Foliar Damage and Flower Production of Landscape Plants Sprinkle Irrigated with Reuse Water

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Abstract. Nineteen flowering landscape species were sprinkle irrigated with either reuse water or fresh water, with an additional treatment of reuse water plus shade (solar radiation reduced by 24%), for 113 days during late summer and early fall in southern Nevada. The species selected were common to mixed landscape areas on golf courses in southern Nevada transitioning to reuse water. An index of visual damage (IVD) was assessed, along with an assessment of flower production, canopy temperature, tissue ion analysis and spectral reflectance. The IVD values separated based on species ($p < 0.001$), treatment ($p < 0.001$) and by a species by treatment interaction ($p < 0.001$). Irrigating with reuse water plus shade reduced the IVD compared to the reuse without shade in 7 of the 19 species ($p < 0.05$). When IVD values were included for all species, 40% of the variation in the IVD values could be accounted for if N, B, Ca, Mg, Na, and Zn were included in the regression equation. Higher r^2 values were obtained when individual species were isolated, with regression equations differing based on tissue ion combinations [e.g., ice plant (*Mesembryanthemum crystallinum* L.) $r^2 = 0.81$ IVD $\uparrow$, Na $\downarrow$, Mn $\uparrow$]. Three vegetation indices chlorophyll index (CHL), red/ far red (R/FR) and water band index/normalized difference vegetation index (WBI/NDVI) accounted for 51% of the variation in the IVD values. As much as 72% of the variation in vegetation indices could be accounted for based on tissue ion concentrations when separated based on treatment, with Na being the only common ion in all of the highest correlations. Flower production was highest in the reuse plus shade treatment in all 13 species flowering during the experimental period, with as much as 86% of the flower production variation driven by different tissue ion concentrations [purple cup (*Nierembergia hippomanica*), $r^2 = 0.86$, flowers $\uparrow$, Mn $\uparrow$, Zn $\downarrow$]. Nine of the nineteen species had acceptable levels of foliar damage (IVD < 2.0). We believe that if the spray irrigation can be minimized (bubblers/drip) and/or partial shade provided, through multi-story landscape designs, a more favorable response will be observed.

Increased population and an extended drought in the southwestern U.S. have forced municipalities to reassess their available water resources and to give greater consideration to the use of poorer quality waters for nonpotable uses. Golf courses in particular are transition-

ing to reuse water in California, Arizona, and Nevada because of mandates, cost incentives or because reuse water has become a more reliable source of water (Devitt et al., 2004). Reuse water contains beneficial nutrients but it also contains an elevated salt load. In Clark County,

Nev., reuse water contains salts in excess of 1.1 g·L⁻¹ (Jordan et al., 2001). When reuse water is sprinkle irrigated on golf course fairways and greens, adjacent mixed landscape areas often receive this same water intentionally or unintentionally as uncontrolled drifting spray. A wide range in species response to reuse water (and simulated reuse waters) has been documented for trees, shrubs and landscape plant species (Jordan et al., 2001; Quist et al., 1999; Wu et al., 1999). Many of the golf courses in the southwestern U.S. provide colorful scenic landscapes to enhance the golfing experience, and superintendents have expressed a concern over the extent of foliar damage that might occur if they transition to reuse water (Devitt et al., 2004). Previous research (Jordan et al., 2001; Quist et al., 1999; Wu et al., 1999) has indicated that the extent of foliar damage is not only species and water quality dependent but also dependent on climatic conditions of the area (potential ET, rainfall, etc.). Plant response to applied reuse water is species dependent, thus the types of irrigation strategies which might minimize foliar damage on mixed landscapes are limited (Devitt et al., 2004). Instead, emphasis by the end user has been on replacement of plants that are damaged or dead and minimizing overspray into mixed landscape areas. On one particular golf course in southern Nevada, the budget for plant replacement was over \$100,000 in one year (Bill Rohret, personal communication). In a previous study we reported on the extent of foliar damage to ornamental trees sprinkle irrigated with reuse water (Jordan et al., 2001). We concluded that under the environmental conditions of southern Nevada, spray irrigating with reuse water containing elevated levels of soluble salts, resulted in only a limited number of tree species tolerant to such conditions (only 7 of 20 species had acceptable levels of foliar damage). Detecting early signs of such foliar damage would provide management the opportunity to alter current irrigation practices. Remote sensing based on leaf spectral reflectance has been shown to be related to changes in vegetation characteristics and growth due to stress agents (Blackmer et al., 1994; Carter, 1994; Penuelas et al., 1997; Yoder and Pettigrew-Crosby, 1995). The objectives of this study were to 1) quantify foliar damage and flower production of flowering landscape plants sprinkle irrigated with reuse water, 2) develop a list of recommended tolerant species, and 3) assess the extent to which the damage could be explained by tissue ion concentrations and spectral reflectance data.

