Report for 2004AZ50B: Impact of drought on management of salt sensitive plants with reclaimed water

- Other Publications:
  - Schuch, U.K. 2005. Effect of reclaimed water and drought on salt-sensitive perennials. HortScience (abstract in press).
  - Schuch, Ursula K., (2005), Salinity, What's Tolerant, What's Not?" Southwest Horticulture, March/April, Vol. 22 (2), 11 and 20.

Report Follows

A. Problem and Research Objectives

Growing plants under saline conditions may restrict growth because of drought stress through low water potential of the rooting media, ion toxicity because of excessive uptake of chloride and sodium, and imbalance of mineral nutrients, particularly of calcium (Marschner, 1995). Salt tolerance of plants is affected by an interaction of plant, soil, water, and environmental conditions and plant responses are best qualified on a relative rather than an absolute basis (Maas, 1986). Most crops are more sensitive to salinity in hot, dry climates compared to humid, cool ones. Plants are sensitive to salinity during all stages of growth, and sensitivity may change during different growth stages (Maas, 1986).

Salinity of water is an ever increasing issue in the arid Southwest. With water demand for municipal and industrial usage predicted to almost double from the 1990 levels by 2030, the question arises how to manage the existing water resources. The population of Arizona is expected to double in the next 40 years and is estimated to increase to 6.1 million by 2010 and to over 7.5 million by 2020. Residential and commercial landscapes will increase proportionally and require additional sources of irrigation. A compounding factor on water demand is that Arizona has been in a drought for several years. The Governor's drought task force plan has been initiated in March 2003 because precipitation throughout the State of Arizona for six of the last seven years has been significantly below normal and this lack of precipitation has reduced stream flows, surface and ground water supplied in the state, resulting in drought conditions throughout the state. Current suppliers of potable water will have increasing difficulties of meeting the needs of a rapidly expanding population in a state where droughts occur periodically. Finite ground water and surface water resources can be stretched by reclaiming water. Reclaimed water is the only water source that will increase proportional to water use and is expected to become increasingly vital to sustain the quality of life for desert communities.

Increasing salinity of soils and water supplies are a constant challenge in arid areas. Phoenix area water officials contend that about one million tons a year of salt are coming into the area and will contribute to deteriorating water quality. Groundwater supply in the southwest area of Phoenix has already reached salt levels of 2,500 mg/L. Tucson water supply generally does not exceed salinity of 650 mg/L, probably because water supplies are pumped from deeper and deeper wells. With desalination of brackish water being explored to augment the drinking water supply in the state, it is likely that in the future more potable water will be allocated for municipal and industrial use and restrictions for using potable water for landscape irrigation may be imposed. Drought conditions in the state exacerbate the salinity problem as less natural leaching occurs because of decreased precipitation and a greater amount of higher salinity water is used for irrigation. Reclaimed water is already supplied to Phoenix and Tucson area golf courses, schools, and parks, and is also used for recharging aquifers and wetlands in both metropolitan areas. The amount of reclaimed water produced will increase significantly in the future, and guidelines for the safe use of reclaimed water for landscape irrigation will benefit the landscape industry and residents alike.

Plants add an important component to the quality of life and fulfill many functional needs such as trees and shrubs that provide shade, filtering air, buffering noise, and serving as visual screens. Landscapes add significant value to properties and contribute to the aesthetics of both residential and commercial properties. Loss of plants in landscapes due to saline water and soil conditions can become very costly and result in tremendous input requirements for replacement of plants, labor for installation, and the loss of functional and aesthetic value of plants in the interim, which can be several years. Previous research has shown that several of the species widely used in Southwestern landscapes are not tolerant to higher salinity and will likely be damaged if irrigated with higher salinity water.

Citrus trees in orchards have been irrigated successfully with reclaimed municipal wastewater in Florida (Koo and Zekri, 1989). Trees under wastewater irrigation appear to benefit from the higher mineral content in the water, but juice quality was adversely affected by the wastewater. Different application rates of reclaimed water to ornamental plants in Florida resulted in three response groups, with the higher irrigation rate resulting in sufficient leaching to prevent damage to salt sensitive plants (Parnell, 1989). When 31 cultivars of ornamental plants were watered with a blend of half recycled and half fresh water, relative growth of those plants averaged 106% compared to those irrigated with fresh water. Relative growth rates ranged from 73% to 171% for the different species (Skimina, 1986).

