Impact of Water Treatment on Foliar Damage of Landscape Trees Sprinkle Irrigated with Reuse Water[1]

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Abstract

An experiment was conducted on four container-grown tree species placed under five different irrigation reuse water treatments to determine the extent of foliar damage after a 14.5-month period. The tree species included Heritage oak (*Quercus virginiana* Mill. 'Heritage'), desert willow (*Chilopsis linearis* (Cav.)/Sweet), flowering plum (*Prunus cerasifera* Ehrh 'Atropurpurea'), and Chinese pistache (*Pistacia chinensis* Bunge). Plant response and an index of visual damage (IVD) were assessed at different times throughout the experiment. Ion concentrations in the leaf tissue were different for species (S) ($p < 0.001$), treatment (T) (Na, K, SO_4, $p < 0.05$) and by a species by treatment interaction (S × T) (Na, Ca, Mg, K and SO_4, $p < 0.05$). SPAD measurements varied by S ($p < 0.001$), T ($p < 0.001$) and by an S × T interaction ($p < 0.045$). SPAD measurements decreased as the leaf tissue Na concentration increased (SPAD = 47.49 – 12.46(Na), $r^2 = 0.38$, $p < 0.01$). The IVD varied by S ($p < 0.001$), T ($p < 0.001$) and by an S × T interaction ($p < 0.001$). Na, Ca and SO_4 tissue ion concentrations could account for 52% of the variability in the IVD (IVD = –1.93 + 4.63(Na) + 2.60(Ca) – 0.001(SO_4), $p < 0.01$). Because the irrigation treatment resulting in the lowest IVD was species dependent, irrigation treatment selection should be based upon an evaluation of the landscape species composition and the potential cost of implementing a given strategy. The response observed in this study suggests that a single universal irrigation strategy does not exist, indicating that emphasis must be placed on initial and replacement plant selection.

Index words: salinity, sodium, SPAD.

Species used in this study: Heritage oak (*Quercus virginiana* Mill. 'Heritage'); desert willow (*Chilopsis linearis* (Cav.))/Sweet; flowering plum *(Prunus cerasifera* Ehrh. 'Atropurpurea'); Chinese pistache *(Pistacia chinensis* Bunge).

Significance to the Nursery Industry

In many parts of the United States, treated sewage effluent (reuse water) is used to irrigate golfcourses, parks, schools and nursery plants. Because good quality water is limited in many of these areas, reuse water is a valuable resource, characterized by a high nutrient and total salt content. Many plants can tolerate high levels of salt in irrigation water if this water is applied directly to the soil as opposed to the application of such water directly on plant tissue. However, in landscapes where reuse water is applied by overhead irrigation, the soil and foliage of both turfgrass and landscape plants intercept this water directly or indirectly through irrigation and drifting spray. Because many landscape plants exhibit foliar damage when such spray consistently lands on the foliage, landscapers and nurserymen need to know which species are tolerant and what irrigation strategies might be employed to minimize this type of damage. In this study we confirmed that Chinese pistache and flowering plum incurred greater foliar damage than desert willow and Heritage oak when irrigated with reuse water with different irrigation treatments. However, the amount of damage to each of these four species varied depending upon which treatment strategy was employed (diluting the reuse water, following the reuse irrigation with a post irrigation rinse of fresh water or by pH adjusting the reuse water, aerating and passing the reuse water through a carbon filter). Because the best irrigation treatment strategy to implement was species dependent, final selection must be made based upon an evaluation of the landscape species composition and potential cost of implementing a given strategy. Findings in this study suggest that species selection at the time of landscape planning is the most important strategy to avoid the negative effects of reuse irrigation water.

