Study of California Native Grass and Landscape Plant Species for Recycled Water Irrigation in California Landscapes and Gardens

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In the face of California's rapid population growth, the competition and cost for increasingly limited water resources have necessitated the use of recycled water for landscape irrigation, particularly in urban areas. Recycled water is water that has been previously used, suffered a loss in quality and has been treated to a point where it is suitable for subsequent use. The first wastewater treatment plant used solely for recycling and reuse of water was built in San Francisco in 1932. Today, wastewater is recycled at over 300 locations throughout California for agricultural and landscape irrigation, ground water recharge, and industrial use. The California Water Reuse Board estimates that by the year 2010, landscape irrigation will account for the second largest use of recycled water next to groundwater recharge. To facilitate the implementation of recycled water programs in California landscapes, a method of screening plants for their relative sensitivity to the elevated concentrations of chemical compounds found in recycled waters is needed. After treatment, sodium chloride is the only chemical compound remaining in recycled water that is potentially detrimental to landscape plants. Other elements such as boron, selenium, magnesium, and cadmium are rarely found to be above safety limits.

The objective of this research project was to conduct screening trials on landscape plants to determine their tolerance to salt in recycled-water irrigation. Several questions were examined for establishing a routine screening protocol and strategies for landscape irrigation:

(1) Does planting method (container or in the landscape) affect plant response to salt stress?

(2) Does the salt concentration used for this study affect flowering of the plant species?

(3) What will be the fluctuation of soil salinity over the dry and wet seasons?

(4) Considering the research data generated from this study, can we establish a landscape plant screening method using less time and handling larger numbers of plants?

Materials and Methods

1. Comparative studies of field and container plantings

Field plots. Field trials were conducted at the Department of Environmental Horticulture, University of California, Davis. Two separate field blocks, each measuring 100 ft by 100 ft (33m) were constructed in the spring of 1997. One block was designated for sprinkler irrigation (Figure 1) and the other was designated for drip irrigation. Each block was divided into nine plots, each measuring 15 ft (4.5m) by 30 ft (9m). Each of the field plots was then divided into two 15 ft x 15 ft (4.5m) subplots. One of the subplots was designated for field planting (soil classified as Yolo Loam) and the other designated for placement of containers. There was a 10-foot (3m) buffer zone between the two blocks and a 4-foot (1.2m) buffer zone between plots. Within each block, 9 field plots were randomly designated for the three levels of salt concentration treatments, and each treatment was replicated three times. A 100 gallon (363 L) tank was installed for storage of the salt treatment stock solution. Liquid fertilizer injectors were used to deliver the salt treatment solutions into the irrigation water.

Chemical properties of recycled waters. The chemical properties of recycled water reported by the Marin Municipal Water District (MMWD), Corte Madera, California and by South Bay Water Recycling, San Jose, CA from 1995 to 1998 indicated that the principal chemical compound in recycled water that might be detrimental to plants was NaCl. The average sodium (Na) concentrations ranged from 6.78 mM (156 $mg \cdot L^{-1}$) to 9.78 mM (225 $mg \cdot L^{-1}$) and the average chloride (Cl) concentrations ranged from 4.79 mM (167 $mg \cdot L^{-1}$) to 9.02 mM (316 $mg \cdot L^{-1}$). Concentrations of calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), boron (B), and nitrate (NO_3) were not exceptionally high. Sodium and chloride, therefore, became the target elements for the plant screening studies.

Irrigation and salt treatments. Three irrigation waters were used for the screening trials: control (potable water), low salt (500 $mg \cdot L^{-1}$ NaCl), and high salt (1500 $mg \cdot L^{-1}$ NaCl). The irrigation water containing 500

$mg \cdot L^{-1}$ NaCl supplied about 200 $mg \cdot L^{-1}$ Na and 300 $mg \cdot L^{-1}$ Cl, thus approximating the highest concentrations of these ions found in recycled waters as reported by the MMWD and South Bay Water Recycling. The irrigation water containing 1500 $mg \cdot L^{-1}$ NaCl provided 600 $mg \cdot L^{-1}$ Na and 900 $mg \cdot L^{-1}$ Cl, levels intended to induce significant salt stress in plants. Each salt concentration treatment was replicated three times for both the sprinkler and drip irrigation blocks. Irrigation frequency was adjusted depending on the weather conditions, and the quantity of water applied was recorded.