Reclaimed water with higher salinity for irrigation of ornamental plants brings potential problems of increasing soil salinity and possibly causing reduced growth, foliar injury, or death of plants over time. An estimated 200 to 400 mg/L increase in salt content are expected from water that has been reclaimed one time from a treatment plant. Further treatments of effluent from reclaimed water will incrementally increase salinity of the water. Irrigation water with TDS (total dissolved solids) of up to 1,280 mg/L or an EC (electrical conductivity) of up to 2.0 dS/m is considered acceptable in terms of salinity (Marschner, 1995). However, evaporation without leaching will lead to salt accumulation in the soil and therefore much higher concentrations of salts in the plant root zone (Maas, 1986). Current drought conditions, now entering the 6th year have set the stage for such a scenario in the State of Arizona.

The first objective of this study was to determine the performance of salt sensitive plants when irrigated with reclaimed or potable water. A second objective determined how those plants performed under drought stress.

B. Methodology

On May 24, 2004 liners were obtained from local nurseries and were planted in 5-gal. containers in media consisting of 80% compost and 20% sand. Species used in the experiment were *Chilopsis linearis* 'Warren Jones' (desert willow), *Tecoma stans (yellow bells)*, *Salvia greggi* 'Cherry' (Chihuahuan sage), and *Verbena pulchella gracilior (moss verbena)*. These species were identified as salt sensitive in previous experiments. Each container was amended with Micromax (Scotts Co., Marysville, Ohio) at the recommended rate and Osmocote 18-6-12 (9 month release) at 62 g per container for *C.*

linearis and *T. stans*, and at 35 g per container for *S. greggii* and *V. pulchella gracilior*. Fertilizers were topdressed and incorporated into the top 4 cm of the media immediately after transplanting.

Half of the plants were irrigated with reclaimed water and half of the plants were irrigated with potable water. Irrigation was applied to achieve an average of 20% leaching and application rates and runoff were measured several times during the experiment to maintain the desired leaching. Starting 5 weeks after transplanting, irrigation was switched from a timer to a system activated by tensiometers (Model LT, Irrometer Co., Riverside, Calif.) when soil moisture dropped below -6 kPa.

EC of water was determined regularly during the experiment. EC and nitrate-N of runoff were measured three times during the experiment. Total mineral content of runoff from *C. linearis* treated with either potable or reclaimed water was measured on July 22, 2004. After plants had received their regular irrigation and were drained, 1 L of distilled water was applied to the top of the substrate and runoff was captured.

Plant growth data was recorded 4, 8, and 12 weeks after transplanting and included plant height, two canopy widths, number of flowers, and number of buds. Growth index was calculated by adding plant height and the two canopy widths and dividing it by three. The percent increase in growth index was calculated between measurement dates for each plant. Dieback was rated as percentage of canopy area affected in 10% increments. One flower at anthesis was considered a terminal raceme for *C. linearis*, a panicle for *T. stans*, a racemose inflorescence for *S. greggii* and a dense spike appearing head like for *V. pulchella gracilior*. After 12 weeks of treatment with potable or reclaimed water, plants were harvested and number of flowers, buds, and percentage of dieback was recorded. Shoots and roots were separated and dry weights were determined.

On September 13, 2005 plants were moved from outdoors into a retractable roof structure and were watered to saturation. When the substrate had drained and container capacity was reached, plants were weighed and the weight was recorded. Plant water potential was recorded with a pressure chamber. Shoot tips of approximately 10 cm length were cut and were immediately measured in the pressure chamber. Stomatal conductance, transpiration, and leaf temperature of desert willow and yellow bells were measured with a porometer immediately following the water potential readings. Plants were allowed to dry out in full sun conditions (roof and side walls fully retracted) or with the side walls of the building closed to slow down wind speed during measurements. Plant weight and the accompanying physiological measurements were taken once or twice during the following days, depending on the speed of drying out. The experiment was concluded when plants started to wilt and irrigation was applied again. At the conclusion of the experiment plants were well irrigated and damage from the drought treatment as expressed in leaf abscission or branch dieback was recorded after two weeks. The same procedure was repeated with another set of previously well watered plants.