Introduction

Southern Nevada has had unprecedented growth over the last 15 years, maintaining a growth rate of nearly 6,000 new residents per month (2000 Clark County census). As the population has increased, so has the demand for water (Southern Nevada Water Authority, personal communication). Projections now indicate that there is only enough water to maintain this growth rate for a few more years. As such, scientists and water purveyors have been looking for alternative water resources, such as nonpotable water, to supplement the amount allocated from the Colorado River. One such water resource is treated sewage effluent otherwise known as reuse water. Although reuse water has been used in California and Arizona for decades, only minimal usage has occurred in Nevada due to the credits given to Nevada (return flow credits) when treated sewage effluent is returned to the Colorado River. However, a recent economic feasibility analysis (Southern Nevada Water Authority, personal communication) that has taken into account the changing cost associated with using fresh water versus reuse water now supports more widescale use of reuse water in southern Nevada. Unfortunately for Nevada, water drawn from the Colorado River carries about one ton of salts per acre-foot of water and this value

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Table 1. **Tree species height and trunk diameters at the beginning of the experiment.**

Common name	Species	Tree height (m)	Trunk diameter (cm)
Heritage oak	*Quercus virginiana* Mill.'Heritage'	2.6 ± 0.3[z]	3.0 ± 0.4
Desert willow	*Chilopsis linearis* (Cav.)	2.8 ± 0.3	3.4 ± 0.5
Sweet flowering plum	*Prunus cerasifera* Ehrh 'Atropurpurea'	3.0 ± 0.2	3.4 ± 0.2
Chinese pistache	*Pistachia chinensis* Bunge	2.3 ± 0.1	2.4 ± 0.4

[z]± one standard deviation.

nearly doubles by the time it is used and returned to the treatment plant to be treated and discharged. Although many turfgrass species have been demonstrated to have moderate to high salt tolerance (5, 8, 15, 21), many landscape species have been demonstrated to be far more sensitive (2, 10, 16, 22). In particular, the application of saline irrigation water directly to the foliage as opposed to the soil surface has been demonstrated to cause significant foliar damage in many landscape and crop species and in some cases even leading to the death of the plant (1, 3, 4, 7, 9, 11,12, 13, 14). Although foliar application of reuse water has been studied in detail (8, 10, 16, 22), such results are not entirely applicable to other locations due to differences in salt load, specific ion composition and climatic conditions. A study conducted in southern Nevada on foliar damage to landscape plants irrigated with reuse water (10), suggested that only seven out of the twenty landscape trees species would be recommended for use where reuse water landed directly on the foliage (olive, mesquite, Aleppo pine, Mondell pine, African sumac, stone pine and Raywood ash). The current study was designed to determine if different irrigation management strategies with reuse water would lead to a more favorable response to four species that did not make the initial recommended list of Jordan et al. (10). In particular, we wanted to quantify the amount of foliar damage to Chinese pistache, flowering plum, desert willow and Heritage oak when reuse water was 1) sprinkler irrigated onto the foliage, 2) treatment 1 followed by a post irrigation rinse of fresh water, 3) reuse water acidified, aerated and then passed through a carbon filter, 4) reuse water that underwent a 25% dilution with fresh water or 5) reuse water that underwent a 50% dilution with fresh water.

Material and Methods

This research was conducted at the Clark County Sanitation District (CCSD) facility in Las Vegas, NV. The experiment involved 5 water quality treatments and 4 species of landscape trees (Table 1). Each treatment was confined to a separate experimental block with species randomized and replicated three times within each block (5 irrigation blocks, 4 species, n = 12 trees per block, n = 60 trees total). The treatments included the foliar application (via raised sprinkler heads) of 1) reuse water, 2) reuse water followed by a fresh water rinse (to reduce salt deposition on leaves and foliar absorption of salts), 3) reuse water acidified to a pH of 6.1 (to reduce bicarbonate), aerated and passed through a carbon filter (to reduce low level contaminants such as volatile organics), 4) reuse water diluted by 25% with fresh water and 5) reuse water diluted by 50% with fresh water. Both the reuse and fresh water were provided at the site by the CCSD and piped directly to three 1000-gallon tanks, where final water qualities were established for treatments 3, 4 and 5. In the case of the post irrigation rinse (treatment # 2), reuse and fresh water were piped directly to the plot, where shut-off valves enabled reuse water to be vented to the system followed by fresh water. Water treatment 3 was pH adjusted to 6.1 daily with concentrated sulfuric acid and monitored with a pH meter. The pH-adjusted water was aerated for 6 hours each day with an air pump connected to a distribution system that was placed at the bottom of the tank. Water pumped from the pH-adjusted tank was then passed through an inline carbon filter (U.S. Filter Corp., replaced every 4 months). Samples of all five waters were collected weekly and analyzed for salinity and major cations and anions (via atomic absorption spectrophotometry — Ca, Mg, Na, K; spectrophotometer — SO_4; chloride titrator — Cl; titration — HCO_3/CO_3) . The chemical composition of the irrigation water varied according to treatment and is reported in Table 2. The salinity of the reuse water was high when compared to reuse water for other treatment facilities in the United States (17, 19). However, the fresh (municipal) water was also relatively high in salts when compared to other drinking water sources in the United States (17). The fresh water had a salinity level 50% lower than the reuse water, indicating a doubling in salt load as the water was used, returned and treated. However, the sodium in the reuse water increased 2.7 fold and the chloride increased 7 fold over the concentrations in the fresh water. Dilution of the reuse water with fresh water led to a 13%

