of the 13.5-month experimental period in representative leaf tissue (40 random leaves of similar age) from the canopies of each tree in each plot. Based on the response to post irrigation rinse treatments, only guava and elm were tissue sampled for ion analysis at the end of the rinse period. Briefly, leaves were rinsed with distilled water and dried at 70 °C for 48 h and then ground to a fine powder with a stainless steel mill. The ground tissue samples were sent to a commercial laboratory (A&L Laboratory, Modesto, Calif.) for major cation and anion analysis.

Field-based spectra (350 to 1100 nm) for each tree within each treatment were acquired using a spectrometer (Unispec; PP Systems Inc., Haverhill, Mass.). A bifurcated fiber optic cable was attached to the Unispec detector and internal light source at one end and a leaf clip at the other end. The leaf clip was clamped onto separate leaves (three per tree) from each tree to measure spectral signatures. Only mature leaves were measured and the leaf clip was placed at the midleaf position but not too primary vein to ensure consistency and comparability within the spectral data. Spectral measurements were acquired on 28 Aug. 2003 from 12:20 to 15:40 HR (end of water treatments) and on 15 Oct. 2003 from 09:00 to 11:00 HR (end of rinse). A suite of vegetation indices (Table 3) was calculated for each spectral measurement and average values were calculated for each tree species within each treatment.

A controlled evaporation study was conducted in the laboratory with the six irrigation waters to assess evapoconcentration that might occur on leaves. One hundred ml of water from each irrigation sample was placed in a 150 mL large-mouth flask. The flasks were then placed in a water bath at 37 °C under an open hood. Separate irrigation water samples were evaporated down 25%, 45%, 75%, and 95% based
on weight change (replicated). One to five ml of water was carefully pipetted for chemical analysis from each flask (avoiding glass walls) immediately after the evaporation point had been obtained. Only in the case of the 95% evaporation MgCl\(_2\) samples were suspended salts observed. These samples were centrifuged at 2000 rpm for 20 min and carefully decanted and passed through a fine porosity high flow rate glass filter before analysis. All samples were analyzed for electrical conductivity with a conductivity bridge with all measurements adjusted to 25 °C. Samples were also analyzed for Ca and Mg by titration, Cl with a Cl1 titrator, Na with a flame photometer (model 2655; Cole Parmer Instrument, Chicago Ill.), SO\(_4\) with a spectrophotometer and vapor pressure with a vapor pressure osmometer (model 5100C; Wescor Inc., Logan Utah).

The data were analyzed with descriptive statistics, analysis of variance (ANOVA) and/or linear and multiple linear regression analysis. Multiple regressions were performed in a backward stepwise manner, with deletion of terms occurring when \(P\) values for the \(t\) test exceeded 0.05.

### Results

**Treatments.** Soil samples taken before the study indicated no statistical difference in soil salinity between species, with an average value (2.28 ± 0.65 dS·m\(^{-1}\)) below the classification for a saline soil (4.0 dS·m\(^{-1}\)) (U.S. Salinity Laboratory, 1954). However, after 13.5 months of irrigating with the 6 different waters, EC values separated based on treatment (\(P < 0.001\)) and species (\(P < 0.01\)) with no treatment by species interactions. The CaSO\(_4\) treatment had the highest EC values (2.91 dS·m\(^{-1}\)), statistically different from all other treatments and willow had the highest EC values among species (2.57 dS·m\(^{-1}\)), statistically different from the guava and privets (2.08 and 2.03 dS·m\(^{-1}\), respectively). All of these average treatment and species soil salinity values were also less than the classification for a saline soil. Midday leaf water potential showed a statistical separation based only on species (\(P < 0.001\)) and not on water treatment, with no decreasing trend with time. No visual symptoms were observed to suggest plant water stress, indicating that the matrix sensor feedback was effective in scheduling irrigation volumes and frequencies to minimize a significant decline in soil moisture or rise in soil salinity. Trunk diameter and tree height separated by species (\(P < 0.001\)) but not by water treatment or by an interaction, indicating that the degree of foliar damage was not directly related to these growth factors over a growing period of 13.5 months. Spad measurements however, did separate by species, water treatment and by a treatment × species interaction (\(P < 0.001\)), suggesting that if the foliar damage study had been maintained over several growing seasons, a reduction in leaflevel chlorophyll production would eventually translate into a reduction in overall growth. No significant correlations existed between spad measurements and tissue ion concentrations.