Material and Methods

The research was conducted at the Clark County Sanitation District (CCSD) in Las Vegas, Nev. (1 Aug. to 21 Nov. 2002). The experiment involved three treatments and 19 species of flowering annuals and/or perennials (Table 1) placed in a randomized block design, with three replicates per species in each treatment ($n = 171$). The treatments included foliar application (via raised sprinkler heads) of reuse water, municipal water and reuse water plus

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Table 1. Flowering landscape species used and numbers planted into a 43.1 cm (#15) nursery container.

Common name	Scientific name	Plants/pot (no.)
Aptenia	<i>Aptenia cordifolia</i> (L. f.) Schwant.	5 ^z
Bougainvillea	<i>Bougainvillea spectabilis</i> Willd.	1 ^y
Daylily	<i>Hemerocallis fulva</i> (L.) L.	3 ^x
Dianthus	<i>Dianthus chinensis</i> L.	5 ^y
Dusty Miller	<i>Centaurea cineraria</i> L.	5 ^y
Gaillardia	<i>Gaillardia aristata</i> Pursh	5 ^y
Gazania	<i>Gazania</i> spp. Gaertn.	3 ^x
Gold Coin	<i>Asteriscus maritimus</i> (L.) Less 'Gold Coin'	3 ^x
Ice plant	<i>Mesembryanthemum crystallinum</i> L.	3 ^x
Iris	<i>Iris germanica</i> L.	3 ^x
Lantana	<i>Lantana camara</i> var. <i>aculeata</i> (L.) Moldenke	3 ^x
Lavender	<i>Lavandula stoechas</i> L.	3 ^x
Moss rose	<i>Portulaca grandiflora</i> Hook.	5 ^y
Purple cup	<i>Nierembergia hippomanica</i> var. <i>caerulea</i> (Miers) Millan 'Purple Cup'	5 ^y
Red bird	<i>Poinciana pulcherrima</i> L.	3 ^x
Red yucca	<i>Hesperaloe parviflora</i> (Torr.) Coult.	3 ^x
Sundancer	<i>Coreopsis grandiflora</i> Hogg ex Sweet 'Sundancer'	3 ^x
Verbena	<i>Verbena officinalis</i> L.	3 ^x
Zinnia	<i>Zinnia elegans</i> Jacq.	5 ^y

^zFrom 9.84 cm containers.^yFrom 25.74 cm (#5) containers.^xFrom 15.2 cm (#1) containers.

Table 2. Average chemical composition of treatment waters used in the foliar study.

Parameter	Municipal (fresh)	Reuse
EC (dS·m ⁻¹)	0.86	1.94
Na (mEq·L ⁻¹)	3.31	10.03
K (mEq·L ⁻¹)	0.02	0.90
Ca (mEq·L ⁻¹)	3.32	6.20
Mg (mEq·L ⁻¹)	3.12	3.05
Cl (mEq·L ⁻¹)	2.66	7.33
SO ₄ (mEq·L ⁻¹)	4.60	8.81
pH	8.00	7.84

shade. Both waters were provided by CCSD at the site and were analyzed for electrical conductivity, pH and major cations and anions (Table 2). Shade was provided to plants in one of the reuse plots by placing white shade cloth over the plants, supported by a wire screen structure, resulting in a 24% reduction in solar radiation. All shade structures were removed during overhead irrigations, and for plant measurements and evaluations, and then replaced. Plants were purchased from a local supplier (Table 1) and transferred to 43.1-cm (#15) standard nursery containers. Each container was then placed in a second, below-ground, 43.1-cm container (pot in pot to reduce transfer of heat to containers) and spaced 1.5 m apart. The second container was filled with a 10-cm layer of pea-gravel to prevent the lodging of containers. Soils used in the containers were an equal blend of horticultural grade peat, vermiculite and sand (1:1:1, by volume). Each container was mulched with 2 to 4 cm of bark mulch to shade the surface of containers and minimize evaporative water loss. Exposed surfaces of containers were painted white and wrapped in white plastic-covered R-19 insulation to help regulate temperatures during the summer-fall months. Soil samples (0 to 30 cm) were taken from all containers before initiation of the experiment and at the end of the experiment. Saturation extracts (USSL, 1954) were analyzed for electrical conductivity using a Beckman Conductivity bridge (model RC-20; Beckman Coulter, Inc., Fullerton, Calif.) with all measurements adjusted to 25 °C.