Plant materials and soil analysis. Selection of plant species was based on their popularity in California landscapes and growth habit, including vines, shrubs and trees. Ten landscape plant species, approximately 10 to 18 inches tall and of uniform size within species, were purchased from High Ranch Nursery in Loomis, California. The species were: Chinese Pistache (*Pistacia chinensis*), Oleander (*Nerium oleander*), Mexican Piñon Pine (*Pinus cembroides*), Japanese Boxwood (*Buxus japonica*), Liquidambar (*Liquidambar styraciflua*), Trumpet Vine (*Clytostoma callistegioides*), Ceanothus (*Ceanothus thyrsiflorus*), Nandina or Heavenly Bamboo (*Nandina domestica*), Rose (*Rosa* sp.) and Jasmine (*Jasminum polyanthum*). The plants were transplanted to the field plots or placed in the plots in 5-gallon (18.2 L) containers in June 1997. The containers were filled with UC Mix (1:1:1, peat moss: redwood sawdust: sand). Slow release 21-5-6 Apex Polyon Coated Fertilizer was applied in June 1997 and in March 1998, at the rate of 2g of fertilizer per plant per application. All plants were irrigated with potable water for 6 weeks until established, and salt treatments were started on August 1, 1997. Plants were monitored for growth, symptoms of salt-induced stress and other possible damage. For evaluation of salt stress response, parameters such as plant height, canopy diameter and chlorosis of leaves were recorded. Soil samples were collected from both field and container plantings on September 15, 1997; October 15, 1997; January 28, 1998 and May 15, 1998. Soil samples were analyzed for pH, EC (electrical conductivity), and Cl and Na concentrations. Leaves of Ceanothus, Chinese Pistache, Liquidambar, and Nandina, displaying severe salt stress symptoms under sprinkler irrigation with the high salt solution, were collected for salt deposit analysis. Fresh leaves were briefly rinsed (about 30 seconds) with distilled water or not rinsed and dried in a drying oven for 72 hours. Leaf tissue was

Figure 1. Common landscape plant species were irrigated in field plots with water containing elevated salt levels.

ground into powder and extracted overnight with 0.2 M HNO_3. Tissue chloride concentrations were measured with a Buchler Cotlove automatic titrator and sodium concentrations were measured by atomic absorption spectrophotometry.

2. Field planting for ten additional plant species.

In the fall of 1998, after the completion of the field and container planting studies, the container plants were removed from the field. Ten additional landscape plant species were planted in the field plots. They were Silk Tree *(Albizia julibrissin)*, Strawberry Tree (*Arbutus unedo)*, Chinese Hackberry *(Celtis sinensis)*, Raywood Ash *(Fraxinus angustifolia)*, Ginkgo *(Ginkgo biloba)*, Goldenrain Tree *(Koelreuteria paniculata)*, Skyrocket juniper *(Juniperus virginiana)*, Dwarf Olive *(Olea europea 'Montra')*, Coast Live Oak *(Quercus agrifolia)* and California Fan Palm *(Washingtonia filifera)*. Irrigation and salt concentration treatments were identical to those described previously. The field irrigation and salt concentration treatments were discontinued on December 1, 1998 due to wet winter weather and were resumed on March 1, 1999. Symptoms of salt stress response were recorded in the summer of 1999.

3. Greenhouse studies

In order to determine if there is a positive relationship between the plant salt tolerance revealed by sprinkler irrigation (foliage direct contact) and the salt tolerance revealed by drip irrigation, an experiment was conducted under controlled greenhouse conditions. Two salt-tolerant species, Oleander (*Nerium oleander*) and Japanese *Boxwood (Buxus japonica*), and two salt-sensitive species, Liquidambar (*Liquidambar styraciflua*) and Rose (*Rosa* sp.), were chosen for this study. The plants, about 30 to 60 cm (1-2 ft) tall depending on the species, were transplanted into 5-gallon plastic containers filled with UC Mix (1:1:1, peat moss: redwood sawdust: sand). The plants were placed on a greenhouse bench in a randomized block design, with three blocks. Each block measured 120 x 240 cm (4 x 8 ft) and consisted of one plant of each species. Hoagland's nutrient solution (1/4 strength) supplemented with 500, 1500, 2500, or 5000 $mg \cdot L^{-1}$ of NaCl was used for the salt stress treatments and Hoagland's solution without addition of NaCl was used to irrigate the control plants. Greenhouse temperatures were 21º C (68º F) day, 18º C (66º F) night, and day length was 15 hours with a minimum photon flux density of 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In order to maintain a relatively constant salt concentration in the soil, the plants were irrigated three times a week with 2-3 liters of the treatment solutions until the soil became saturated and water drained from the bottom of the pots. After 8 and 16 weeks of the salt treatments, the salt stress response of each plant was recorded as the percentage of leaves displaying symptoms of chlorosis and desiccation. About 30 g of leaf tissue were randomly collected from each plant and dried for Na and Cl analysis.

