Plate 1. A view of the sprinkler irrigation field block where ten landscape plant species were randomly planted both in the field and in containers.

Studies of Salt Tolerance of Landscape Plant Species and California Native Grasses for Recycled Water Irrigation

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Significance to the Landscape and Nursery Industries

In the face of California's rapid population growth, the competition for increasingly limited water resources has necessitated the use of recycled water for landscape and nursery irrigation. A reference list of the sensitivity of plant species to recycled water would facilitate implementation of recycled water irrigation. The information generated by this study is valuable for both landscape and nursery irrigation management.

Species used in this study: *Abelia grandiflora* 'Edward Goucher' (Abelia), *Acacia redolens* (Redolen Acacia), *Albizia julibrissin* (Silk Tree), *Arbutus unedo* (Strawberry Tree), *Buddleia davidii* (Butterfly Bush), *Buxus microphylla japonica* (Janpanese Boxwood), *Ceanothus thrysiflorus* (Ceanothus), *Cedrus deodara* (Deodar Cedar), *Celtis sinensis* (Chinese Hackberry), *Clytostoma callistegioides* (Trumpet Vine), *Cornus mas* (Cornelian Cherry), *Cotoneaster microphyllus* 'Rockspray' (Cotoneaster), *Escallonia rubra* (Escallonia), *Euryops pectinatus* (Golden Marguerite), *Forsythia intermedia* (Forsythia), *Fraxinus angustifolia* (Raywood Ash), *Ginkgo biloba* (Ginkgo), *Jasminum polyanthum* (Jasmine), *Juniperus virginiana* 'Skyrocket' (Juniper), *Koelreuteria paniculata* (Goldenrain Tree), *Lantana camara* (Lantana), *Liquidambar styraciflua* (Liquidambar), *Mahonia pinnata* (California Holly Grape), *Myrtus communis* (True Myrtle), *Nandina domestica* (Heavenly Bamboo), *Nerium oleander* (Oleander), *Olea europea 'Montra'* (Dwarf Olive), *Pinus cembroides* (Mexican Piñon Pine), *Pistacia chinensis* (Chinese Pistache), *Pittosporum tobria* (Tobira Pittosporum), *Plumbago auriculata* (Cape Plumbago), *Prunus caroliniana* (Carolina Laurel Cherry), *Quercus agrifolia* (Coast Live Oak), *Rhaphiolepis indica* (Indian Hawthorn), *Rosa sp.* (Rose), *Sambucus nigra* (Elderberry), *Sapium sebiferum* (Chinese Tallow Tree), *Washingtonia filifera* (California Fan Palm), *Bromus carinatus* (California Brome), *Deschampsia caespitosa* (California Hairgrass), *Deschampsia elongata* (Slender Hairgrass), *Elymus glaucus* (Anderson valley ecotype), *Elymus glaucus* (Blue Wildrye, coast range ecotype), *Elymus glaucus* (Stainslaus, 2000 ft. elevation), *Elymus glaucus* (Stainslaus, 5000 ft. elevation), *Festuca californica* (California Fescue), *Melica californica* (California Melic), *Poa scabrella* (Pine Bluegrass), *Muhlenbergia rigens* (Deergrass), *Sporobolus airoides* (Alkali Sacaton), and *Stipa pulchra* (Purple Needlegrass).

PART I
Testing Salt-tolerance of Landscape Plants for Recycled Water Irrigation

Introduction

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 additional use. The first wastewater treatment plant used solely for recycling water and reuse was built in San Francisco in 1932. Today, wastewater is recycled at over 300 locations throughout California for agricultural and landscape irrigation, groundwater recharge and industrial use. The California Water Resources Control Board estimated that by the year 2010, landscape irrigation will account for the second largest use of recycled water next to groundwater recharge (Westcot and Ayers, 1984). After most of the water treatment processes, sodium chloride is the only chemical compound remaining in recycled water that is potentially detrimental to landscape plants (Westcot and Ayers, 1984; Hays *et al*., 1990; Pepper and Mancino, 1994). Other elements such as boron, selenium, magnesium, and cadmium are rarely found to be above harmful levels.

The objective of this research project was to conduct screening trials on landscape plants to determine their tolerance to salt for recycled water irrigation. This study addressed these questions: (1) Are the salt concentration levels used for this study able to induce detectable salt stress symptoms and differentiate salt tolerant and salt sensitive plant species? (2) Does planting of plants in containers or in the field affect the results of plant response to salt stress? (3) What will be the fluctuation of soil salinity over the dry and wet seasons? (4) Considering the research results generated from this study, can we establish a simple and rapid salt tolerance testing method?