All plants were fertilized before initiating the experiment with a 15N–6.5P–12.5K fertilizer with N applied at the rate of 4.89 g·m⁻². All plants thereafter were given a foliar drench of a nutrient solution (every 4 weeks) until run-off occurred (label rates of 20N–8.6P–16.6K Miracle Grow, Marysville, Ohio).

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_o). The ET_o total for the experimental period (1 Aug. to 21 Nov. 2002) was 61.9 cm with an average temperature of 27.0 °C (±4.9 °C), average wind speed of 4.0 m·s⁻¹ (±2.6 m·s⁻¹) and average relative humidity of 17.8 % (±4.2).

Each plot received its irrigation treatment via nine sprinkler heads operated at 44 psi (PS Spray Sprinkler, Hunter Industries Inc., San Marcos, Calif.) mounted on fixed 183-cm risers and operated within manufacturer's recommended pressure and spacings. All sprinkler irrigations were applied for 10-min durations, long enough to wet the foliage to runoff. Sprinkler irrigation events (53) occurred between the start up date of 1 Aug. 2002 and the last irrigation on 21 Nov. 2002. Tensiometers (to measure soil matric potential) were placed at a 15-cm depth in one pot of each species in each treatment. Daily tensiometer measurements were taken with a pressure transducer. If the soil matric potential exceeded a set threshold of –0.008 MPa [–0.015 MPa for red yucca (*Hesperaloe parviflora* (Torr.) Coult.)], a 10-L application of the appropriate treatment water was applied directly into the pot via a garden hose. 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.

Plants were monitored bimonthly for canopy temperature (T_c, at solar noon) with an infrared thermometer (model 39800; Cole Parmer, Vernon Hills, Ill.) relative to ambient temperature (T_a) to obtain T_c – T_a values. Tissue ion concentrations were measured at the end of the experiment by collecting 20 random

mature leaf samples from each container. 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 then sent to a commercial laboratory for acid digestion and complete analysis (A and L Laboratory, Modesto, Calif.).

Field-based reflectance measurements were acquired between 1030 and 1400 HR with a spectral analysis system (Unispec; PP Systems, Amesbury, Mass.) to determine if this approach could be used as means to assess foliar damage. An internal light source and leaf clip were used to acquire reflectance measurements under consistent light conditions and geometry (three leaves per pot). The Unispec acquires spectra from 400 to 1000 nm in 3.3-nm intervals. The resulting data were resampled to 1-nm intervals using a software package developed specifically to convert Unispec spectra into 1-nm bands (Multispec, Faiz Rahman, Ball State University, and John Gamon, California State University, Los Angeles). Vegetation indices were calculated and averaged for each plant species and treatment combination. The vegetation indices tested included indices acquired from the literature that have been demonstrated to be sensitive to changes in plant chlorophyll content, water status and overall health and vigor. These indices included; PRI (photochemical reflectance index (R₅₃₁ – R₅₇₀)/(R₅₃₁ + R₅₇₀)) (Gitelson and Merzlyak, 1994), SR (simple ratio R₈₀₀/R₆₆₀) (Peñuelas and Fillela, 1998), CHL (chlorophyll index (R₇₅₀ – R₇₀₅)/(R₇₅₀ + R₇₀₅)) (Gamon and Surfus, 1999), SIPI (structure insensitive pigment index (R₈₀₀ – R₄₄₅)/(R₈₀₀ – R₆₈₀)) (Peñuelas et al., 1995), NDCI (normalized total pigment to chlorophyll a index, (R₆₈₀ – R₄₃₀)/(R₆₈₀ + R₄₃₀)) (Peñuelas et al., 1994), WBI (water band index R₉₀₀/R₉₇₀) (Peñuelas et al., 1997), NDVI (normalized difference vegetation index (R₈₀₀ – R₆₈₀)/(R₈₀₀ + R₆₈₀)) (Peñuelas et al., 1997), NPQI (normalized phaeophytinization index (R₄₁₅ – R₄₃₅)/(R₄₁₅ + R₄₃₅)) (Barnes et al., 1992), λ Red Edge (λ where maximum slope in the increase of reflectance from red to near infrared occurs) (Fillela and Penuelas, 1994), R/FR (red to far red R₆₆₀/R₇₃₀) (Rajcan et al., 2004), and WBI/NDVI (Peñuelas et al., 1997).