4. Rapid screening for salt tolerance

The above studies demonstrated that there was a positive relationship between the salt tolerance detected by sprinkler irrigation and the salt tolerance detected by drip irrigation. A rapid screening procedure for salt tolerance on 19 plant species was conducted on container-grown plants in the can yard of the Department of Environmental Horticulture at UC Davis. Plants ranging from 30 cm (1 ft) to 60 cm (2 ft) tall depending on plant species were grown in 1 gallon plastic containers. The plants were placed on benches, 1.3 m (4 ft) wide and 5 m (15 ft) long, in a randomized block design with three replications of each of the thee salt concentration treatments (control, 500 $mg \cdot L^{-1}$ and 1500 $mg \cdot L^{-1}$ salt). Irrigation was applied every other day with an overhead sprayer on the canopy of the plants and by hand to the pots. After 6 weeks of the salt treatments, the symptoms of salt stress response were recorded.

5. California native perennial grass species

Eight commercially-available California native grass species were supplied by Pacific Coast Seed, Inc. including California Brome *(Bromus carinatus)*, California Hairgrass *(Deschampsia caespitosa)*, Slender Hairgrass *(Deschampsia elongata)*, California Fescue *(Festuca californica)*, Coast Range Melic *(Melica imperfecta)*, Deergrass *(Muhlenbergia rigens)*, Pine Bluegrass *(Poa scabergia)* and Blue Wildrye *(Elymus glaucus)*. The grasses were established from seeds and were grown in 1 gallon containers in sand culture under greenhouse conditions (21º C day, 18º C night with minimum photon flux density of 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$). The plants were allowed to grow for 8 weeks before salt treatments were imposed. The treatments were irrigated with 1/10 strength Hoagland's nutrient solution alone (control) or supplemented with 500 or 1500 $mg \cdot L^{-1}$ NaCl. The design of the sprinkler and drip irrigation systems was identical to the field experiment. Plants were irrigated three times per week to ensure sufficient leaching and prevent salt accumulation in the soil. At the end of 6 weeks of growth, plant height and dry weight were measured and the salt tolerance ratio (dry weight under salt regime x 100/control dry weight) was determined for each species. Plant tissue was collected, dried and analyzed for sodium and chloride.

Results

1. Comparative studies of field and container plantings

Soil chemical properties. After 6 weeks of the irrigation treatments, the EC (electrical conductivity) values for all soils irrigated with potable water ranged from 0.30 to 0.36 $dS \cdot m^{-1}$ (Table 1). All soils irrigated with the lower salt concentration (500 $mg \cdot L^{-1}$) had EC values ranging from 1.18 to 1.20 $dS \cdot m^{-1}$, a threefold increase over the control treatment. The soils irrigated with the high salt concentration (1500 $mg \cdot L^{-1}$) had EC values between 1.81 and 2.48 $dS \cdot m^{-1}$, a sixfold increase over the control treatment. Soil EC values were comparable to EC values of the irrigation waters, suggesting that there was no apparent salt accumulation in the soil during the experiment. Soil pH values were in a narrow range from 6.5 to 7.0 with no apparent difference between the irrigation and planting treatments (Table 1).

Chloride concentrations in soils irrigated by potable water ranged from 42 to 80 $mg \cdot kg^{-1}$ (Table 1).

Table 1. Chemical properties of field and container soils after 6 weeks of irrigation with three salt concentrations.

Irrigation Treatment	Salt treatment ($mg \cdot L^{-1}$)	Planting	EC ($dS \cdot m^{-1}$)	pH	Cl ($mg \cdot kg^{-1}$)	Na ($mg \cdot kg^{-1}$)
Sprinkler	Control	Field	0.36*	6.70	71	45
Sprinkler	500	Field	0.91	6.85	384	209
Sprinkler	1500	Field	2.08	6.73	1201	794
Sprinkler	Control	Container	0.31	7.11	144	122
Sprinkler	500	Container	1.20	7.02	794	553
Sprinkler	1500	Container	1.81	7.01	1479	1057
Drip	Control	Field	0.32	6.70	80	59
Drip	500	Field	1.18	6.47	416	314
Drip	1500	Field	2.48	6.80	2356	1923
Drip	Control	Container	0.30	6.50	42	31
Drip	500	Container	1.21	7.05	794	544
Drip	1500	Container	2.30	6.80	2027	1015

Control: potable water. *: Mean value of three replicated composite samples.