**Visual damage.** At the end of the 13.5-month experimental period, the index of visual damage (IVD) separated by water quality treatment, species and by a species × treatment interaction (\(P < 0.001\)). IVD values increased in association with the following water quality treatments; reuse (2.08), Na\(_2\)SO\(_4\) (2.18), MgSO\(_4\) (2.34), CaSO\(_4\) (2.51), NaCl (3.30), and MgCl\(_2\) (5.19), with statistical separation between MgCl\(_2\) and all other treatments and NaCl and all other treatments. The fact that IVD’s for the NaCl treatment were significantly higher than the Na\(_2\)SO\(_4\) treatment and that the IVD’s for the MgCl\(_2\) treatment were significantly greater than the MgSO\(_4\) treatment suggests a Cl vs. SO\(_4\) response. Although no statistical differences in the IVD’s existed between the three SO\(_4\) treatments, a clear separation occurred between MgCl\(_2\) and NaCl treatments. Visual damage also increased according to

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### Table 4.

Tissue ion concentrations separated by irrigation treatment\(^{f}\) for each species at the end of the experiment.

| Treatment | Na Conc (g·kg\(^{-1}\)) | Ca Conc (g·kg\(^{-1}\)) | Cl Conc (g·kg\(^{-1}\)) | SO\(_4\) Conc (g·kg\(^{-1}\)) |
|-----------|-------------------------|--------------------------|-------------------------|-----------------------------|
| Guava     | 2.7 ab 22.9 b 5.1 a 7.8 b 1.0 a | 1.9 ab 26.1 b 5.4 a 10.9 b 3.4 a | 1.1 a 12.7 a 8.1 a 6.2 ab 2.0 a | 4.2 b 16.2 ab 10.4 b 7.2 b 0.6 a |
| Desert willow | 4.2 ab 27.3 b 5.8 a 9.5 b 1.5 a | 2.7 ab 21.8 b 6.2 a 5.0 a 2.7 a | 4.7 b 23.7 ab 5.4 a 10.9 b 2.4 ab | 0.8 a 12.6 a 10.7 b 3.3 a 2.8 ab |
| Elm       | 3.0 a 18.2 a 8.9 a 8.3 a 1.5 a | 1.7 a 11.3 a 11.0 ab 8.0 a 2.5 a | 3.5 a 17.1 a 7.3 a 8.8 a 4.0 a | 4.0 a 12.3 a 7.0 a 8.1 a 1.7 a |
| Laurel    | 5.4 b 17.8 ab 5.2 a 4.8 a 0.8 a | 3.7 ab 24.3 b 3.6 a 3.6 a 4.8 b | 2.0 a 14.2 ab 7.1 ab 3.8 a 1.8 ab | 2.9 ab 13.0 a 8.8 b 5.0 b 0.4 a |
| Willow    | 3.6 ab 19.5 ab 5.5 a 4.7 a 0.7 a | 3.1 ab 19.4 ab 5.0 a 3.7 a 2.8 b | 0.7 a 17.9ab 5.3 a 3.6 a 0.7 a | 3.4 ab 19.3 ab 5.3 a 3.6 a 0.7 a |
| Guava     | 0.7 a 18.7 ab 4.3 a 4.6 a 2.3 ab | 0.8 a 12.6 a 10.7 b 3.3 a 2.8 ab | 0.7 a 12.3 a 8.8 b 5.0 a 1.4 a | 2.5 a 19.0 ab 7.5 b 10.4 b 2.4 ab |

\(^{f}\)Mean separation within columns by LSD, \(P < 0.05\).

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**Fig. 1.** Index of visual damage (IVD) for all five species at the end of 13.5 months of sprinkler irrigating with six different water qualities. An acceptable IVD value of 2.0 is designated by a horizontal line.
species as follows: laurel (1.95), guava (2.72), willow (2.76), privet (3.49), and elm (3.75), with statistical separation between laurel and all species, privet and all species and elm and all species ($P < 0.05$). Highest IVD values for all species occurred in the MgCl$_2$ treatment with no values below the acceptable IVD rating of 2.0 (Jordan et al., 2000). IVD values of 10.0 were assigned to the privets in the MgCl$_2$ treatment because of mortalities. No other species died in any of the other water quality treatments. Slightly lower IVD values occurred in the NaCl treatment compared to the MgCl$_2$ treatment but still all values exceeded 2.0. Only in the reuse treatment did 4 of the 5 species have acceptable IVD values (Fig. 1).