Foliar damage was assessed using a visual rating system developed by Jordan et al. (2001). Every 2 weeks visual evaluations were completed on one container of each species in each treatment. Visual evaluations were done once per month and at the end of the experiment on all 171 annuals and perennials. Assessments were based on six visual parameters; absence of dieback, overall canopy discoloration, presence of dead leaves, presence of deformed leaves, discolored leaves and tip damage. Except for absence of dieback, each parameter was evaluated on a 1 to 9 scale (where 1 = 10% and 9 = 90% damage respectively). Absence of dieback was evaluated on a 1 or 0 basis (where 1 = dieback and 0 = 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 damage and presence of dead leaves).

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

Soil salinity. Reuse water was applied over a 113-d experimental period occurring from late summer to early fall. Soil samples taken before the study indicated no statistical difference in soil salinity between species, with an average value ($1.83 \pm 0.76 \text{ dS}\cdot\text{m}^{-1}$) below the classification for a saline soil ($4.0 \text{ dS}\cdot\text{m}^{-1}$, USSL, 1954). Soil salinity measured at the end of the experiment varied by species ($p < 0.001$) and treatment ($p < 0.001$) with no species by treatment interaction. Average soil salinity treatment values were not significantly different ($p < 0.05$) between the reuse treatment ($\text{EC}_e = 3.03 \text{ dS}\cdot\text{m}^{-1}$) and reuse plus shade treatment ($\text{EC}_e = 2.79 \text{ dS}\cdot\text{m}^{-1}$) but both were significantly different ($p < 0.05$) from the municipal (fresh) water treatment ($\text{EC}_e = 1.73 \text{ dS}\cdot\text{m}^{-1}$). Only soil salinity in 5 of a possible 57 species by treatment combinations exceeded the classification of a saline soil, with the highest EC_e value of $6.35 \text{ dS}\cdot\text{m}^{-1}$ in gazania (*Gazania* spp. Gaertn.) irrigated with reuse water. No visual symptoms such as wilting occurred during the experiment suggesting that irrigating based on matric sensor feedback was effective in scheduling irrigation volumes and frequencies to avoid water deficit and water saturated conditions that might complicate the salt response.

Tissue ion concentrations. Based on ANOVA, all ions showed a species response ($p < 0.05$), all ions except B showed a treatment response ($p < 0.05$) and all ions except S and Fe showed a species by treatment interaction ($p < 0.05$). On a treatment basis, chloride

was nearly identical in the reuse ($29.3 \text{ g}\cdot\text{kg}^{-1}$) and reuse plus shade treatments ($28.3 \text{ g}\cdot\text{kg}^{-1}$) but statistically different ($p < 0.05$) from the fresh treatment ($21.6 \text{ g}\cdot\text{kg}^{-1}$). Sodium also revealed no statistical difference between the reuse and reuse plus shade treatments ($16.5 \text{ g}\cdot\text{kg}^{-1}$ vs. $16.2 \text{ g}\cdot\text{kg}^{-1}$) but both were significantly different from the fresh treatment ($10.1 \text{ g}\cdot\text{kg}^{-1}$). However, in the case of N, the reuse plus shade treatment ($27.7 \text{ g}\cdot\text{kg}^{-1}$) revealed a statistical separation ($p < 0.05$) from both the reuse ($23.3 \text{ g}\cdot\text{kg}^{-1}$) and fresh treatments ($22.1 \text{ g}\cdot\text{kg}^{-1}$). Tissue N concentrations are reported for all species and treatments in Table 3, where 6 of the 19 species demonstrated a statistical difference ($p < 0.05$) between the fresh and the reuse plus shade treatments. Although a large number of ions revealed a statistical separation between the fresh treatment and one or both of the reuse treatments, only a limited number of species showed a statistical separation between the tissue ion concentrations in the reuse treatment vs. the reuse plus shade treatment (Table 4), with ice plant (*Mesembryanthemum crystallinum* L.) and bougainvillea

(*Bougainvillea spectabilis* Willd.) having the largest number of such separations (5 and 4 respectively). In the case of chloride, only in the two succulents (ice plant and aptenia (*Aptenia cordifolia* (L. f.) Schwant.)) did chloride in the tissue significantly vary ($p < 0.05$) between the reuse and reuse plus shade treatments, with ice plant increasing in concentration in the reuse plus shade treatment (63.1 vs. $111.4 \text{ g}\cdot\text{kg}^{-1}$) while aptenia significantly decreased in concentration (60.0 vs. $43.2 \text{ g}\cdot\text{kg}^{-1}$). Tissue Mn concentrations had the greatest number of statistical separations (4) between the reuse and the reuse plus shade treatments, decreasing in all cases in the presence of shade.