The experiment was arranged in a completely randomized block design. Data for each species were analyzed separately and analysis of variance and mean separation was used to determine treatment effects. The statistical program SAS was used for the analysis.

C. Principal Findings and Significance

Water quality and substrate characteristics

Chemical composition of potable and reclaimed water sources used in the experiment are shown in Table 1. The potable water mineral concentration and chemical characteristics indicate a high quality that is very well suited for irrigation of even salt sensitive plants. No problems should result from using this water source (Southern Nurserymen's Assoc., 1997). Reclaimed water is still of good quality, however, increasing SAR, bicarbonates and chloride over time might result in some problems in salt sensitive plants.

Table 1. Chemical composition of reclaimed and potable water used for irrigating plants.

	Potable water	Reclaimed water	% increase reclaimed versus potable
N (ppm)	2.50	3.65	46
P (ppm)	0.0034	0.72	21,000
K (ppm)	1.0	6.0	500
Ca (ppm)	40.5	67.5	67
Mg (ppm)	2.0	13.0	550
S (ppm)	5.6	45.5	712
Na (ppm)	25.5	132	417
Cl (ppm)	15.5	102	558
B (ppm)	0.03	0.25	733
Bicarbonate(ppm)	140	241	72
EC (dS/m)	0.3	1.0	233
pH	7.9	7.7	-2
SAR	1.1	3.8	245

Table 2. Composition of leachate collected from desert willow 8 weeks after irrigation with reclaimed or potable water had started.

	Potable water	Reclaimed water
N (ppm)	82	151
P (ppm)	0.8	1.3
K (ppm)	36	74
Ca (ppm)	157	245
Mg (ppm)	30	58
S (ppm)	43	166
Na (ppm)	76	409
Cl (ppm)	52	336
B (ppm)	0.15	0.55
Bicarbonate(ppm)	266	351
EC (dS/m)	1.3	3.6
pH	7.7	7.8
SAR	1.4	6.1

A pour-through test conducted after plants were irrigated with the two water sources for 8 weeks indicated that all variables measured in the root zone solution of desert willow irrigated with potable water were within recommended limits thus allowing maximum growth. The root zone solution of plants under the reclaimed water regime started to accumulate Na and Cl, and bicarbonate and EC started to reach levels where problems in salt sensitive plants might be expected. SAR also increased to levels that suggest possible Na problems.

Pour-through tests conducted on all species after 12 weeks of treatment indicated that final EC in the root zone differed significantly between water treatments. Potable water resulted in root zone EC of 0.6 dS/m and reclaimed water resulted in an EC of 1.7 dS/m.

Plant growth

Canopy size, number of flowers or flower buds of desert willow and yellow bells were not affected by water quality during the 12 weeks of the experiment (Table 3). No dieback was observed for the two species and growth rate was not affected either. Sage plants irrigated with reclaimed water started to show symptoms of dieback, slower growth rate and had smaller canopies than plants irrigated with potable water within 8 weeks after treatments started (Table 3). This trend continued for the next 4 weeks, however, plants under reclaimed water treatment still maintained growth, though not as fast as those under the potable water treatment. Verbena plants had a larger growth index and more flowers and buds when irrigated with reclaimed water for four weeks (Table 3). After 8 weeks of treatments, reclaimed water still stimulated more flowers, but resulted in a slower rate of canopy growth. After 12 weeks, canopy size was smaller for those plants treated with reclaimed versus potable water. After 12 weeks, sage plants irrigated with reclaimed water were more attractive because of their compact canopy compared to plants irrigated with potable water.