Materials and Methods

A. Field and Container Plantings

Field plots

Field trials were conducted on a plot measuring 70 x 70m at the Department of Environmental Horticulture, University of California, Davis. The field was divided into 18 blocks, each measuring 5 x 10m (Plates 1 and 2). There was a 1.5 m buffer zone between blocks. Nine of the 18 blocks were designated for sprinkler irrigation and the other 9 were designated for drip irrigation. The field blocks were randomly designated for three levels of salt concentration treatments, and each treatment was replicated three times. The field soil was a loam clay soil (fine, mixed, mesic Typic Hapludalf). A 500 L tank was installed for storage of salt treatment stock solution. Liquid fertilizer injectors were used to deliver salt treatment solutions into the irrigation water.

Chemical properties of recycled waters

This cooperative research project was partially supported by Marin County Municipal Water District and the City of San Jose, California. The chemical analysis of the recycled water reported by Marin Municipal Water District (MMWD), Corte Madera, California for 1993 and 1995 and the water treatment facility of the City of San Jose, California in 1996 and 1997 indicated NaCl to be the principal compound in the recycled water that might be detrimental to plants. The average sodium (Na) concentrations ranged from 6.78 mM (156 mg L^{-1}) to 9.78 mM (225 mg L^{-1}), chloride (Cl) concentrations ranged from 9.02 mM (175 mg L^{-1}) to 4.79 mM (319 mg L^{-1}). Concentrations of calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), boron (B), and nitrate (NO_3) were below the level that might be toxic to plants. Sodium chloride (NaCl) was, therefore, the target chemical compound for the plant testing studies.

Plate 2. A view of drip irrigation field block where the ten landscape plant species were randomly planted both in the field and in containers.

Irrigation treatments

The three salt (NaCl) concentrations used for irrigation were: control (potable water); low salt (500 mg L^{-1} NaCl), and high salt (1500 mg L^{-1} NaCl). The low salt treatment supplied 200 mg L^{-1} Na and 300 mg L^{-1} Cl, thus approximating the highest Na and Cl concentrations found in recycled waters. To insure a relatively higher salt stress, 1500 mg L^{-1} NaCl was chosen for the high salt concentration treatment. This salt concentration provides 600 mg L^{-1} Na and 900 mg L^{-1} Cl. Each salt treatment was replicated three times for both the sprinkler and drip irrigations. Through the dry season, from April to November, the field was irrigated every other day with 2.5 cm water from both the sprinkler and drip irrigation systems. From December to March, irrigation frequency was adjusted depending on the weather conditions. Two grams of slow release Apex Polyon Coated Fertilizer (21-5-6) were applied per plant in June 1997, and in March 1998.

Planting, salt stress evaluation, and soil analysis

Selection of plants was based on both the popularity of the species in California landscapes and the inclusion of a wide range of growth habits (from Trumpet Vine to Mexican Piñon Pine). Ten landscape plant species ranging from 25 to 45 cm tall among species and with comparable size within a single species were purchased from High Ranch Nursery in Loomis, California. The ten species were: Chinese Pistache (*Pistacia chinensis*), Oleander (*Nerium oelander*), Mexican Piñon Pine (*Pinus cembroides*), Japanese Boxwood (*Buxus microphylla japonica*), Liquidambar (*Liquidambar* *styraciflua*), Trumpet Vine (*Clytostoma callistegioides*), Ceanothus (*Ceanothus thyrsiflorus*), Heavenly Bamboo (*Nandina domestica*), Rose (*Rosa* sp.), and Jasmine (*Jasminum polyanthum*). Within each field block, one plant of each of the 10 species was transplanted into the field as well as in 18.9 L containers in June of 1997, and all plants were randomly arranged. The containers were filled with UC Mix (1:1:1, peat-moss: redwood sawdust: sand). Two grams of Apex coated slow release fertilizer (21-5-6) were applied to each plant. All plants were irrigated with potable water for 6 weeks during establishment before salt treatments started. Plants were monitored for growth, symptoms of salt induced stress and other possible damage.

For evaluation of salt stress response, symptoms such as chlorosis and leaf burn were recorded as percentage of leaves affected, and were translated into salt tolerance indices (%) by subtracting from 100%. In addition, plant height and canopy diameter were measured after 6 weeks of salt treatment. A tolerance index was calculated as: Index of salt tolerance = (mean value of plant height plus canopy diameter of salt treated plants / mean value of plant height plus canopy diameter of control plants) x 100. The 10 plant species were placed into three salt tolerance categories according to their tolerance indices (above 90% = High; above 50% less than 90% = Moderate; less than 50% = Low).