**Tissue nutrient concentrations vs. IVD.** Tissue samples harvested at the end of the 13.5-month experimental period were analyzed for macro and micronutrients (Table 4, macro nutrients only). Analysis of variance indicated a significant treatment effect ($P < 0.01$) for all nutrients except K, Mn, and Cu, a significant species effect ($P < 0.05$) for all nutrients except Mn and Zn and significant treatment × species interactions ($p < 0.05$) for Cl, B, Zn, Al, and N (privet not included because of mortalities in the MgCl$_2$ treatment and wind damage in the reseauleuse). Tissue concentrations were then regressed against IVD values in a backward stepwise fashion, eliminating tissue nutrients that were not significant at the $P < 0.05$ level. Because the sample size per species was about 18 (some variation due to mortalities or severe wind damage—privets and elms) only three regressors were accepted, with the aim of maintaining a ratio at or near five samples per regressor (minimizing the risk of multicollinearity, Grossman et al., 1996). Only 33% of the variability in the IVD values of laurel could be accounted for based on Ca and Mn tissue concentrations ($R^2 = 0.33, P = 0.02$, IVD as Ca$_4$). In guava, 61% of the variability in IVD values could be accounted for based on tissue nutrient concentrations of N, P, and K ($R^2 = 0.61, P = 0.01$, IVD as N and P$_4$). Tissue nutrient concentrations of Mg, Mn and Fe accounted for 49% of the variability in the IVD values of willow ($R^2 = 0.49, P = 0.01$, IVD as Mg, Mn and Fe$_4$). In privet (no reuse or MgCl$_2$ treatments due to mortalities) 96% of the variability in the IVDs could be accounted for based on N, K, and Mg ($R^2 = 0.96, P < 0.001$, IVD as N$_4$). In elm 37% of the variability in the IVD values could be accounted for based on N and P ($R^2 = 0.37, P = 0.04$, IVD as N$_4$). When all species were combined (max of 6 regressors accepted based on larger sample size), only 25% of the variability could be accounted for based on Na and B ($R^2 = 0.25, P < 0.001$, IVD as Na and B$_4$). Combining species led to a lower $R^2$ value and the selection of entirely different tissue nutrients contributing to the correlation. The fact that the ANOVA demonstrated that Mn did not show significant differences based on treatment, species or by a treatment × species interaction indicated that some care should be taken in the interpretation of IVD regressions that included Mn (laurel and willow). When regressions were run a second time without Mn, the $R^2$ value for laurel increased (0.51, $P < 0.01$) and the tissue nutrients contributing to the correlation changed from Ca and Mn to N, Na, Cl and Cu ($P < 0.001$ for all four nutrients, reducing to three regressors reduced the $R^2 < 0.20$). Whereas with willow, the $R^2$ value changed little (0.47, $P < 0.001$) while the tissue nutrients contributing to the correlation remained Mg and Fe with P switching for Mn.

Backward stepwise regressions were also done on a treatment basis. Interestingly, the single salts that were added to each treatment showed little correlation with the IVD. In particular, Na and SO$_4$ were removed from the regression for the Na$_2$SO$_4$ treatment ($R^2 = 0.25, P < 0.05$, IVD as K$_4$), Na and Cl were removed from the regression for the NaCl treatment ($R^2 = 0.61, P < 0.05$, IVD as B, Fe and P$_4$), Mg and SO$_4$ were removed from the

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**Table 5. ANOVA results for species and treatment effects on 11 spectral indices.**

| Effect | Red Edge | Chl | PRI | SIPI | WBI | NDPI | NVDI | WBI/NVDI | NPQI | SR | R/FR |
|--------|---------|-----|-----|------|-----|------|------|----------|------|-----|------|
| Species | *** | *** | *** | * | *** | *** | *** | *** | *** | NS | ** |
| Treatment | * | NS | ** | * | NS | NS | NS | NS | NS | NS | ** |