Chloride concentrations in soils irrigated with the low salt solution ranged from 384 to 794 $mg \cdot kg^{-1}$, a seven-fold increase over the control treatment. Soils irrigated by the high salt solution had chloride concentrations ranging from 1201 to 2356 $mg \cdot kg^{-1}$, a twenty-fold increase over the control treatment. Differences in soil chloride levels between field and container soils were more pronounced for the sprinkler irrigation method than for the drip method. Containers irrigated with sprinklers had nearly twice as much soil chloride as the field soils irrigated by the same method.

Soils irrigated with potable water had Na concentrations ranging from 31 to 59 $mg \cdot kg^{-1}$ (Table 1). The low salt solution caused a six-fold increase in soil sodium and the high salt solution raised the soil sodium levels by a factor of 18. Again, the most dramatic differences in sodium levels between the field and container soils was under the sprinkler irrigation method. The container soils had over twice as much sodium as the field soils under sprinkler irrigation. The Cl/ Na ratio for all the soil samples was around 1.5, suggesting that NaCl was the primary salt compound in the soil.

Symptoms of salt stress response. Leaf chlorosis and wilting or desiccation are the typical symptoms of salt stress. After 6 weeks of irrigation with the high salt solution (1500 $mg \cdot L^{-1}$) using the sprinkler method, seven of the ten plant species exhibited these symptoms and suffered a decrease in growth compared to the control plants (Table 2). Only two species showed salt stress symptoms and substantial reductions in growth under the drip irrigation method. Of those plants receiving the low salt solution (500 $mg \cdot L^{-1}$) by the sprinkler method, three of the ten species showed salt stress symptoms on their leaves. All plants irrigated by the drip method with the low salt solution appeared normal.

Based on these results, the ten species in the study fell into three categories of salt stress response: (1) Oleander, Japanese Boxwood, and Mexican Piñon Pine were salt-tolerant and not affected by either level of salt in the irrigation water. (2) Ceanothus, Rose, Trumpet Vine, and Nandina were moderately salt tolerant; their growth was affected by the high salt solution but was normal under the low salt regime. (3) Chinese Pistache, Liquidambar (Figure 2) and Jasmine were the most salt-sensitive plants in this study; their growth was severely inhibited by sprinkler irrigation with 1500 $mg \cdot L^{-1}$ salt, and was slightly affected by 500 $mg \cdot L^{-1}$ salt.

Effects of salt and irrigation on new growth of plants. Salt treatments were terminated on December 1, 1997 because irrigation was not needed during the wet winter season. Irrigation and salt treatment were resumed on March 1, 1998. Irrigation was applied three times a week for 15 minutes per application, providing about 2.5 cm (1 inch) of water per irrigation. The irrigation program was continued regardless of wet weather. A growth baseline for each plant was established on January 15, 1998 by recording the height and average canopy diameter. On May 29, 1998 height and canopy of the plants were measured again. The difference between the baseline values and the values four months later were used as a measure of the new growth of the plants. An index of growth response to salt stress was determined, expressing the growth of salt-treated plants as a percentage of the growth of the control plants receiving potable water. No apparent detrimental effects were detected for any species under drip irrigation. Of those under sprinkler irrigation, Oleander, Mexican Piñon Pine and Japanese Boxwood showed no ill effects of irrigation with either salt solution on their new growth. New growth was reduced by 50 % for Ceanothus plants irrigated by sprinklers with the high salt solution. New growth was reduced to zero for Chinese Pistache, Liquidambar, Trumpet Vine, Rose, Nandina and Jasmine under the high salt and sprinkler irrigation regime.

Chloride and sodium uptake. No significant differences were found in tissue chloride or sodium levels between the rinsed and non-rinsed leaves, so leaf rinsing before tissue analysis seems unnecessary. In general, there were no differences in tissue chloride or sodium levels between the field-planted and container plants, and the more salt tolerant species contained the lowest amounts of chloride and sodium in their leaves.

To detect salt uptake differences between salt concentration treatments, five species that had clear differences in salt stress response under sprinkler irrigation with the high salt solution were analyzed for leaf tissue Cl and Na concentrations. The leaf chloride levels for plants irrigated with potable water ranged from

Table 2. Growth and symptoms of salt stress for 10 selected landscape plant species after 6 weeks of drip or sprinkler irrigation with two levels of salt concentration.