Soil samples (0 to 30 cm deep) were collected on September 15 and October 15, 1997, January 28 and May 15, 1998. Soil samples were dried at room temperature for 4 weeks or more before analysis for pH, EC (electrical conductivity), Cl, and Na concentrations. Leaves of all the 10 plant species after 6 weeks of salt treatment were collected randomly from each plant. Leaves were dried at 60°C in a drying oven for 72 hours, ground into powder, and extracted overnight with 0.2 M HNO_3. Tissue chloride concentrations were measured with a Buchler Cotlove automatic titrator. Sodium concentrations were measured using atomic absorption spectroscopy.

B. Field planting for additional 10 plant species

In fall, 1998, after completion of the field and container planting studies, container-grown 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*), Golden Raintree (*Koelreuteria paniculata*), Skyrocket juniper (*Juniperus virginiana*), Dwarf Olive (*Olea europea 'Montra'*), Coast Live Oak (*Quercus agrifolia*), and Fan Palm (*Washingtonia filifera*). Irrigation and salt concentration treatments were identical to those described previously. Irrigation was discontinued on December 1, 1998, because of wet winter weather and was resumed on March 1, 1999. Salt stress response of

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

Irrigation Treatment	Salt Treatment ($mg\ L^{-1}$)	Planting	EC ($dS\ m^{-1}$)	pH	Cl ($mg\ kg^{-1}$)	Na ($mg\ kg^{-1}$)
Sprinkler	Control	Field	0.63*	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	44	22
Sprinkler	500	Container	1.20	7.02	794	253
Sprinkler	1500	Container	1.81	7.01	1479	757
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	1356	823
Drip	Control	Container	0.30	6.50	62	31
Drip	500	Container	1.21	7.05	790	244
Drip	1500	Container	2.30	6.80	1127	755
ANOVA						
Between field and container			$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$
Between irrigation treatment			$P < 0.01$	$P > 0.05$	$P < 0.01$	$P < 0.01$

*Control: Potable water. *: Mean values of three replicated composite samples.*

Table 2. Symptoms of salt stress, growth, and salt tolerance of the 10 selected plant species after 6 weeks irrigation with sprinkler or drip system and with low (500 mg L^{-1}) or high (1500 mg L^{-1}) levels of salt concentrations.

Plant species and Irrigation Treatment	Growth of container plants (% of control)		Growth of field plants (% of control)		Clorotic container plant leaves (%)		Chlorotic field plant leaves (%)	
Low salt concentration (NaCl 500 mg L^{-1})	Drip	Sprinkler	Drip	Sprinkler	Drip	Sprinkler	Drip	Sprinkler
Chinese Pistache	86	65	95	75	N	20	N	25
Oleander	120	120	100	100	N	N	N	N
Mexican Pinon Pine	105	105	110	110	N	N	N	N
Japanese Boxwood	100	100	105	105	N	N	N	N
Liquidambar	105	75	100	65	N	25	N	30
Trumpet Vine	90	90	100	100	N	N	N	N
Ceanothus	90	80	95	95	N	N	N	N
Heavenly Bamboo	100	68	100	100	N	N	N	N
Rosa sp.	108	70	95	75	N	20	N	25
Jasmine	100	100	95	95	N	10	N	15
ANOVA								
Between species	$P > 0.05$	$P < 0.01$	$P > 0.05$	$P < 0.01$				
High salt concentration (NaCl 1500 mg L^{-1})	Drip	Sprinkler	Drip	Sprinkler	Drip	Sprinkler	Drip	Sprinkler
Chinese Pistache	95	25	85	30	5	55	5	60
Oleander	100	100	110	110	N	N	N	N
Mexican Pinon Pine	100	100	100	100	N	N	N	N
Japanese Boxwood	95	95	105	105	N	N	N	N
Liquidambar	95	35	93	25	N	70	N	65
Trumpet Vine	105	85	100	78	N	15	N	20
Ceanothus	90	70	100	65	N	N	N	15
Heavenly Bamboo	100	45	85	52	10	60	10	60
Rosa sp.	100	35	100	38	N	70	N	65
Jasmine	95	35	90	30	N	75	N	75
ANOVA								
Between species	$P > 0.05$	$P < 0.01$	$P > 0.05$	$P < 0.01$				

N: No apparent salt stress symptom

plants was recorded in June 1999, and was translated into low, moderate, and high salt tolerance categories as previously described.