Table 2. **Average chemical composition of treatment irrigation waters based on weekly analysis, where the reuse plus fresh water rinse would be represented by a combination of the reuse and fresh water qualities.**

Treatment	Salinity dSm^{-1}	Na	K	Ca	Mg	Cl	SO_4	HCO_3	pH	SAR_{adj}[z]
		Meq l^{-1}								
Reuse	1.87	8.7	0.7	6.9	6.1	4.9	5.9	2.5	7.5	6.99
Reuse pH adjusted, aerated, carbon filter	1.91	8.4	0.8	7.5	6.7	4.8	9.8	1.0	6.1	5.34
Reuse 25% dilution	1.63	6.9	0.5	6.6	6.3	3.7	7.3	2.1	7.2	5.33
Reuse 50% dilution	1.49	6.2	0.4	6.6	4.9	2.9	6.2	2.2	7.2	3.62
Fresh water	0.93	3.2	0.1	4.3	4.1	0.7	5.4	2.7	7.6	3.00

[z]Adjusted sodium adsorption ratio (17).

decrease in the salinity of the irrigation water in the 25% volume dilution treatment and a 20% decrease in the 50% volume dilution treatment. Acidifying treatment 3 to a pH value of 6.1 with sulfuric acid led to a 66% increase in the sulfate concentration, a 60% decrease in the bicarbonate concentration, a 24% decrease in the adjusted sodium adsorption ratio (SAR_{adj}) (17) but only a 2% increase in the salinity

Trees were not planted in the ground because the soil at the research site adjacent to the sewage treatment plant was highly saline and possessed a shallow water table (6 ft (~180 cm)). Each tree was left in its original #15 standard nursery container (15 gal). These containers with trees were placed in a second, belowground, #15 container (pot in pot), which was filled with 10 cm (3.9 in) of pea-gravel. Each pot was heavily mulched with pine bark to minimize evaporative water loss. Exposed container surfaces were painted white and wrapped in white plastic covered R-19 insulation. The mulched surface was covered with shade cloth to help moderate soil temperature in both winter and summer. Spacing between pots was 1.5 m (4.9 ft), to prevent shading and interference during overhead irrigations. Soil samples (0–1 ft (~0–30 cm)) were taken from all containers prior to initiation of the experiment and 14.5 months later at the end of the experiment. Salinity (EC_e) was measured in all soil samples taken before and after the experiment using the saturation extract technique (20). Electrical conductivity was measured with a Beckman Conductivity bridge with all measurements adjusted to 25C (77F). EC_e of container soils measured at the beginning of the experiment revealed a statistically significant difference ($p < 0.001$) based on species (S) (reflecting different soil and growing conditions for the four species obtained from different growers in the southwestern United States). Although three of the four species (average EC_e, desert willow, 9.06 dSm^{-1}, Heritage oak, 5.45 dSm^{-1} and Chinese pistache, 6.59 dSm^{-1}) exceeded 4.0 dSm^{-1} in the saturation extract, indicative of a saline soil (20), all of the plant material was healthy showing no visual signs of stress or salt damage

The site was equipped with an automated weather station (Campbell Scientific, Logan, UT). Meteorological variables monitored included relative humidity, temperature, wind run, solar radiation and rainfall. The modified Penman Combination equation was used to estimate potential evapotranpiration (ET_o). The yearly total ET_o for the year 2000 was 191 cm (6.3 ft) with high summer daytime temperatures of 46C (115F).