**Table 6. Multiple regression results for tissue ion concentrations and spectral indices.**

| Species | Regression | Ca | Mg | K | Na | Cl | SO$_4$ |
|---------|------------|----|----|---|----|----|-------|
| Elm | $R^2$ | 0.71$^*$ | 0.80$^*$ | 0.91$^*$ | 0.40$^*$ | 0.66$^*$ | 0.71$^*$ |
| Regressors | SR, PRI, NDPI | SR, SIPI, PRE, SIPI, WBI, NDPI, CHL, WBI/NVDI, SIPI, NDPI |
| Guava | $R^2$ | 0.49$^*$ | 0.48$^*$ | 0.55$^*$ | 0.55$^*$ | 0.66$^*$ | 0.71$^*$ |
| Regressors | NS | NS | NS | NS | NS | NS |
| Privet | $R^2$ | NS | NS | NS | NS | NS | NS |
| Regressors | NS | NS | NS | NS | NS | NS |
| Willow | $R^2$ | 0.48$^*$ | 0.49$^*$ | 0.55$^*$ | 0.66$^*$ | 0.71$^*$ | 0.71$^*$ |
| Regressors | NS | NS | NS | NS | NS | NS |

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**Fig. 2.** Index of visual damage (IVD) for guava at the end of the 13.5-month experimental period (six water qualities) compared to the end of the 30-d postirrigation rinse period. An acceptable IVD value of 2.0 is designated by a horizontal line.
regression for the MgSO$_4$ treatment ($R^2 = 0.57$, $P < 0.05$, IVD↑ as Na and Ca↑ and Cl↓), Ca and SO$_4$ were removed from the regression for the CaSO$_4$ treatment ($R^2 = 0.32$, $P < 0.05$, IVD↑ as K↑ and Cl↓) and only in the case of the MgCl$_2$ treatment was Mg included in the regression equation ($r^2 = 0.82$, $P < 0.01$, IVD↑ as SO$_4$↓, Mg and P↑), suggesting a possible role of suppression in addition to accumulation for these major cations and anions.

Spectral reflectance indices vs. IVD. Spectral reflectance measured at the leaf level in the 400- to 1100-nm range (end of experiment) was used to generate eleven different indices as reported in Table 3. Analysis of variance (general linear model with no interactions, missing privet data, Table 5) indicated significant differences based on treatment ($P < 0.05$, except NPQI (normalized phaeophytinization index) and species ($P < 0.05$). The indices were regressed in a backward stepwise fashion against IVD values, as described in the tissue nutrient section. In laurel, 63% of the variability in the IVD could be accounted for by including the simple ratio (SR), chlorophyll index (CHL), and the red edge (Red Edge), ($R^2 = 0.63$, $P < 0.001$, IVD↑ as CHL↓). In guava, SR and NDVI (normalized difference vegetation index) accounted for 58% of the variability in the IVD could be accounted for by including NDVI, CHL, and PRI (photochemical reflectance index) ($R^2 = 0.51$, $P < 0.01$, IVD↑ as CHL↓). Whereas, in willow, 51% of the variability in the IVD could be accounted for by including NDVI, CHL, and PRI (photochemical reflectance index) ($R^2 = 0.51$, $P < 0.01$, IVD↑ as CHL↓). In elm, 70% of the variability in the IVD could be accounted for by including Red Edge, NDVI and WBI/NDVI (water band index/NDVI) ($R^2 = 0.70$, $P < 0.01$, IVD↑ as Red Edge, NDVI and WBI/NDVI). Only 26% of the variability in the IVD of privet could be accounted for including NDVI and R/FR (red reflectance–far-red reflectance) ($R^2 = 0.26$, $P < 0.05$, IVD↑ as R/FR and NDVI). When all species were combined, only 20% of the variability in the IVD could be accounted for based on including NPQI, NDPI (normalized total pigment to chlorophyll a index), WBI, SIPI (structure insensitive pigment index) and SR ($R^2 = 0.20$, $P < 0.001$, IVD↑ as WBI, SIPI and SR). This lower $R^2$ value associated with all species described by different spectral indices was similar to the response noted for the IVD tissue nutrient correlations, suggesting that the strong species effect does not warrant the further merging of data.

Spectral reflectance indices were also regressed against tissue ion concentrations for each species (Table 6). Only in the case of elm did significant correlations exist for all six of the major cations and anions ($R^2$ ranging from 0.40 to 0.91). In privet, no significant correlations existed, whereas in willow and laurel only one significant correlation existed (Mg). Tissue Mg concentrations revealed significant correlations with spectral indices in four of the five species, with SIPI and/or NDPI included in each regression.