C. Salt Tolerance Testing Using Container Grown Plants

The above field trials demonstrated that differences in salt tolerance among plant species could be detected by sprinkler irrigation. Therefore, salt tolerance was tested on an additional 18 container grown species in a simpler manner. The 18 species were 'Edward Goucher' Abelia (*Abelia grandiflora*), Redolen Acacia (*Acacia redolens*), Butterfly Bush (*Buddleia davidii*), Deodar Cedar (*Cedrus deodara*), Cornelian Cherry (*Cornus mas*), 'Rockspray' Cotoneaster (*Cotoneaster microphyllus*), Escallonia (*Escallonia rubra*), Golden Marguerite (*Euryops pectinatus*), Forsythia (*Forsythia intermedia*), Lantana (*Lantana camara*), California Holly Grape (*Mahonia pinnata*), True Myrtle *(Myrtus communis*), Tobira Pittosporum (*Pittosporum tobria*), Cape Plumbago (*Plumbago auriculata*), Carolina Laurel Cherry (*Prunus caroliniana*), Indian Hawthorn (*Rhaphiolepis indica*), Elderberry (*Sambucus nigra*), and Chinese Tallow Tree (*Sapium sebiferum*). Plants ranging from 30 cm to 60 cm tall depending on plant species were grown in 20 cm diameter by 20 cm deep plastic containers in the soil mix previously described. Plants

Plates 3 and 4. Chlorosis on leaves of Liquidambar (left) and Rose (right) irrigated with water contatining 500 mg L^{-1} salt.

were placed on 1.3 m wide and 8 m long benches in a randomized block design with three replications for each of the three salt level treatments (control, 500 mg L^{-1} and 1500 mg L^{-1} salt). Plants were irrigated with automated sprinklers on every other day. A total of 2.5 cm water was applied per irrigation. Two grams of Apex coated slow release fertilizer were applied to each plant prior to irrigation treatment. After 6 weeks of irrigation, symptoms of salt stress were recorded as percentage of leaves showing salt damage, and the index of salt tolerance (%) was determined as previously described. The salt tolerance indices were translated into the three salt tolerance categories, high, moderate and low (Table 5).

Results

A. Field and container plantings

Soil chemical characteristics

Chemical characteristics of the soil samples after 6 weeks of irrigation treatments are presented in Table 1. Electrical conductivity (EC) values for soils irrigated with potable water ranged from 0.30 to 0.63 dS m^{-1}. Soils irrigated with the low salt water (500 mg L^{-1}) had EC values ranging from 0.91 to 1.21 dS m^{-1}, a three-fold increase over the control. EC values of soils irrigated with the high salt water (1500 mg L^{-1}) ranged from 1.81 to 2.48 dS m^{-1}, a six-fold increase over the control. Soil pH values were in a narrow range from 6.50 to 7.11 with no apparent difference between the irrigation and planting treatments ($P>0.05$) (Table 1).

Chloride concentrations in soils irrigated by potable water ranged from 44 to 80 mg kg^{-1} and from 384 to 794 mg kg^{-1}in soils irrigated with low salt water. In soils irrigated with high salt water, chloride concentrations ranged from 2021 to 1356 mg kg^{-1}, a ten-fold increase over the control treatment. Overall, the soil chloride concentrations were significantly different between salt treatments ($P < 0.01$), but not significantly different between plantings (Table 1).

Soils irrigated with potable water had Na concentrations ranging from 31 to 45 mg kg^{-1}. The low salt irrigation caused an approximate five-fold increase in soil sodium, while the high salt irrigation raised soil sodium levels by a factor of 10. The container and field soils had similar sodium concentrations ($P>0.05$).

Symptoms of salt stress response

A summary of salt stress symptoms and growth of the original ten landscape plant species are presented in Table 2. After 6 weeks of sprinkler irrigation with the high salt solution (1500 mg L^{-1}) seven of the 10 species exhibited leaf chlorosis. Fifty percent or more leaves of Chinese Pistache, Liquidambar, Jasmine, Heavenly Bamboo, and Rose showed chlorosis (Plates 3 and 4), and only had 25 to 35% growth (tolerance index). Trumpet Vine and Ceanothus exhibited moderate salt damage with approximately 15 to 20% of their leaves showing chlorosis and had 70 to 90% growth. No salt stress symptoms were found in Mexican Piñon Pine, Japanese Boxwood, or Oleander (Table 2). The correlation between the salt tolerance indices represented by growth and the salt tolerance indices represented by salt stress symptoms indicated that the two sets of values were significantly positively correlated (Fig. 1).