Each plot received its irrigation treatment via nine sprinkler heads (Hunter 200 model — 44 psi) mounted on 6-foot (183 cm) risers, which provided an irrigation uniformity coefficient of >0.80. Irrigation applications were measured by time (10 minutes per application, 2 minutes for post irrigation rinse). The first irrigation event occurred on July 30, 1999, and the last irrigation occurred on October 11, 2000 (168 total). Sprinkler irrigations occurred four to five times per week during summer months and were reduced to as low as once per week during the months of December and January. All irrigations occurred between the hours of 0600 and 0800 to minimize evaporation and wind drift. Tensiometers (Irrometer, Riverside CA, to measure soil matric potential) were placed at 15 cm (6 in) in one pot of each species in each plot. Daily tensiometer measurements were taken with a pressure transducer. If the soil matric potential exceeded a set threshold of –0.02 MPa (–0.03MPa for desert willow), a 10-liter (2.6 gal) application of the appropriate treatment water was applied directly into the container by hand. Drainage from the containers was never impeded and tensiometer feedback assured that moisture stress was not a compounding factor to the presence of soluble salts.

The plant water status of the trees was monitored biweekly. The measurements included mid-day leaf water potential (pressure bomb, Soil Moisture Corp.), stomatal conductance (steady state porometer, Li-Cor 1600) and canopy temperature (Cole Parmer 39800 infrared thermometer). Other physiological measurements taken during the experiment included spad measurements (Minolta SPAD 502 chlorophyll meter, biweekly), tree height and trunk diameters (1 ft (~ 30 cm) from soil surface, pre and post experiment). Tissue ion concentrations were measured at the end of the experiment (October 2000) in leaf tissue (40 random leaves of similar age) selected from the canopies of each tree in each plot. Leaves were rinsed with distilled water and dried at 70C (158F) for 48 hours and then ground to a fine powder with a stainless steel mill. The ground tissue samples were then acid digested in 25 ml of 0.5 M nitric acid and placed in a vacuum for 20 minutes. The extracts were filtered prior to analysis and analyzed for Ca and Mg (atomic absorption spectrophotometry), Na and K (flame photometry), Cl (Haake Buchler digital chloride titrator) and SO_4 (A&L commercial laboratory, Modesto, CA).

Because visual appearance of landscape trees is crucial to landscape managers, a visual rating system (10) was used to rate the extent of foliar damage. Biweekly visual evaluations were completed by two evaluators on one designated tree of each species in each treatment. All 60 trees underwent visual evaluations four times a year. Assessments were based on six parameters: absence of crown dieback, overall canopy discoloration, presence of dead leaves, presence of deformed leaves, discolored leaves and tip or marginal damage. Except for absence of crown dieback, each parameter was evaluated on a 1 to 9 scale (where a value of 1 equated to a rating of 10% damage and a value of 9 equated to a rating of 90% damage). Absence of crown dieback was evaluated on a 1 or 0 basis (where a value of 1 equated to dieback and a value of 0 equated to no dieback). An index value of visual damage (IVD) was generated by giving equal weight to a canopy-based assessment value (canopy dieback plus overall canopy discoloration) and a leaf level assessment value (average rating of leaf discoloration, deformed leaves, tip or marginal damage and presence of dead leaves). The IVD equation can be defined as:

IVD = (Canopy dieback (1 or 0 rating) + overall canopy discoloration (1 to 9 rating) + (Σ (leaf discoloration, deformed leaves, tip or marginal damage, dead leaves (all on a 1 to 9 rating)) / 4.

Leaf wetting times were measured on individual trees (10 times per species) during the months of June, July and August of the second year. The time required for all leaves to dry after a 10 minute irrigation were measured with a stopwatch.

The data were analyzed with descriptive statistics, analysis of variance (ANOVA) and 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 and Discussion

Soil salinity. After 14.5 months of irrigating with the five treatment waters, soil salinity varied not only by S ($p = 0.02$) but also by treatment (T) ($p = 0.002$). Interestingly, EC_e actually decreased over the experimental period for desert willow, Heritage oak and Chinese pistache (6.38 dSm^{-1}, 4.72 dSm^{-1} and 4.45 dSm^{-1}, respectively), suggesting that these container trees might have been under irrigated at the nurseries where they were grown. Only in the case of flowering plum did the average soil salinity show a slight non-significant increase over the experimental period (3.60 dSm^{-1} to 3.91 dSm^{-1}) but still below the saline soil classification. Separation of EC_e by T ($p < 0.05$) occurred only when the reuse water and acid treated reuse water were compared with the 50% volume dilution treatment (5.65 dSm^{-1} and 5.57 dSm^{-1} vs. 3.50 dSm^{-1}).