Spectral reflectance. Spectral reflectance was measured at the leaf level toward the end of the experiment and typical curves (reuse and reuse plus shade) are shown in Fig. 1 for moss rose (*Portulaca grandiflora* Hook.), ice plant and aptenia. Although the curves are somewhat similar, greatest separation occurred in the blue and near infrared regions, with the shade treatment associated with lower reflectance in the blue and greater reflection in the near infrared

Table 3. Tissue nitrogen concentrations ($\text{g}\cdot\text{kg}^{-1}$) at the end of the experiment for all 19 species grown under fresh, reuse and reuse plus shade treatments.

Species	Fresh	Reuse	Reuse + shade
Aptenia	15.10 a ^z	15.67 a	20.17 a
Bougainvillea	26.50 a	34.67 b	41.50 b
Daylily	31.20 a	13.97 b	30.70 a
Dianthus	25.67 a	28.17 a	34.90 b
Dusty Miller	17.90 a	23.67 ab	26.87 b
Gaillardia	20.50 a	25.13 ab	30.90 b
Gazania	20.93 a	27.30 a	25.60 a
Gold Coin	37.23 a	28.30 b	25.70 b
Ice plant	12.80 a	17.50 a	33.60 b
Iris	19.73 a	22.90 a	20.17 a
Lantana	27.50 a	29.37 a	30.00 a
Lavender	29.17 a	25.20 a	28.40 a
Moss rose	15.30 a	10.63 a	14.33 a
Purple cup	16.83 a	23.37 a	24.63 a
Red bird	25.20 a	31.03 a	33.4 a
Red yucca	17.27 a	19.60 a	20.60 a
Sundancer	19.07 a	25.00 a	26.37 a
Verbena	22.77 a	27.00 ab	33.67 b
Zinnia	19.13 ab	14.90 a	24.70 b

^zTreatment means (reuse, fresh, reuse plus shade) for each species followed by different letters are statistically different at $p = 0.05$ level

Table 4. Tissue ion concentration in Reuse (R) and reuse plus shade (R + S) treatments where statistical separation occurred ($p < 0.05$). Species and ions not listed showed no statistical separation.

Species	Ion concn ($\text{g}\cdot\text{kg}^{-1}$)										
	N	Ca	Mg	Na	K	Cl	S	Al	B	Mn	Zn
Aptenia, R						60.0				0.16	
Aptenia, R+S						43.2				0.11	
Bougainvillea, R			39.8	20.3				7.6		0.16	
Bougainvillea, R+S			29.8	12.3				4.4		0.01	
Daylily, R	14.0										
Daylily, R+S	30.7										
Dianthus, R					8.6						
Dianthus, R+S					22.9						
Ice Plant, R	17.5		27.4	86.2		63.1				0.84	
Ice Plant, R+S	33.6		21.9	77.2		111.4				0.37	
Gaillardia, R					29.5	7.6					
Gaillardia, R+S					37.4	10.2					
Lantana, R										0.30	0.12
Lantana, R+S										0.22	0.07
Lavendar, R								0.25			
Lavendar, R+S								0.13			
Zinnia, R	14.9				29.2				0.19		
Zinnia, R+S	24.7				18.3				0.14		

(species dependent). There were also noticeable changes in the slope and the peak (inflection point) of the red edge (reflectance between 680 and 720 nm) known to be related to leaf chlorophyll content (Fillela and Penuelas, 1994). ANOVA's were run on all spectral indices, however, only NDVI and CHL separated at the $p < 0.001$ level based on treatment, species and species by treatment interaction. To demonstrate the benefits of providing a 24% reduction in solar radiation, NDVI and CHL are plotted in Fig. 2, contrasting the reuse vs. the reuse plus shade treatments. Seven species revealed a statistical separation ($p < 0.05$) based on NDVI (higher values with shade) and eight species separated based on CHL (higher values with shade) (5 species overlapping both indices). However, moss rose which incurred the greatest amount of visual damage (next section) did not show significant separation with either of these spectral indices.