Of the plants irrigated by sprinklers with low salt water, four species displayed moderate salt stress symptoms. Jasmine, Liquidambar, Chinese Pistache and Rose had 10 to 25% chlorosis in their leaves and had 65 to 80% growth. There was no visually detectable salt stress on the other 6 species that had over 80% growth.

Plants sprinkler irrigated with 1500 mg L^{-1} salt fell into three categories of salt stress response: (1) Both plant growth and leaf appearance of Oleander, Japanese Boxwood, and Mexican Piñon Pine were not affected by the high salt water irrigation, thus designated "salt tolerant". (2) Ceanothus and Trumpet Vine were moderately salt tolerant, and had 15 to 20% growth reduction and moderate leaf chlorosis. (3) Chinese Pistache, Liquidambar, Jasmine, Heavenly Bamboo, and Rose were the most salt sensitive plants in this study. Growth of these plant species was severely affected by sprinkler irrigation with

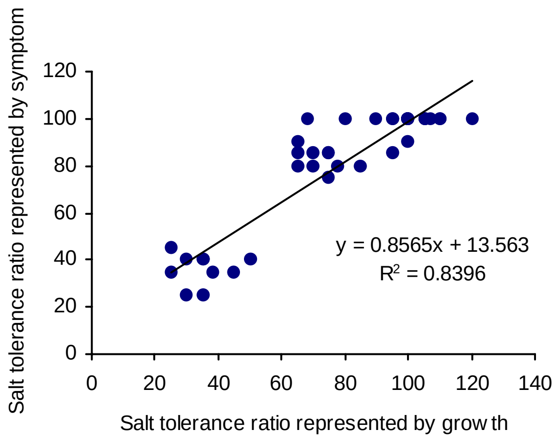

Fig.1. Joint distribution and correlation of salt tolerance (%) of landscape plants represented by growth and symptom of salt stress

1500 mg L^{-1} salt, and was slightly affected by 500 mg L^{-1} salt (Table 2).

All drip-irrigated plants appeared normal. Of those receiving 1500 mg L^{-1} salt irrigation, only Chinese Pistache and Rose developed chlorosis in fewer than 10% of their leaves. Correlations between the salt tolerance indices represented by growth and salt stress symptoms (100 minus recorded % of symptom) indicate that the two sets of values are significantly positively correlated (Fig. 1).

Of the 10 additional field planted species sprinkler-irrigated with 1500 mg L^{-1} salt, leaves of Chinese Hackberry, Silk Tree, Raywood Ash, and Ginkgo were severely damaged, and chlorosis appeared on 70% or more of their leaves. Moderate damage (10 to 30%) on leaves was found in Strawberry Tree, Goldenrain Tree, and Coast Live Oak. No salt stress damage was noticed on Dwarf Olive or California Fan Palm. Of the plants sprinkler-irrigated with 500 mg L^{-1} salt; Chinese Hackberry and Gingo had chlorosis on 50 to 60% of their leaves, Silk Tree and Raywood Ash showed moderate salt tolerance (less than 10% leaf chlorosis) and no salt stress appeared on the remaining 5 species. Salt tolerance of these plant species were summarized and placed into low, moderate, or high tolerance categories (Table 5). All drip-irrigated plants had normal growth and no symptoms of salt stress.

Chloride and sodium uptake

Leaf chloride levels for container plants irrigated with potable water ranged from 2.2 mg g^{-1} dry weight in Oleander to 8.6 mg g^{-1} dry weight in Liquidambar (Table 3). Plants irrigated with the low salt concentration (500 mg L^{-1}) had 2 to 4 times more leaf tissue chloride than the controls. Leaf chloride concentrations of plants irrigated with high salt water (1500 mg L^{-1}) were 4 to 5 times greater than those of plants irrigated with potable water. Tissue chloride concentrations of the field planting plants were similar to the container plants, and were significantly different between salt treatment and between plant species, but not significantly different between plantings (Table 3). Tissue sodium concentrations of the container plants irrigated with potable water ranged from 0.3 mg g^{-1} dry weight in Rose to 1.5 mg g^{-1} dry weight in Liquidambar. Plants irrigated with low salt water had 2 to 15 times more sodium in their leaves than the controls. Ten to 20 times more sodium was detected in leaf tissue of plants irrigated with high salt water (Table 3). Differences in plant tissue Na concentration were significant between treatment and plant species, but not significantly different between plantings (Table 3).