Growth and plant water status. Irrigation treatments did not affect trunk diameters, tree heights, canopy temperatures, stomatal conductances or leaf xylem water potentials ($p > 0.05$), suggesting that the irrigation strategy employed provided adequate soil water to prevent plant water stress (matric induced). Heritage oak, desert willow and flowering plum all had similar summer midday water potentials (–1.78 MPa, –1.68 MPa and –1.54 MPa, respectively). However, Chinese pistache maintained a higher average midday water potential of –0.43 MPa, which was statistically different from the other species ($p < 0.05$). Only SPAD measurements (indicative of chlorophyll levels) varied by S ($p < 0.001$), T ($p < 0.001$) and by an S × T interaction ($p = 0.045$). Within the treatment category, only the 50% dilution treatment revealed a separation ($p < 0.05$) in the average SPAD value (43.86) based on a comparison with the rinse treatment (37.23) and acid treatment (39.46). Within the species category, SPAD values for Chinese pistache (37.17) and flowering plum (33.77) were not significantly different but all other species comparisons were different (desert willow 41.66, Heritage oak 47.60). Differences in SPAD values based on interactions were only significant for desert willow when comparing the 50% dilution (49.07) with the 25% dilution (37.34) and the rinse treatment (36.41).

Tissue ion concentrations. Tissue ion concentrations, measured at the end of the experiment, were significantly different based on S ($p < 0.001$), T ($p \leq 0.05$) and by an S × T interaction (Na, Ca, Mg, K and SO_4, $p \leq 0.05$) (Table 3). Only in the case of Na and K could an increased amount of variation be accounted for if S (species) were included as an independent variable with the other tissue ion concentrations in a backward stepwise regression (Na, adjusted $R^2 = 0.57$, $p = 0.001$, K, $R^2 = 0.48$, $p = 0.002$). However, when the S was not included as an independent variable both tissue Ca and K revealed no association with any of the other tissue ion concentrations ($p > 0.05$). Sixty-seven percent of the variation in SO_4 concentration could be accounted for by including the Na and Mg concentrations in the regression analysis ($SO_4 = -0.11 + 0.16(Na) + 0.47(Mg)$, $p \leq 0.001$), whereas 39 percent of the variation in the Na concentration could be accounted for by including only the SO_4 concentration ($Na = 0.33 + 1.70(SO_4)$, $p = 0.002$). Seventy percent of the varia-

Table 3. Average tissue ion concentrations in percent separated by irrigation treatment for each species at the end of the experiment.

Treatment	Na	Ca	Mg	K	Cl	SO_4
	%					
Oak						
Reuse	0.39a[z]	1.74a	0.30a	0.94a	0.76a	0.10a
Reuse + Rinse	0.29a	0.95b	0.11b	0.68a	0.74a	0.05a
Reuse pH 6.1	0.34a	1.19ab	0.35a	0.81a	0.42a	0.13a
25% dilution	0.33a	1.10ab	0.15b	0.64a	0.62a	0.05a
50% dilution	0.25a	1.48ab	0.23ab	0.56a	0.37a	0.06a
Desert willow						
Reuse	0.56a	1.85a	0.51a	1.06a	2.10a	0.19b
Reuse + Rinse	0.52a	1.77a	0.48a	1.09a	1.84a	0.17b
Reuse pH 6.1	0.51a	2.31a	0.56a	1.17a	2.35a	0.41a
25% dilution	0.58a	2.02a	0.57a	0.93a	1.95a	0.21ab
50% dilution	0.69a	1.96a	0.57a	0.94a	2.14a	0.17b
Plum						
Reuse	1.36a	1.41a	0.48a	1.59a	1.24a	0.33a
Reuse + Rinse	1.37a	1.12a	0.37a	0.94b	1.74a	0.33a
Reuse pH 6.1	0.99a	1.56a	0.44a	1.66a	1.39a	0.32a
25% dilution	0.50b	1.31a	0.45a	1.90a	1.48a	0.21ab
50% dilution	0.53b	1.35a	0.43a	1.80a	1.45a	0.19b
Chinese pistache						
Reuse	0.58a	2.20ab	0.25a	1.24a	1.03a	0.05a
Reuse + Rinse	0.60a	2.51a	0.32a	0.65b	0.72a	0.04a
Reuse pH 6.1	0.54a	1.68b	0.16a	1.56a	0.91a	0.05a
25% dilution	0.53a	2.22ab	0.31a	1.66a	0.79a	0.04a
50% dilution	0.49a	2.32ab	0.20a	0.94a	0.72a	0.04a