Reclaimed water reduced one or more dry weight component of each species (Table 4). Leaf dry weight of desert willow was reduced by 15% for plants irrigated with reclaimed versus potable water, which was probably due to abscission of leaves that started to be damaged by the increase in salinity in the root zone. In yellow bells, reclaimed water significantly reduced root dry weight by 40% and reduced root:shoot ratio of plants. Reclaimed water applied to sage resulted in 50% to 61% reduction of leaf, stem, root, and total dry weight, while root:shoot ratios remained unchanged by the different water qualities. Verbena plants were not affected by potable and reclaimed irrigation, although there was a trend, especially for shoot dry weights, to decrease under the reclaimed irrigation regime.

First damage on some plants was observed on July 27, 2004 at the time when the two different sources of water were applied. Symptoms on sage included leaves abscising or leaves with leaf edge burn. On verbena damage was expressed as leaves turning yellow or brown. High temperatures seemed to exacerbate visual symptoms of salt stress which became more severe during August. However, when maximum daytime temperatures started to decrease, visual quality of plants improved and leaf edge burn was not much of a problem any more.

Plant response to drought

Plants irrigated with potable water and exposed to drought showed symptoms of wilting earlier and for some species showed more damage than plants irrigated with reclaimed water. No damage was observed on yellow bells exposed to drought in both drought cycles. Although plants wilted, all leaves fully recovered after rehydration. Desert willow irrigated with reclaimed water showed no damage from the first drying cycle when up to 28% of fully saturated soil moisture was depleted and showed only a few desiccated leaves on two plants when 32% of the fully saturated soil moisture was depleted. However, plants irrigated with potable water sustained between 10% to 90% leaf dieback in both drying cycles when moisture depletion reached up to 35% of fully saturated media. Sage plants defoliated in response to drought, and percent defoliation of potable and reclaimed water treated plants was 60% and 23%, respectively. Verbena irrigated with potable water sustained 83% mortality when fully saturated soil moisture was depleted by 27% or more. Plants irrigated with reclaimed water sustained up to 22%

Table 3. Effect of reclaimed and potable water on plant growth 4, 8, and 12 weeks after treatments began.

Weeks after treatments began	Water	Height (cm)	Growth index	Flowers (No.)	Buds (No.)	Dieback (%)	Growth increase (%)[z]
		C. linearis 'Warren Jones'					
4	Potable	66.3 a[y]	38.3 a	0.2 a	1.2 a	0	-
	Reclaimed	64.5 a	40.0 a	0 a	0.4 a	0	-
8	Potable	89.2 a	63.4 a	2.0 a	0.8 a	0	65 a
	Reclaimed	89.2 a	62.7 a	1.8 a	1.1 a	0	57 a
12	Potable	108.6 a	72.1 a	5.3 a	5.2 a	0	90 a
	Reclaimed	111.3 a	75.9 a	2.1 a	3.3 a	0	89 a
		T. stans					
4	Potable	31.6 a	24.2 a	0.1 a	3.9 a	0	-
	Reclaimed	34.7 a	25.3 a	0.5 a	4.6 a	0	-
8	Potable	34.7 a	38.5 a	5.8 a	3.2 a	0	61 a
	Reclaimed	35.2 a	38.3 a	4.3 a	3.0 a	0	52 a
12	Potable	48.1 a	45.3 a	6.3 a	1.8 a	0	87 a
	Reclaimed	43.6 a	42.9 a	4.7 a	1.4 a	0	70 a
		S. greggii 'Cherry'					
4	Potable	22.8 a	15.3 a	1.4 a	2.1 a	0	-
	Reclaimed	19.8 a	13.8 a	2.1 a	2.3 a	0	-
8	Potable	27.6 a	19.7 a	3.8 a	7.5 a	0 b	30 a
	Reclaimed	21.8 b	15.4 b	0.6 b	5.9 b	12 a	15 b
12	Potable	31.0 a	25.9 a	12.8 a	8.4 a	0 b	71 a
	Reclaimed	21.7 b	19.1 b	7.2 b	6.5 a	3 a	39 b
		V. pulchella gracilior					
4	Potable	19.1 a	20.9 b	2.5 b	1.0 b	0	-
	Reclaimed	22.5 a	27.8 a	5.9 a	3.6 a	0	-
8	Potable	24.5 a	44.7 a	27.4 b	4.3 a	7 a	120 a
	Reclaimed	26.1 a	44.6 a	37.1 a	2.4 b	14 a	63 b
12	Potable	22.5 a	49.9 a	66.9 a	13.3 a	2 a	148 a
	Reclaimed	25.1 a	45.4 b	59.0 a	7.3 b	4 a	66 b

[z] Growth increase is calculated as the difference between growth index from the current sampling and the previous sampling.