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Plant response to postrinse treatment. At the end of the 30-d rinse period, soils were
sampled, plants were visually evaluated for foliar damage (IVD) and then measured for leaf spectral reflectance and tissue sampled for ion analysis. Soil salinity values declined below preexperimental values (1.88 ± 0.78 dS m⁻¹) indicating that the post rinsing was very effective in leaching soluble salts from the containerized root zones. IVD values separated based on treatment, species, and by a species x treatment interaction (P < 0.001). However, when a three way ANOVA was conducted including time as a factor, only guava had a significant time within species interaction (Fig. 2), whereas elm showed a significant (P < 0.05) change in the IVD (1.79 increasing to 4.46) only in the reuse treatment after the 30-day rinse period. A decision was made based on cost and the non significant IVD response to the rinse treatment in the laurel, privets and willow to tissue analyze only the guava and elms after the rinse period. When tissue ion concentrations were compared before and after the rinse period for guava (all treatments combined), all concentrations declined except nitrogen (increasing from 16.2 to 22.6 g kg⁻¹, P < 0.05) and sulfate (increasing from 2.0 to 6.6 g kg⁻¹, P = 0.05). However, when the NaCl treatment was isolated for guava (greatest decline in IVD after rinse, 3.79 to 1.75) only Ca showed a significant response (P < 0.05) to the rinse treatment, declining from 27.6 to 14.2 g kg⁻¹. Whereas in elm (reuse treatment, greatest increase in IVD after rinse, 1.79 to 4.46) only N and Ca showed significant separation (P < 0.05), with both increasing in response to the rinse treatment (Ca increasing from 17.7 to 24.1 g kg⁻¹ and N increasing from 29.9 to 36.6 g kg⁻¹). Unlike the IVD and the tissue ion concentrations, many spectral reflectance indices had significant changes in response to the rinse period. However, in the NaCl treatment with guava, only the simple ratio changed significantly (decreasing rather than increasing, as would have been expected with a reduced IVD). Elm had the highest number of significant changes in indices in response to the rinse but again many changed in a direction opposite of what was expected (Table 7). The CHL index for the reuse treatment however did decrease (0.47 to 0.38, P < 0.05) in response to the rinse as the IVD increased. The mixed results with the spectral indices after a post rinse irrigation may indicate that recovery had not yet translated into a visual rating improvement, which may require a longer period of time. Reflectance measurements were also not obtained directly over damaged areas, which remain after a rinse period occurs and are included in the visual rating.

Irrigation evapoconcentration. The irrigation waters were not established as iso-osmotic solutions but contained elevated single salts blended with Colorado River water. Since 50% of the electrical conductivity (EC) was based on mixed salts found in water from the Colorado River, similar elevated ECs had similar osmotic potentials (OP) (Fig. 3). This was especially true at lower evaporation rates (25% evaporation, OP = 0.108 ± 0.006 MPa). However, a clear concentration effect occurred after 75% evaporation (salinity increasing to values between 41 and 49 dS m⁻¹ at 95% evaporation, except for the CaSO₄ water which peaked at 23 dS m⁻¹). As was expected, waters dominated by specific ions (Ca, Mg, Na, Cl, SO₄) had higher concentrations of those specific ions. However, in only six out of the 30 cases (Mg, Na, Ca, Cl, SO₄ in the six irrigation waters), did the concentration at 95% evaporation exceed what would have been predicted by a simple 20-fold increase in concentration, with no consideration for precipitation or ion pair formation. Chloride concentrations in the MgCl₂ treatment was higher than what would have been predicted (1.24× at 299 meq L⁻¹, Fig. 4), as was Mg in the reuse (2.28×, 139 meq L⁻¹), Mg in the MgSO₄ (2.41×, 431 meq L⁻¹), Mg in the MgCl₂ (1.87×, 306 meq L⁻¹) and SO₄ in the MgCl₂ and NaCl treatments (1.30×, 137 and 136 meq L⁻¹). These results would suggest that greater concentrations of both Mg and Cl would exist on the leaf surface during the final phase of evaporation (relative to a simple 20 fold evapoconcentration).