Irrigation Treatment and Plant Species	Growth of container plants (% of control)		Growth of field plants (% of control)		% of foliage with salt stress symptoms (mean)	
	Drip	Sprinkler	Drip	Sprinkler	Drip	Sprinkler
Low salt concentration (NaCl 500 mg·L^{-1})						
Chinese Pistache	86	56	95	55	N	15%
Oleander	120	120	100	100	N	N
Mexican Piñon Pine	105	105	110	110	N	N
Japanese Boxwood	100	100	105	105	N	N
Liquidambar	105	95	100	100	N	10%
Trumpet Vine	90	90	100	100	N	N
Ceanothus	90	80	95	95	N	N
Nandina	100	68	100	100	N	N
Rose	108	95	110	100	N	N
Jasmine	100	100	95	95	N	10%
High salt concentration (NaCl 1500 mg·L^{-1})						
Chinese Pistache	95	25	85	30	5%	60%
Oleander	100	100	110	110	N	N
Mexican Piñon Pine	100	100	100	100	N	N
Japanese Boxwood	95	95	105	105	N	N
Liquidambar	95	35	93	25	N	60%
Trumpet Vine	105	85	100	78	N	20%
Ceanothus	90	45	100	55	N	20%
Rose	100	45	85	52	10%	60%
Nandina	100	35	100	38	N	60%
Jasmine	95	35	90	30	N	70%

N: No apparent salt stress symptom

Figure 2. Sprinkler irrigation with 500 mg·L^{-1} salt resulted in severe damage to leaves of Liquidambar.

4 to 6 mg·g^{-1} dry weight (Table 3). Plants irrigated with 500 mg·L^{-1} of salt had 2 to 3 times more chloride in their leaves than the control plants. Leaf chloride levels for plants irrigated with 1500 mg·L^{-1} salt were 4 to10 times greater than those for the control plants. Sodium concentration ranged from 0.3 to 1 mg·g^{-1} dry weight in leaf tissue of the plants irrigated with potable water (Table 3). Plants irrigated with 500 mg·L^{-1} salt had 3 to 5 times more sodium in their leaves than those irrigated with potable water. Five to 10 times more sodium was detected in the leaf tissue of plants irrigated with 1500 mg·L^{-1} salt.

Seasonal soil salinity changes. Soil salinity values were at their highest for all treatments in October 1997. Soils receiving potable water (control) had EC values around 0.5 dS·m^{-1}, those receiving the low salt solution had EC values around 1 dS·m^{-1} and soils receiving the high salt solution showed EC values around 2 dS·m^{-1}. In January 1998, EC measurements for all soils were less than 0.4 dS·m^{-1}, reflecting the winter cessation of the irrigation treatments and significant leaching by winter rains. Irrigation began again in March 1998 and by May 1998, all soils showed some increase in salinity levels.

2. Final evaluation of field plantings

The symptoms of salt stress response were recorded in the last week of June 1999 for the 10 additional species along with the 10 species of the previous study. Mortality of Liquidambar, Chinese Pistache, Rose, Jasmine, Trumpet Vine, and Heavenly Bamboo occurred in the spring and summer of 1999 in the plantings receiving the high salt solution by the sprinkler method. Oleander, Mexican Piñon Pine, and Japanese Boxwood showed no symptoms of salt damage but their growth rates were reduced by 50% compared to the control plants. Among the ten species that were added for the field trial in the fall of 1998 the leaves of Chinese Hackberry, Silk Tree, Raywood Ash, and Ginkgo were severely damaged by sprinkler irrigation with 1500 mg·L^{-1} salt. Minor leaf damage was found on Strawberry Tree and Coast Live Oak. No salt stress symptoms were found on Skyrocket Juniper, Dwarf Olive or Fan Palm. Of the species subjected to sprinkler irrigation with 500 mg·L^{-1} salt, Trumpet Vine, Jasmine, Liqudambar, Chinese Pistache, Rose, Silk Tree, Chinese Hackberry, and Raywood Ash had moderate salt stress damage, but no salt stress symptoms were found on the remaining species. All plants irrigated by the drip method had normal growth and no symptoms of salt stress.

3. Greenhouse studies

After 16 weeks of irrigation with the control, 500, and 1500 mg·L^{-1} NaCl solutions, no salt stress symptoms were detected on Oleander, Japanese Boxwood, Liquidamber or Rose. After 8 weeks of irrigation with the 2500 mg·L^{-1} salt solution, only minor marginal leaf chlorosis was apparent on Liquidambar and Rose. Severe leaf desiccation, chlorosis and abscission occurred at 8 weeks for Liquidambar and Rose irrigated with 3500 and 5000 mg·L^{-1} salt. Oleander and Japanese Boxwood showed no salt stress symptoms after 8 weeks of irrigation with the 3500 and 5000 mg·L^{-1} salt solutions. Sodium uptake after 16 weeks of irrigation with salt solutions up to 1500 mg·L^{-1} ranged from about 1 mg·g^{-1} dry leaf tissue in Rose to about 2.6 mg·g^{-1} dry leaf tissue in Japanese Boxwood. Chloride uptake ranged from

Table 3. Chloride and sodium in leaf tissue of 5 salt-sensitive landscape plant species grown either in the field or in containers after 6 weeks of drip irrigation with three salt concentrations.