[z]Means followed by the same letter are not significantly different at $P = 0.05$.

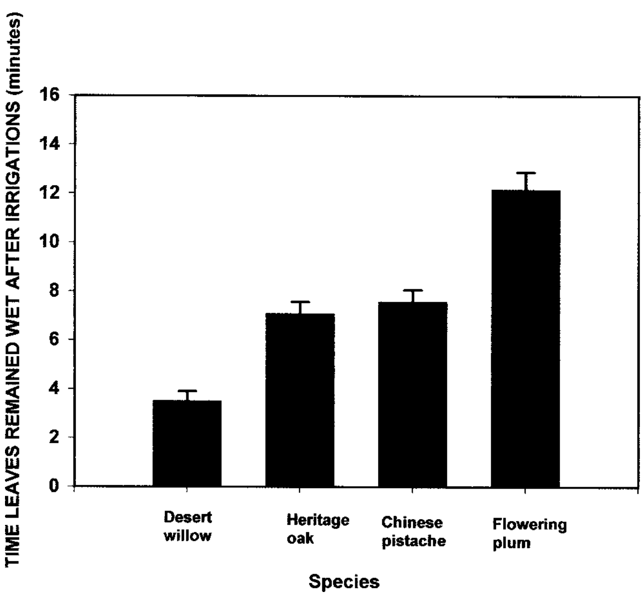

Fig. 1. Time leaves remained wet after irrigations, based on ten measurements made during the months of June, July and August of the second year. Bars represent average values plus standard errors.

tion in the Mg concentration could be accounted for by including only the Cl concentration (Mg = 0.11 + 0.20(Cl), $p < 0.001$) and 70 percent of the variation in the Cl concentration could be accounted for by including only the Mg concentrations (Cl = –0.05 + 3.55(Mg), $p \leq 0.001$).

Leaf wetting times. A significant difference in wetting times were measured between flowering plum and all other species ($p < 0.001$) and between desert willow and all other species ($p < 0.001$), with no significant difference in wetting times between Heritage oak and Chinese pistache ($p = 0.912$) (Fig. 1). Although the experiment was not setup to truly evaluate the impact of wetting times (wetting time variation as a function of S and T), Ca concentrations in the tissue declined (Ca = 2.11 – 0.03(time) – 0.002(time)^2, $r = 0.48$, $p < 0.05$) as the wetting time increased (a function of S) whereas the Na concentration increased with the wetting time (Na = 1.18 – 0.22(time) + 0.02(time)^2, $r = 0.79$, $p < 0.01$, function of S).

Index of visual damage. The Index of Visual Damage (IVD) varied by S ($p < 0.001$), by T ($p < 0.001$) and by an S × T interaction ($p < 0.001$) (Table 4). IVDs based on S and T are reported in Fig. 2 with standard error bars. No difference in IVD was observed with oak placed under the five irrigation treatments. In desert willow only those trees irrigated with reuse water had higher IVD ratings ($p < 0.001$). Plum IVD values were highest for the reuse plus fresh water rinse treatment, which was different from all other treatments ($p < 0.001$). The reuse treatment and the reuse pH adjusted treatment for plum had higher and different IVD values than the two dilution treatments ($p < 0.001$), which were not significantly different from each other. IVD values for Chinese pistache were lowest for the reuse pH adjusted treatment which was different from the reuse and reuse plus rinse treatments ($p < 0.01$) but not from the two dilution treatments.

Linear correlations between tissue ion concentrations and the IVD proved significant only for Na and only when Chi-

Table 4. Main sources of variation (ANOVA) for Index of Visual Damage (IVD) calculated at the end of the experiment.