Foliar absorption of salts are linked to solubility and the point of deliquescence (POD), where the POD is defined as the humidity over saturated solution, or the deliquescence point (Schonherr, 2002). The POD values for the five salts added separately to the irrigation tanks range from a low of 33% for MgCl₂·6H₂O, ≈50% for NaCl and MgSO₄·H₂O to 84% for Na₂SO₄ (Cziecko et al., 1999; Schonherr, 2002), (CaSO₄·H₂O not reported but assumed very high). Maximum relative humidity measured on a daily basis at the field site during the summer months of June, July and August are reported in Fig. 5 (time of maximum canopy development, transpiration, irrigation applications and foliar damage). The horizontal lines represent the POD for MgCl₂·H₂O (33%) and NaCl(=50%). The maximum relative humidity exceeded the POD for MgCl₂·H₂O 24% of the time during these summer months but exceeded the POD for NaCl only 8% of the time. The POD value was exceeded by a greater extent at night than during the day, with maximum relative humidity exceeding the POD of MgCl₂·H₂O 31% at night vs. 20% during the daylight hours.

Discussion

Foliar damage to landscape ornamentals sprayed irrigated with reuse water is a critical factor in lowering the acceptance of reuse water as an irrigation source on mixed landscapes, especially première golf courses. In this study, all plants were irrigated both at the soil surface and directly on the canopy. Soil salinity levels were in an acceptable range (<3.0 dS m⁻¹), yet foliar damage occurred. The contribution of leaf level damage associated with root level absorption cannot be ruled out, however, the low soil salinity levels would suggest that the damage was magnified by the foliar application. The IVD indicated a clear separation in the amount of damage based on treatment, with a significantly higher amount of damage with NaCl and MgCl₂ irrigation waters (8 to 12 meq L⁻¹ for each ion). Based on the salt treatments in this experiment, results would suggest that Cl salts are more damaging than SO₄ salts (NaCl treatment tissue Na 3.4 g kg⁻¹ vs Na₂SO₄ treatment tissue Na 2.0 g kg⁻¹, P < 0.05) and that Mg associated with Cl is more damaging than Na associated with Cl (death of privets, high IVDS in most treatments) (Fig. 1). Over 60 years ago, Wadleigh and Gauch (1944) cautioned that knowledge of both the cation and associated anion are necessary when describing the inhibitory effects of a given substrate. Although their studies were not based

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Fig. 5. Hourly maximum relative humidity measured at the research site during June, July, and August. Horizontal line A designates the point of deliquescence (POD) for NaCl and horizontal line B designates the POD for MgCl₂.
on the foliar application of salts, our results would support this same cautionary statement. The IVD response was also species dependent (Fig. 1) with laurel showing the least amount of damage (IVD 1.95) and privet and elm showing the greatest amount of damage (IVD 3.49 and 3.75 respectively). IVD values were correlated with tissue ion concentration, with 33% to 96% of the variation being accounted for by a combination of three different tissue ion concentrations (different for each species). When IVD values were separated by treatments, only in the case of the MgCl2 treatment was a major elevated ion (Mg) contributing to a significant amount of the variation in the IVD ($R^2 = 0.82$, $P < 0.01$, IVD↑ as SO2 and P↑). This response suggests that elevated cations and anions in the irrigation water may be involved in the suppression of ion uptake as much as a concentration to toxic levels in the leaf tissue. Mg toxicity associated with MgCl2, waters has been reported for guayule (Wadleigh and Gauch, 1944). Mg is known to have high mobility within plants yet little is known about Mg transporters in the plasma membrane (Mengel, 2002). Mg also has a relatively small ionic radius (Mg 0.71Å vs. Ca 0.99Å), which may be important with regards to diffusion pathways, contributing to elevated leaf concentrations. Foliar applications of MgCl2, and MgSO4 were shown to have the same efficiency with regards to increasing leaf Mg content of apples (Thalheimer and Paoli, 2002). Tissue concentration of Mg was elevated in the MgCl2, and the MgSO4 treatments, yet IVD values were lower for the MgSO4 treatment. Spectral indices correlated with IVD values in a similar range as tissue ion concentrations ($R^2$ values ranging from 0.26 to 0.70), suggesting that this technique with further development could potentially become a quick nondestructive tool in assessing foliar damage (species dependent). Although we are not aware of any previously published work correlating spectral indices with foliar damage associated with saline irrigation water, extensive work has been done correlating indices such as NDVI, WBI and SR to biomass, water status and overall plant health (Gamon et al., 1995; Ma et al., 1996; Penuelas et al., 1994; Sims and Gamon, 2003). Previous work has also been published correlating changes in spectral reflectance to nutrient status (Carter, 1994; Filella et al., 1995), diseases (Jones et al., 1992) and chlorophyll content (Gitelson et al., 1999; Filella and Penuelas, 1995). We believe if canopy level reflectance had been measured instead of leaf level reflectance (integrating the entire canopy, damaged tissue and healthy tissue) a closer correlation would have occurred with IVD values. However, damaged tissue will remain on the intact leaves even after stress recovery, making interpretation of the spectral response difficult. This would suggest that obtaining both canopy and leaf level measurements would be invaluable. In our study, the chlorophyll index, NDVI, red edge and the simple ratio were four indices that were highly correlated with IVD values, while NDPI, SR, and PRI were more correlated with tissue ion concentrations. The spectral response was species dependent, with elm showing significant correlations between spectral indices and IVD ($R^2 = 0.70$) and between spectral indices and major tissue ion concentrations ($R^2 = 0.40$ to 0.91$)$. However, when data from multiple species were combined, poor results were obtained. These poorer results with mixed species suggest care should be taken when merging data and interpreting results.