Index of visual damage. Visual damage ratings assessed at the end of the experiment are depicted in Fig. 3 for all three treatments. A horizontal line is included as an acceptable threshold based on the work of Jordan et al (2001) and agreed upon by the two evaluators in this study. IVD values separated (ANOVA) based on species ($p < 0.001$), treatment ($p < 0.001$) and by a species by treatment interaction ($p < 0.001$). Average treatment values for the IVD were 3.26 for the fresh water treatment, 2.62 for the reuse treatment and 1.88 for the reuse plus shade treatment. Only 7% of the variation ($p > 0.05$) in the IVD values could be accounted for based on EC_e values at the end of the experiment. Greater visual damage (higher IVD values) was observed in the fresh water treatment compared to either the reuse or reuse plus shade treatments in 14 of the 19 species (see discussion). Irrigating with reuse water plus shade reduced the IVD compared to reuse without shade in 7 of the 19 species ($p < 0.05$). Highest IVD values in the reuse treatment were recorded on moss rose; dianthus (*Dianthus chinensis* L.) and aptenia, with all three showing significant reduction in visual damage (57%, 43%, and 45% respectively) when provided the additional shading. Whereas daylily (*Hemerocallis fulva* (L.) L.), gazania, bougainvillea, lantana (*Lantana camara* var. *aculeata* (L.) Moldenke), dusty miller (*Centaurea cineraria* L.) and gold coin (*Asteriscus maritimus* (L.) Less 'Gold Coin') all recorded minimal amounts of foliar damage (IVD < 2.0) when irrigated with reuse water, with or without shade. A final foliar damage plant list for reuse water (with and without shade) is reported in Table 5, with final recommendation categories assigned based on IVD.

Correlations between IVD and tissue ion concentrations and spectral reflectance indices. IVD values were correlated with tissue ion concentrations using backward stepwise regression analysis. When IVD values were included for all species, 40% of the variation in the IVD values could be accounted for if N, B, Ca, Mg, Na, and Zn were included in the regression equation. IVD values decreased as N, B, Ca, and Na increased (↑) and Mg and Zn decreased (↓). Higher R^2 values were obtained when individual

species were isolated, with regression equations differing based on tissue ion combinations (ice plant $r^2 = 0.81$ IVD↑, Na↓, Mn↑, dianthus $r^2 = 0.78$, IVD↑, N↑, K↓, aptenia $r^2 = 0.91$ IVD↓, P↑, Mn↑ and moss rose $r^2 = 0.48$ IVD↓, Ca↑, all at $p < 0.05$ or lower).

Spectral reflectance indices correlated with IVD values when all species were included in the regression analysis. CHL, R/FR, and WBI/NDVI accounted for 51% of the variation in the IVD values (IVD↑, WBI/NDVI↑). Vegetation indices were also regressed against tissue ion

concentrations and reported in Table 6 if the R^2 value was greater than 0.45, significant at the $p < 0.001$ level. The highest R^2 values were found for SIPI in the fresh (0.72) and reuse (0.63) treatments and WBI in the reuse plus shade (0.70) and for all treatments combined (0.48). Na was the only common ion included in all four of these highest correlations.

Flower production. The number of flowers produced per pot were counted at the end of the experiment and given a classification number of either, 0, 1, 2, or 3 (defined in Fig.

Fig. 1. Spectral reflectance (400 to 1000 nm) at mid-day for moss rose, ice plant and aptenia in the reuse and reuse plus shade treatments. Vertical bars represent the standard error of the mean.

4). Only 13 of the 19 species were flowering during the experiment, and are plotted in Fig. 4 based on all three treatments. Average flower production was highest in the reuse plus shade treatment in all 13 species (*Zinnia elegans* Jacq.) given the same high rating in all three treatments). Only 2 of 13 species in the fresh water treatment had a flower production classification ≥ 2 , while reuse had 3 of 13 ≥ 2 and reuse plus shade had 7 of 13 species ≥ 2 . Flower production is a species dependent parameter and the number of plants per pot varied based on species (such as one bougainvillea vs. three ice plants), thus multiple regression analysis combining all

species was not attempted. However, when individual species flower production was assessed based on tissue ion concentrations, regression equations differed based on tissue ion combinations (purple cup (*Nierembergia hippomanica* var. *caerulea* (Miers) Millan 'Purple Cup') $r^2 = 0.86$ flowers, $Mn \uparrow$ $Zn \downarrow$, moss rose $r^2 = 0.72$ flowers $\uparrow$, $Ca \uparrow$, $K \uparrow$, and ice plant $r^2 = 0.67$, flowers $\uparrow$, $Na \uparrow$, $Mn \downarrow$, all at $p < 0.01$ or lower). Flower production ($\uparrow$) and IVD ratings ($\downarrow$) in moss rose were both associated with increased tissue Ca ($\uparrow$), while ice plant revealed increased tissue Na ($\uparrow$) associated with increased flower production ($\uparrow$) and decreased IVD ratings ($\downarrow$).