[Y] Means within a column and the same sampling date are significantly different at $p<0.05$ if followed by a different letter.

Table 4. Dry weight components of four species irrigated with potable or reclaimed water for 12 weeks.

Species	Water	Leaf	Stem	Root	Total	Root:Shoot ratio
		Dry weight (g)				
C. linearis ‘ Warren Jones’	Potable	52.7 a	93.4 a	40.3 a	186.5 a	0.27 a
	Reclaimed	45.0 b	77.4 a	38.2 a	160.7 a	0.31 a
T. stans	Potable	27.4 a	18.7 a	16.8 a	62.9 a	0.37 a
	Reclaimed	22.9 a	12.3 a	10.0 b	45.2 a	0.29 b
S. greggii ‘Cherry’	Potable	7.9 a	6.5 a	1.9 a	16.4 a	0.14 a
	Reclaimed	3.9 b	2.5 b	0.8 b	7.2 a	0.12 a
V. pulchella gracilior	Potable	49.5 a	44.2 a	6.6 a	100.2 a	0.08 a
	Reclaimed	40.8 a	28.7 a	5.9 a	75.5 a	0.09 a

ǂ ***, **, * or ns indicates significance of $p<0.0001$, $p<0.01$, $p<0.05$, or $p>0.05$.

leaf browning with subsequent dieback. Differences between individual plants varied greatly, and some plants sustained no damage, while others had up to 50% leaf damage. This suggests a potential for selecting cultivars of verbena that are more drought tolerant and possibly more salt tolerant.

A less negative water potential was maintained by yellow bells, sage, and desert willow up to about 20% media moisture loss for plants previously irrigated with potable versus reclaimed water (Fig. 1). With greater media moisture depletion water potential of plants treated with either water source decreased rapidly, indicating loss of turgor. Verbena irrigated with either water source maintained water potential around -0.13 MPa up to 27% media moisture loss, but with greater moisture loss started to loose turgor quickly (Fig. 1). All species were able to maintain functional water uptake and transpiration up to a media moisture reduction of 20% (Fig 1, 2). However, as less soil water was available, transpiration decreased sharply for yellow bells and for desert willow, regardless of the water source that had been used to irrigate plants before.