Source of variation	DF	MS	F	P
Treatment	4	11.67	36.47	< 0.001
Species	3	108.65	339.71	< 0.001
Treatment × Species	12	5.60	17.50	< 0.001

nese pistache was removed from the data set (IVD = 0.50 + 2.82(Na), $r = 0.69$, $p < 0.01$). However, when a multiple regression analysis approach was taken, S, T, Ca and SO_4 tissue ion concentrations could account for 70% of the variability in the IVD (IVD = –2.11 + 1.03(S) – 0.65(T) + 3.45(Ca) – 0.001 (SO_4), where S is a 1 to 4 value based on the order in Table 1 and T is a 1 to 5 value based on the order in Table 3). When S and T were removed from the analysis, 52% of the variability could be accounted for based on Na, Ca and SO_4 tissue ion concentrations (IVD = –1.91 + 4.63(Na) + 2.60(Ca) – 0.001(SO4), $r^2 = 0.52$, $p < 0.01$), indicating that a rise in tissue Na and Ca concentrations were associated with a rise in the IVD. SPAD measurements were the only leaf level measurements that separated based on S and T and although increasing tissue Na concentration was correlated with decreasing SPAD measurements when all S were included in the assessment (SPAD = 47.49 – 12.46(Na), $r = 0.62$, $p < 0.01$), SPAD measurements did not correlate with IVDs, sug-

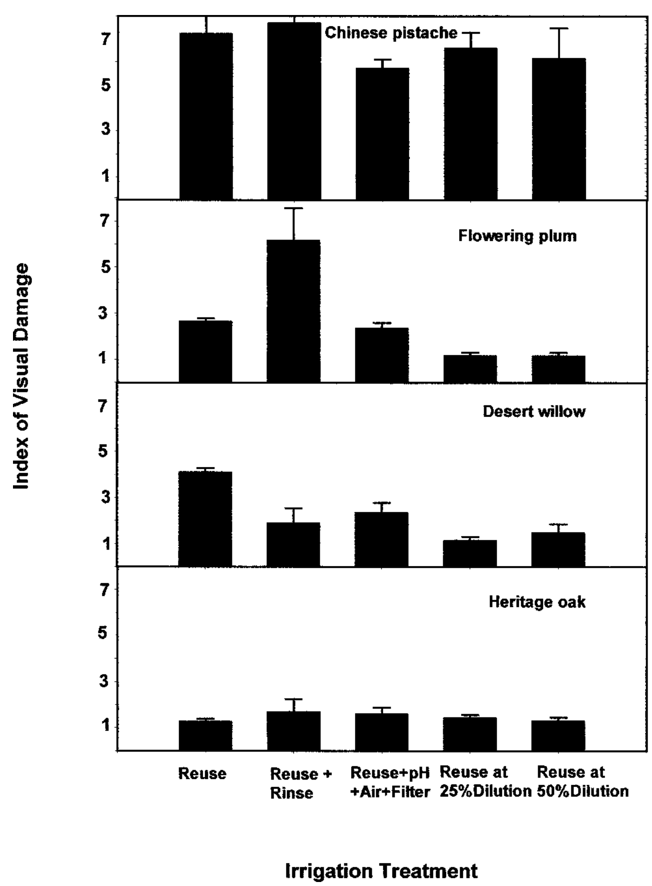

Fig. 2. Index of visual damage (IVD) calculated at the end of the experiment based on separation of irrigation treatments for each species. Bars represent average values plus standard errors.

gesting that the amount of visual damage is a complicated response to both external and internal factors.

Reuse water represents an alternative source of water that can help water manager's better address supply demand issues. Because most reuse water contains relatively high levels of nutrients and salts, using this water for beneficial purposes minimizes contamination problems associated with recharging the reuse water back to a groundwater source or discharging such water directly to rivers and lakes.