Species	Container			Field		
	Control	Low salt	High salt	Control	Low salt	High salt
	Cl ($mg \cdot g^{-1}$)	Cl ($mg \cdot g^{-1}$)	Cl ($mg \cdot g^{-1}$)	Cl ($mg \cdot g^{-1}$)	Cl ($mg \cdot g^{-1}$)	Cl ($mg \cdot g^{-1}$)
Ceanothus	4.59 ± 0.06	10.41 ± 0.70	26.47 ± 5.34	4.77 ± 0.45	9.35 ± 0.49	23.75 ± 0.75
Chinese Pistache	5.31 ± 1.07	12.04 ± 2.23	24.23 ± 2.53	6.11 ± 0.8	13.49 ± 0.60	20.81 ± 1.38
Jasmine	5.57 ± 1.67	18.05 ± 0.65	35.50 ± 2.71	39.90 ± 0.88	12.34 ± 1.00	36.17 ± 0.49
Liquidambar	4.94 ± 1.20	14.73 ± 0.53	39.72 ± 0.45	4.09 ± 0.25	13.76 ± 0.61	36.99 ± 1.74
Rose	4.21 ± 1.66	17.55 ± 0.53	40.75 ± 2.65	4.37 ± 0.67	15.45 ± 0.99	37.87 ± 1.23
ANOVA Between salt concentrations	$F = 57.87$	$P < 0.001$			$F = 51.50$	$P < 0.001$
	Na ($mg \cdot g^{-1}$)	Na ($mg \cdot g^{-1}$)	Na ($mg \cdot g^{-1}$)	Na ($mg \cdot g^{-1}$)	Na ($mg \cdot g^{-1}$)	Na ($mg \cdot g^{-1}$)
Ceanothus	1.30 ± 0.16	4.93 ± 0.09	8.62 ± 0.67	0.83 ± 0.09	2.50 ± 0.25	7.82 ± 0.44
Chinese Pistache	0.80 ± 0.05	1.46 ± 0.18	5.51 ± 0.15	0.88 ± 0.07	1.22 ± 0.10	6.72 ± 0.32
Jasmine	0.66 ± 0.06	0.95 ± 0.06	4.46 ± 0.20	0.49 ± 0.07	1.37 ± 0.31	2.87 ± 1.07
Liquidambar	0.30 ± 0.01	3.70 ± 0.10	6.70 ± 0.63	0.42 ± 0.05	2.86 ± 0.39	9.60 ± 0.90
Rose	0.46 ± 0.06	0.87 ± 0.05	6.73 ± 0.18	0.18 ± 0.03	2.37 ± 0.02	7.51 ± 0.18
ANOVA Between salt concentrations	$F = 9.94$	$P < 0.001$			$F = 14.27$	$P < 0.001$

Control = potable water; Low = 500 $mg \cdot L^{-1}$, High = 1500 $mg \cdot L^{-1}$

about 1.3 $mg \cdot g^{-1}$ in Oleander to about 5.3 $mg \cdot g^{-1}$ in Rose for the same treatments. After 8 weeks of irrigation with the 2500, 3500, and 5000 $mg \cdot L^{-1}$ salt solutions, the Na and Cl levels in Oleander and Japanese Boxwood remained relatively low while the levels in Rose and Liquidambar increased abruptly to over 20 $mg \cdot g^{-1}$ dry leaf tissue. These results suggest that the two salt tolerant species (Oleander and Japanese Boxwood) were able to exclude salt from their tissues better than the two salt-sensitive species (Rose and Liquidambar). The salt exclusion mechanism of the two salt-sensitive plant species was broken down when the salt concentration in the root environment reached 2500 $mg \cdot L^{-1}$ (in irrigation water). This study demonstrates that there is a close relationship between the salt tolerance of plants detected by direct contact of salt on the leaves and the salt tolerance detected by application of salt to the root environment.