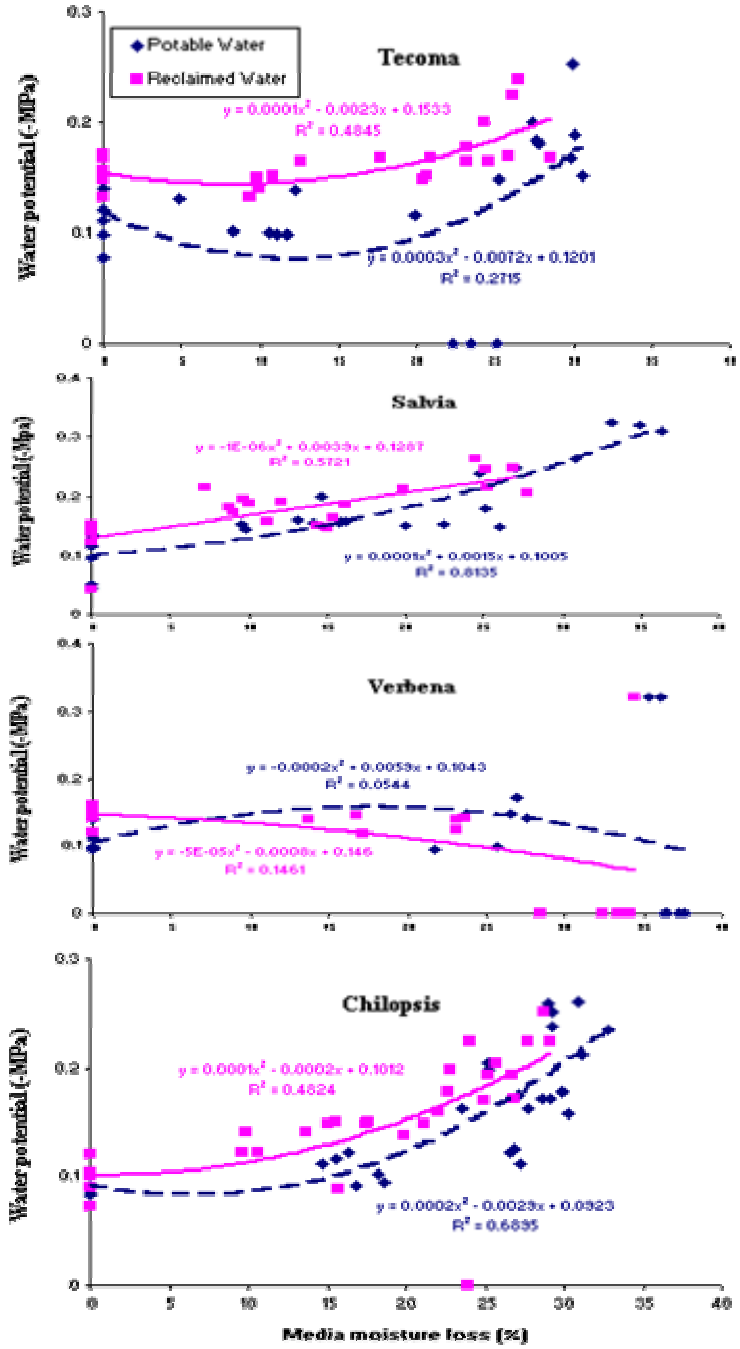

Fig. 1. Water potential of plants irrigated with reclaimed or potable water and exposed to drought conditions.