Previous studies have demonstrated a wide range in plant response when reuse water was applied directly to the foliage of landscape plants (10, 16, 22). This study demonstrated that Chinese pistache and flowering plum incurred more foliar damage than desert willow or Heritage oak but the amount of damage was dependent upon the treatment imposed. Although the IVD for these four species when irrigated solely with reuse water were not identical to those reported previously by Jordan et al. (10), the order of increasing damage was the same (Heritage oak < flowering plum < desert willow < Chinese pistache). In the Jordan study (10) all four of these species when irrigated with reuse water were found to have IVD values above 2.0, which was deemed unacceptable by the authors (oak 2.67, flowering plum 3.92, desert willow 5.75 and Chinese pistache 6.50). However, in this study Heritage oak had an IVD rating of 1.30 when irrigated with reuse water, which would shift this species into the acceptable category (IVD < 2.0). Based on the IVD results for all five treatments, no alteration to the reuse water would be recommended for oak, any treatment option other than straight reuse water would be acceptable for desert willow, the 25% dilution would be recommended for flowering plum and although a positive treatment response was observed for both the acid treatment and the 50% dilution treatment with Chinese pistache when compared with the reuse water, the IVD values were still high and deemed unacceptable.

The highest IVDs for both flowering plum (6.67) and Chinese pistache (7.80) occurred in the rinse treatment, with a more dramatic shift occurring with the flowering plum (a 1.5 fold increase in the IVD when irrigation with reuse water was followed with a rinse vs. just irrigating with reuse water). When tissue ion concentrations of flowering plum were compared between the reuse and the reuse with rinse treatments, Ca and Mg concentrations in the tissue of the rinse treatment decreased 21–23%, K decreased 41%, Na remained virtually unchanged and Cl increased 40%. The only similarity between shifts in ion concentrations under the rinse treatment for Chinese pistache when compared with flowering plum was a similar decline in K (48%) with little change in Na. Maas et al. (12), studying eleven different forage, grain and vegetable crops, found an average 30% decline in K during the sprinkling period with saline water, whereas Bernstein and Francois (3) indicated that leaf K decreased approximately equal to the sum increase in leaf Ca and Na. However, Benes et al. (1) noted higher concentrations of K in maize irrigated with saline water that received a post irrigation rinse with fresh water and a significant decline in leaf sap concentrations of both Cl and Na.

In this experiment, the amount of foliar damage (IVD) increased as the Ca and Na in the leaf tissue increased and the SO_4 concentration decreased. Ehlig and Bernstein (6) noted that fruit tree foliar absorption of Na occurred more slowly from a Na_2SO_4 solution than a NaCl solution. Chlorophyll (as indicated by SPAD measurements) also decreased as Na increased (SPAD = 47.49 – 12.46(Na), $r^2 = 0.38$, $p < 0.01$), suggesting that Na was perhaps the major driving force behind the foliar damage observed. Other studies have suggested that Cl or a combination of Na and Cl are the primary ions causing foliar damage (9, 14). Although Wu (22) reported higher tissue Ca concentrations being positively correlated with plant tolerance to Cl, Bernstein and Francois (3) noted that burned leaves contained higher levels of Cl, Na and Ca than unburned leaves. However, it is also possible that such damage might have been greater if the Ca concentration was lower.

The foliar damage results in this study represent the plant responses to a 14.5-month experimental period. Although soil salinity actually declined in three of the four species, long-term response to reuse water will most likely result from a combination of elevated root zone salinity and absorption of specific ions through leaf surfaces. Results in this experiment do not represent a worse case scenario, as the stresses incurred did not result in negative growth responses (trunk diameter or tree height) or a decline in plant water status. However, we do believe the results are useful at the screening level for plant selection and for the selection of a suitable irrigation management option. The results in this experiment reflect plant response during the early transition period to reuse water. Results over a longer observation period may give somewhat different results, such as those by Mantell et al (14) who noted a residual effect on the yield of plum trees two years after salt spray treatments were discontinued.

Because the best irrigation strategy was species dependent, irrigation treatment selection should be based upon an evaluation of the landscape species composition and the potential cost of implementing a given strategy. However, the response observed in this study does not bode well for a universal irrigation strategy to be implemented. This would suggest that more emphasis must be placed on initial and replacement plant selection and design alterations of irrigation systems. Other strategies employed might include a cyclic irrigation strategy (using two water sources, such as demonstrated by Schaan et al. (18) for turfgrass), a long non-saline rinse period during summer months, low frequency high volume irrigations to minimize foliar absorption opportunity times (3, 13), evening or night irrigations (6) and reducing the amount of Na discharged in reuse water (21).

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