4. Rapid screening for salt tolerance

After 6 weeks of the salt treatments, the symptoms of salt stress response were recorded for the 19 species tested. Butterfly Bush, Elderberry, Abelia, Cornelian Cherry, California Holly Grape, Rockspray Cotoneaster, and Golden Marguerite showed severe leaf chlorosis and desiccation on 80-90% of their leaves when subjected to overhead irrigation with the 1500 $mg \cdot L^{-1}$ salt solution. No signs of salt stress were detected for Tobira Pittosporum, Cape Plumbago, Redolen Acacia, Japanese Boxwood, Deodar Cedar, Indian Hawthorn or Chinese Tallow Tree under the same regime. When irrigated overhead with the 500 $mg \cdot L^{-1}$ salt solution, Butterfly Bush, Abelia and Cornelian Cherry displayed salt stress on about 50 % of their leaves. Elderberry, California Holly Grape, Golden Marguerite and Rockspray Cotoneaster exhibited moderate salt stress (10-30 % of leaves). The remaining species showed no signs of salt stress from overhead irrigation with the 500 $mg \cdot L^{-1}$ salt solution. This study suggests that screening of landscape plant species for salt tolerance under recycled-water irrigation can be achieved in a simple and rapid fashion.

5. California native perennial grass species

No symptoms of salt stress or dry weight reduction were detected for any of the eight California native grass species subjected to irrigation with either the 500 mg·L^{-1} or 1500 mg·L^{-1} salt solution. The salt tolerance ratio (dry weight produced under salt treatment x 100/dry weight produced under control treatment) for all species under the 500 mg·L^{-1} salt treatment was over 90% and over 80% for the 1500 mg·L^{-1} salt treatment. The plants under the control irrigation treatment had tissue sodium levels ranging from 100 to 140 μg·g^{-1} dry weight. Under the 500 and 1500 mg·L^{-1} salt treatments, tissue sodium concentrations ranged from 150 to 300 μg·g^{-1} dry weight. These 8 grass species have been growing in field plots since March 1999, irrigated by sprinklers with 500 or 1500 mg·L^{-1} salt solutions. No salt stress symptoms have been noticed as yet, but more conclusive results may be expected after exposure to the warm and dry summer season and data will be collected in September of 1999.

Discussion

Sodium and chloride are the elements commonly found in relatively high concentrations in recycled water (Westcot and Ayres, 1984) and are potentially detrimental to plants. Most research regarding recycled-water irrigation emphasizes treatment engineering, chemistry, hydrology, and irrigation systems. Very little information is available about the response of landscape plants to recycled water (Pepper and Mancino, 1993; Pettygrove and Asano, 1984). Among species and varieties of crop plants, there is great variation in salt tolerance (Francois and Mass, 1993; Mass, 1990). It is possible, therefore, to select crops whose yield is only slightly affected by a particular level of salinity. An EC value of 10 dS·m^{-1} in irrigation water appears to be the maximum tolerated by agronomic crops without suffering a loss in yield. Unlike the monoculture of agricultural crops, most landscape plantings include a varied array of plant species with differing abilities to tolerate salt in irrigation water. The success of using recycled water for landscape irrigation depends on knowledge of this important parameter for as many ornamental plant species as possible.

The salt concentrations used for this study were practical and, in fact, most recycled waters contain less salt than the lower concentration used here (500 mg·L^{-1}). Plant response under these experimental conditions should be indicative of their performance in the landscape. This study revealed that a wide range of salt tolerance exists among landscape plant species (Table 4). It should be noted, however, that salt tolerance of any given species depends on factors such as climate and weather, irrigation management, genetic variation among varieties, soil texture and structure, and soil fertility (Maas, 1990). Nevertheless, the differences in salt tolerance among the plant species detected by this study were very clear. Foliar injury from saline water applied by sprinklers on crop plants has been reported (Westcot and Ayers, 1984), but the relationship between salt tolerance to leaf spray and salt tolerance to root supply has not been investigated. The present study demonstrated that there was a positive relationship between the salt tolerance revealed by sprinkler irrigation and the salt tolerance revealed by drip irrigation. The concentration required to induce salt stress in the root environment was much higher than that needed when irrigation was incident on leaves. For landscape irrigation using recycled water, drip irrigation was acceptable for nearly all species under the generous irrigation regime used for this study. Two salt-sensitive species, Chinese Hackberry and Golden Raintree, irrigated by sprinklers with the 1500 mg·L^{-1} salt solution, showed severe damage to leaves in direct contact with irrigation water. The leaves above the height of precipitation, however, were healthy and showed no sign of salt stress. A caveat to the use of sodium-laden recycled water for landscape irrigation involves the detrimental effect of this element on soil structure.