Discussion

Foliar damage to flowering landscape plants irrigated with reuse water in this study varied by species, treatment, and by a species by treatment interaction, as was the case in previous studies with ornamental trees (Devitt et al., 2003, 2004; Jordan et al., 2001) and ornamental shrubs (unpublished data). The elevation in soil salinity can not be ruled out as a contributing factor, especially if the study had continued for a longer period of time. However, only 7% of the variation in the IVD could be accounted for based on EC_e values at the end of the experiment. The average soil salinity was still below the classification for a saline soil, suggesting that foliar damage was accentuated by the foliar applications. This conclusion was substantiated by the contrasting results observed for moss rose and dianthus in this study with results previously reported by Devitt et al. (1987). Both of these species were rated tolerant to very tolerant (Devitt and Morris, 1987) when irrigated at the soil level with irrigation water nearly twice as high in soluble salts as that used in this study. These earlier results contrast with the significant amount of damage observed in this study for both species when reuse water was applied directly to the foliage.

Providing shade to reduce the radiation load by 24% led to cooler canopy temperatures (Fig. 5), higher average treatment nitrogen concentrations ($27.7 \text{ g} \cdot \text{kg}^{-1}$ reuse plus shade vs. $22.3 \text{ g} \cdot \text{kg}^{-1}$ reuse), lower levels of foliar damage (Fig. 3) and higher flower production (Fig. 4) in many of the species. Spectral reflectance data indicated that a decreased reflectance in the blue region and an increased reflectance in the near infrared region occurred in many of the species and that the NDVI and CHL spectral indices detected significant changes between the reuse and reuse plus shade treatments, suggesting that these indices could be valuable in assessing foliar damage in many flowering landscape plants. It has been documented that changes in reflectance in the blue region of the spectrum are associated with carotenoids

Fig. 2. Chlorophyll Index and NDVI for 15 species sprinkle irrigated with either reuse water or reuse water with shade provided. *Species with index values that were significantly different at $p = 0.05$ level. Vertical bars represent the standard error of the mean.

and chlorophyll a absorption, while reflectance in the red is only associated with strong chlorophyll a absorption because carotenoids do not absorb in the red, which makes the ratio (carotenoids/chlorophyll a) a good indicator of the physiology and phenology of the plant (Penuelas et al., 1995; Raymond et al., 2004). It has also been found that an increase in relative carotenoid concentration occurs more often when plants are under stress (Gitelson et al., 2002). Thus the decrease in reflectance we found in the blue region when shade was provided, would suggest a decrease in the carotenoids to chlorophyll a ratio. Furthermore, based on the review of Demmig-Adams (1996), carotenoids provide photoprotection under excess solar radiation, which would support our findings of higher reflectance in the blue region when shade was not provided. The structural independent pigment index (SIPI) was observed to strongly correlate with the carotenoid to chlorophyll a ratio in several species (Penuelas et al., 1995, 1998). Although we did not measure pigment concentrations in the leaf during this study, SIPI was shown to be highly correlated with different tissue ion concentrations in the leaves of plants irrigated with fresh water ($R^2 = 0.72^{***}$) and reuse water ($R^2 = 0.63^{***}$). However, in the reuse plus shade treatment, it was the WBI index that was found to be highly correlated with tissue ion concentrations ($R^2 = 0.70^{***}$), suggesting that shade altered the water and ion status of the plants, which led to a greater separation in response based on species. High summer/fall day time temperatures in excess of 40 °C combined with evaporating salts left behind on leaves and flowers led to higher levels of damage in the reuse without shade treatment than the reuse with shade treatment. Irrigation water was applied directly to the foliage of all treatments, however, in the shade treatment, shade was provided immediately after irrigation was completed. We do not believe a significant difference in evaporation from the leaf surface occurred between these two treatments but that reducing the radiation load on the leaves, which led to lower temperatures provided greater protection for photosynthetic mechanisms (increased absorption in the blue and red regions) and nitrogen utilization (especially in zinnia, ice plant and day lily, 1.7 to 2.2 fold increase in N concentration). Chloroplasts have been shown to be quite sensitive to heat stress which may effect the light harvesting that occurs in photosystem II reaction centers (Nilsen and Orcutt, 1996). Each species has a maximum biological temperature (Tesi, 1972) and critical temperatures with regards to flowering (Armitage et al., 1990; Kofranek and Criley, 1983), since most of the species in this study have a nondesert origin, it was not surprising to see enhanced flower production with shade, as reproductive development including flower production is often damaged by heat (Hall, 1992). Morrison and Stewart (2002) found that high mean maximum temperatures during vegetative development resulted in a reduction in flower number for all Brassica species, while Pagadala et al. (2002) reported that variation in flower number of groundnut was quantitatively

related to floral bud temperatures during the day over the range of 28 to 43 °C.