Foliar absorption of salts have been reported to be regulated by a concentration gradient and diffusion process across the cuticle that is affected by humidity over the cuticular pores and by the hygroscopicity of the salt in question (Schonherr, 2002). The same principles that control cuticular penetration when applying nutrients in a foliar spray also apply when salt solutions such as reuse water are sprayed onto the leaf (although the response is not as definitive in a mixed salt solution). Those salts with lower points of deliquescence and higher solubility, which are applied under higher relative humidities, will be absorbed to a greater extent. The longer the salts remain in solution on the cuticle the greater the opportunity for absorption. In hot dry environments, leaf wetting times after irrigations during summer months have been measured to vary from 3 to 12 min (during the day) and to be species dependent (Devitt et al., 2003). However, if the point of deliquescence is exceeded, the opportunity time for absorption is increased beyond the normal leaf wetting time (especially at night). Greater foliar damage occurred in the MgCl2 treatment, which was associated with higher Mg concentrations but not higher Cl concentrations in the leaf tissue. In all species except willow, higher Mg concentrations in the tissue led to lower Ca concentrations, which could have altered membrane integrity (Cramer, 2002). Tissue samples represented total leaf samples, as no attempt was made to isolate the foliar damaged tissue from the healthy tissue. Damaged areas were most likely the result of surface damage (salt burn associated with >40 dS·m−1 water during final phase of evaporation), MgCl2 treatment exceeding the POD 31% during night time hours, localized compartmentalization of unwanted ions and specific damage (tissue and marginal damage) associated with imbalanced ion concentrations (such as Mg vs. Ca). Applying foliar irrigation during a time of active growth (30 consecutive days of 10-min irrigations with municipal water) led to a decrease in soil salinity, a decrease in the IVD of guava, a non response in laurel, privet and desert willow but a rise in foliar damage associated with elm irrigated with reuse water. Similar mixed results to a post irrigation rinse have been reported previously (Devitt et al., 2003). In this study the rinse treatment led to a significant decline in most macro and micronutrients in foliar samples. Comparing two species with the greatest contrast in IVD after the rinse treatment, elm IVD (reuse) increased while guava IVD (NaCl) decreased. The only contrasting factor was the change in tissue Ca concentrations, elm increasing by 36% (IVD↑) while guava decreased in Ca concentration by 49% (IVD↓).

Evpacoconcentration of salts on leaves spray irrigated with reuse water under arid conditions is higher because higher irrigation volumes are required to meet transpirational demand, rainfall is low, evaporation occurs over a shorter period of time and municipal waters (such as water diverted from the Colorado River) contain significantly higher salt loads (Devitt et al., 2003; Jordan et al., 2001). Irrigating with such waters will lead to significant foliar damage in many ornamental trees (Jordan et al., 2001). Although the electrical conductivity of the six waters were very similar (as were osmotic potentials) and the elevated specific cation or anion never exceeded 1 meq L−1, a wide range in response was observed, suggesting that when saline waters are blended with other water sources, care should be given to monitoring not only the EC (and OP) but also the ionic composition, with the aim of minimizing the concentration of Na, Mg, and Cl. Selection of species for landscapes must be based on research relevant to the specific region and water quality. Future research should include evaluating the difference in foliar damage based on irrigating during daytime hours vs. nighttime hours, establishing threshold spray irrigation times and evaluating the effect of adding CaSO4 to reuse water to improve the Ca to Na, Ca to Mg, and SO4 to Cl ratios.

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