Conclusions

Field trials of landscape plants determined their tolerance to irrigation by salt-laden recycled water. Thirty-eight landscape plant species exhibited substantial differences in salt tolerance. Plants were more susceptible to salt stress under sprinkler irrigation than under drip irrigation, because of direct contact of leaves with the salt solution. Fourteen of the 38 plant species (36%) were found to be salt tolerant when they were irrigated by sprinklers with 1500 mg·L^{-1} (ppm) salt and 21 species (54%) were salt tolerant when they were irrigated by sprinklers with 500 mg·L^{-1} salt. No apparent salt stress symptoms were detected when plants were irrigated by drip irrigation either with 500 mg·L^{-1} or 1500 mg·L^{-1} salt (NaCl). Drip irrigation, therefore, may be acceptable for most landscape plantings in California.

A greenhouse study demonstrated that the salt tolerance of plants detected by sprinkler irrigation positively related to the salt tolerance detected by drip irrigation. Nevertheless, the concentration inducing salt

Table 4. Salt tolerance of 38 landscape plant species grown under sprinkler irrigation with two salt (NaCl) concentrations.

Species	Sprinkler irrigation with 1500 mg·L^{-1} salt	Sprinkler irrigation with 500 mg·L^{-1} salt
Abelia grandiflora 'Edward Goucher' (Abelia)	LOW	LOW
Acacia redolens (Redolen Acacia)	HIGH	HIGH
Albizia julibrissin (Silk Tree)	LOW	MODERATE
Arbutus unedo (Strawberry Tree)	MODERATE	HIGH
Buddleia davidii (Butterfly Bush)	LOW	LOW
Buxus japonica (Japanese Boxwood)	HIGH	HIGH
Ceanothus thrysiflorus (Ceanothus)	MODERATE	HIGH
Cedrus deodara (Deodar Cedar)	HIGH	HIGH
Celtis sinensis (Chinese Hackberry)	LOW	LOW
Clytostoma callistegioides (Trumpet Vine)	LOW	LOW
Cornus mas (Cornelian Cherry)	LOW	LOW
Cotoneaster microphyllus 'Rockspray'	LOW	MODERATE
Escallonia rubra (Escallonia)	MODERATE	HIGH
Euryops pectinatus (Golden Marguerite)	LOW	LOW
Forsythia intermedia (Forsythia)	MODERATE	HIGH
Fraxinus angustifolia (Raywood Ash)	LOW	MODERATE
Ginkgo biloba (Ginkgo)	LOW	LOW
Jasminum polyanthum (Jasmine)	LOW	LOW
Juniperus virginiana 'Skyrocket' (Juniper)	HIGH	HIGH
Koelreuteria paniculata (Goldenrain Tree)	LOW	HIGH
Lantana camara (Lantana)	MODERATE	HIGH
Liquidambar styraciflua (Liquidambar)	LOW	LOW
Mahonia pinnata (California Holly Grape)	LOW	MODERATE
Myrtus communis (True Myrtle)	MODERATE	HIGH
Nandina domestica (Heavenly Bamboo)	LOW	MODERATE
Nerium oleander (Oleander)	HIGH	HIGH
Olea europea 'Montra' (Dwarf Olive)	HIGH	HIGH
Pinus cembroides (Mexican Piñon Pine)	HIGH	HIGH
Pistacia chinesis (Chinese Pistache)	LOW	LOW
Pittosporum tobira (Tobira Pittosporum)	HIGH	HIGH
Plumbago auriculata (Cape Plumbago)	HIGH	HIGH
Prunus caroliniana (Carolina Laurel Cherry)	LOW	HIGH
Quercus agrifolia (Coast Live Oak)	MODERATE	HIGH
Rhaphiolepis indica (Indian Hawthorn)	HIGH	HIGH
Rosa sp. (Rose)	LOW	LOW
Sambucus nigra (Elderberry)	LOW	MODERATE
Sapium sebiferum (Chinese Tallow Tree)	HIGH	HIGH
Washingtonia filifera (California Fan Palm)	HIGH	HIGH

stress by drip irrigation was much higher than that applied by sprinkler irrigation. Application of salt directly on leaves may be a method for rapid screening of landscape plants for salt tolerance.

Soil EC (electrical conductivity) values were found to be highest in the fall, approximately 3 $dS \cdot m^{-1}$, and reduced to less than 1 $dS \cdot m^{-1}$ in the spring. This seasonal fluctuation in soil salt concentration may prevent buildup of salinity to damaging levels.

All the 8 California native perennial grass species tested under greenhouse conditions were found to be salt-tolerant. These grass species are being further tested in field plots and the results will be collected in the fall of 1999.

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