It was interesting to note how poorly many of the species in the municipal fresh water treatment did regarding their foliar damage ratings (increased chlorosis) and flower production compared to both reuse treatments. This response was troubling because this was not observed in our previous work with ornamental trees (Jordan et al., 2001) or shrubs (unpublished data). Clearly the reuse water

contained more salt, residual chlorine and a wide range of trace organics not found in the fresh water. This multi-species chlorosis was observed only in the freshwater treatment. Foliar fertilizer applications did not eliminate nor increase the severity of the response in any of the treatments. Based on a positive response to reuse water it could only be concluded that the constant application of macro and micro nutrients contributed to the disparity in flower production and foliar damage between the fresh

Fig. 3. Visual damage ratings for 19 species sprinkle irrigated with reuse water, reuse water with shade provided or municipal fresh water. Vertical bars represent the standard error of the mean.

Table 5. Flowering landscape plant recommendations based on final Index of Visual Damage (IVD) for the reuse treatment. IVD ratings for reuse plus shade are shown for comparison but are not categorized by recommendation.

Species	IVD Reuse	Recommendation	IVD Reuse + shade
Gold Coin	1.00a [†]	Recommended	1.00 a
Dusty Miller	1.06 a [†]		1.00 a
Lantana	1.08 a		1.00 a
Bougainvillea	1.13 a	Questionable	1.25 a
Gazania	1.38 a		1.13 a
Daylily	1.38 a		1.38 a
Gallardia	1.75 a		1.00 b [*]
Zinnia	1.83 a		2.21 a
Ice plant	1.92 a		1.08 b [*]
Red bird	2.21 a		1.83 a
Red yucca	2.41 a		1.48 b [*]
Sundancer	2.58 a		3.04
Iris	2.83 a	Not Recommended	2.54 a
Purple cup	3.04a		1.88b [*]
Verbena	3.11 a		3.04 a
Lavender	3.56 a		2.00 b
Aptenia	3.75 a		2.08 b
Dianthus	3.94 a		2.25 b
Moss rose	10.50 a		4.50 b

[†]Treatment means (reuse vs. reuse plus shade) for each species followed by different letters are statistically different at $p = 0.05$.

^{*}Significant at $p = 0.10$.

Table 6. Multiple regression analysis of vegetation indices (all species) based on tissue ion analysis. Data separated based on all treatments combined or for individual treatments.

Treatments	Index	Tissue ions	R ²
All	WBI	B, Ca, K, Na	0.48***
Fresh	SR	N, Mn, Na, P	0.51***
	Chl	N, B, Na	0.54***
	NDVI	N, B, K, Na, P	0.61***
	R/FR	Fe, K, Na, P, Zn	0.64***
	WBI/NDVI	K, Na, P, Zn, S	0.67***
	SIPI	Fe, K, Na, P, Zn	0.72***
Reuse	NDVI	Al, Fe, Na, Zn, S	0.45***
	WBI	B, K, Mn, S	0.53***
	SIPI	Mg, Mn, Na, S, Zn	0.63***
Reuse + shade	WBI/NDVI	B, Ca, Fe, Mg, Zn	0.49***
	WBI	K, Na	0.70***

²R² values reported only if the coefficient of determination was >0.45.

***Significant at $p < 0.001$.

Fig. 4. Flower production for 13 species sprinkle irrigated with reuse water, reuse water with shade provided or municipal fresh water. Vertical bars represent the standard error of the mean.

water and reuse treatments (future research will attempt to address this directly).

When all species were combined in the IVD regression analysis, a combination of six tissue ions accounted for 40% of the variability in the IVD while three spectral indices accounted for 51% of the variability. However, greater r^2 values were obtained if individual species were isolated, indicating the impact of different morphological and biochemical characteristics on tissue ion analysis and spectral reflectance, suggesting decreased accuracy if mixed landscapes are assessed on an area basis rather than on a species basis. Results from this study confirm the use of a spectral analysis system, as a rapid non invasive means of assessing stress in plants (Blackburn and Steele, 1999; Penuelas and Filella, 1998), especially foliar damage associated with spray irrigation of reuse water in hot, dry desert conditions.

Nine of the nineteen species had acceptable

levels of foliar damage (average ratings ≤ 2.0) compared to 7 of 20 ornamental tree species reported in a previous study (Jordan et al., 2001). We believe that if users of reuse water select from these nine species, aesthetically pleasing mixed landscapes can be maintained when irrigating with reuse water with a salinity level as high as 1.94 dS·m⁻¹. If the spray application can be minimized and/or partial shade provided through multi story landscape designs, we believe the response for many flowering landscape species will be even more favorable and not represent a limiting factor for golf courses in the southwestern U.S., which either select or are mandated to transition to reuse water.

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