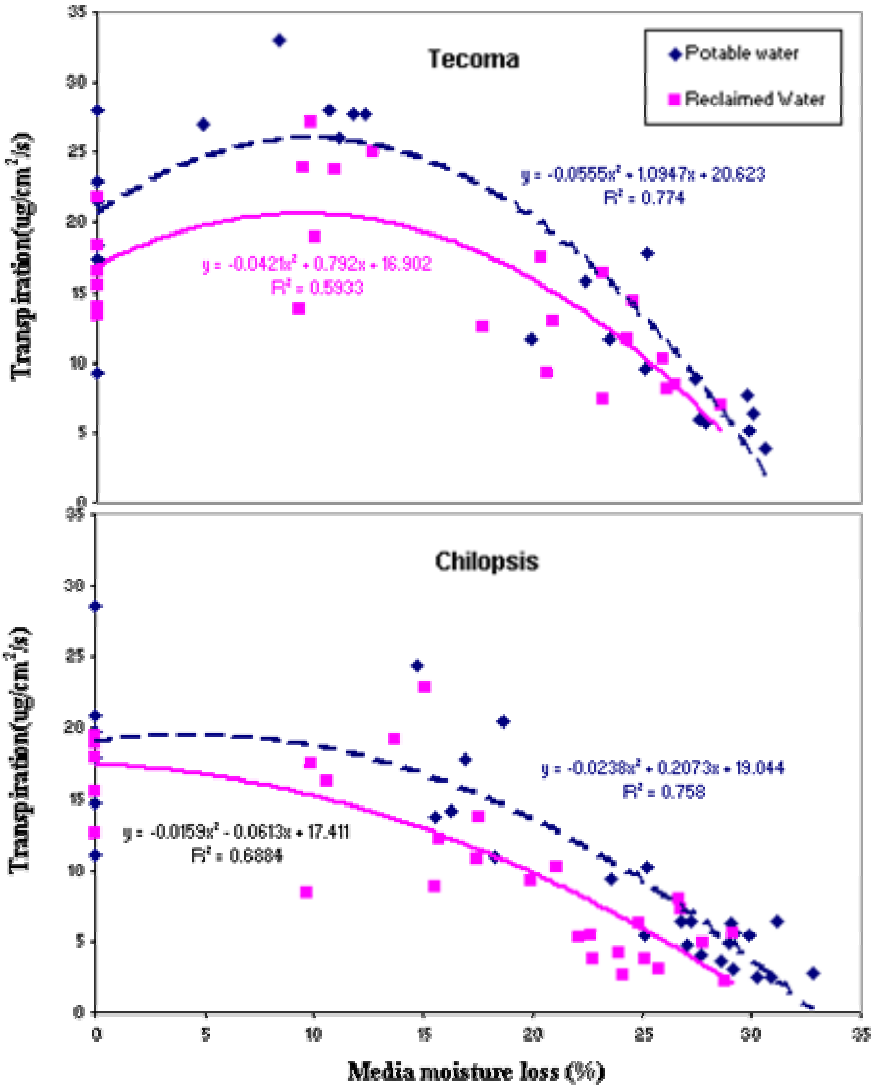

Fig. 2. Transpiration of plants irrigated with potable or reclaimed water and exposed to water stress conditions.

This response is not surprising since most plants under the potable irrigation regime had a greater leaf area as shown by greater leaf dry mass. Transpiration rates measured in yellow bells and desert willow were greater at mild water stress for plants irrigated with potable versus reclaimed water until about 25% of the fully saturated soil moisture was lost. These factors would result in a faster depletion of the available water in the media and result in faster wilting of plants treated with potable water.

The extensive damage of plants irrigated with potable water after the drought are likely a result of these plants being continuously well watered, while the plants irrigated with reclaimed water were gradually adjusted to increasing salinity and therefore were conditioned to physiological drought throughout the 12 weeks of treatments. Saturated paste tests of the dry media at the end of the drought cycle indicated that final EC in the root zone differed significantly between species. Root zone EC of desert willow was 0.8 dS/m (potable) and 2.05 dS/m (reclaimed), of yellow bells EC was 1.2 dS/m (potable and 2.8 dS/m (reclaimed), in sage EC was 0.9 dS/ m (potable) and 3.4 dS/m (reclaimed) and in verbena EC was 1.1 dS/m (potable) and 6.4 dS/m (reclaimed). These results suggest that verbena and sage may be salt excluders, while desert willow appears to include the salts. Yellow bells may incorporate both mechanisms to cope with the additional salts in the root zone. In conclusion, the increased salinity in the root zone conditioned plants irrigated with reclaimed water and thus enabled them to resist drought damage compared to the plants irrigated with potable water which were not acclimated to drought conditions and depleted the water through higher transpiration rates faster.

Salt sensitive plants can be produced with reclaimed water especially if they are well irrigated. While some component of plant dry weight will likely be affected and decrease when irrigating plants with reclaimed versus potable water, overall aesthetic appeal of ornamental plants is most important and small decreases in biomass are acceptable. However, during prolonged exposure to water with higher salinity, visual quality and parameters such as root weight may decrease below acceptable levels and impair the function of plants. This will depend on the species and the chemical composition of the irrigation water. Plants in this experiment likely would have benefited from some shade during the hottest part of the day in July and August when temperatures exceeded 40°C on a daily basis. Visual symptoms of salt injury were greatest during that time period and almost vanished when maximum daytime temperatures decreased. After 12 weeks, sage plants irrigated with reclaimed water were more attractive because of their compact canopy compared to plants irrigated with potable water.

Plants irrigated with reclaimed water and exposed to drought sustained less damage in terms of defoliation and plant dieback compared to plants irrigated with potable water. This is most likely due to the reclaimed water resulting in a mild physiological drought, conditioning plants to tolerate water deficits. Salts accumulated in the root zone of plants irrigated with reclaimed water and long-term studies of plants in the landscape irrigated with potable or reclaimed water are required to determine how much salt accumulation and how much water deficit different species will be able to tolerate.

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