Seasonal soil salinity changes

Soil salinity values were at their highest for all treatments in October 1997. Soil irrigated with potable water (control) had EC values of approximately 0.5dS m^{-1}, those receiving the low salt water had EC values of approximately 1 dS m^{-1}, and soils irrigated with high salt water had 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 irrigation treatments and significant leaching by winter rains. Irrigation started again in March 1998 and by May, 1998, all soils showed some increase in salinity levels.

B. Salt tolerance testing using container grown plants

After 6 weeks of sprinkler irrigation with 1500 mg L^{-1} salt, Butterfly Bush, Elderberry, Abelia, Cornelian Cherry, California Holly Grape, Rockspray Cotoneaster, and Golden Marguerite showed severe chlorosis in over 80 to 90% of their leaves. No signs of salt stress were detected for Tobira Pittosporum, Cape Plumpago, Redolen Acacia, Deodara Cedar, Indian Hawthorn, or Chinese Tallow Tree under the same salt treatment regime. When irrigated with 500 mg L^{-1} salt, Butterfly Bush, Abelia, and Cornelian Cherry displayed salt stress in about 50% of their leaves. Elderberry, California Holly Grape, Golden Marguerite, and Rockspray Cotoneaster exhibited moderate salt stress (10-20% chlorotic leaves). The remaining species showed no sign of salt stress when irrigated with the 500 mg L^{-1} salt. A summary of the salt tolerance of these 18 species is presented in

Table 3. Chloride and sodium concentrations detected in leaf tissues of 10 landscape plant species grown either in the field or in containers after 6 weeks of sprinkler irrigation with water or one of two salt concentrations.

Plant Species	Container			Field		
	Control	Low salt	High salt	Control	Low salt	High salt
	Cl (mg g^{-1})	Cl (mg g^{-1})	Cl (mg g^{-1})	Cl (mg g^{-1})	Cl (mg g^{-1})	Cl (mg g^{-1})
Ceanothus	3.1 ± 1.0	15.1 ± 3.0	14.3 ± 2.0	3.0 ± 0.7	17.6 ± 3.5	13.6 ± 1.5
Chinese Pistache	6.6 ± 0.4	16.2 ± 2.8	35.3 ± 2.5	7.4 ± 1.4	16.5 ± 2.0	40.3 ± 2.0
Japanese Boxwood	4.4 ± 1.2	7.3 ± 1.2	16.5 ± 2.1	4.7 ± 1.6	6.4 ± 1.2	15.3 ± 2.5
Jasmine	5.7 ± 1.8	19.5 ± 2.4	47.8 ± 2.7	4.0 ± 0.5	18.3 ± 3.2	46.7 ± 2.7
Liquidambar	8.5 ± 1.5	32.0 ± 3.0	43.6 ± 2.5	11.0 ± 1.2	30.0 ± 4.1	44.3 ± 4.0
Mexican Pinon Pine	2.4 ± 0.3	6.3 ± 1.0	9.0 ± 1.7	1.9 ± 0.3	10.5 ± 2.1	12.9 ± 2.9
Heavenly Bamboo	8.6 ± 1.5	16.4 ± 2.5	31.5 ± 1.3	6.5 ± 1.4	8.0 ± 2.4	16.0 ± 0.5
Oleander	2.2 ± 0.3	3.6 ± 1.5	8.5 ± 2.5	1.9 ± 0.3	3.9 ± 1.0	8.7 ± 4.5
Rose	7.4 ± 0.8	22.6 ± 4.6	40.5 ± 4.9	6.1 ± 0.4	19.0 ± 1.5	40.9 ± 6.9
Trumpet Vine	6.0 ± 1.0	18.4 ± 4.5	34.8 ± 2.2	7.4 ± 0.9	19.0 ± 2.0	34.7 ± 5.9
ANOVA						
Between plant species	F = 6.97	P < 0.001				
Between treatment	F = 6.36	P < 0.001				
Between planting	F = 0.82	P > 0.05				
	Na (mg g^{-1})	Na (mg $^{-1}$)	Na (mg g^{-1})	Na (mg g^{-1})	Na (mg g^{-1})	Na (mg g^{-1})
Ceanothus	0.4 ± 0.5	5.7 ± 1.5	13.7 ± 2.4	0.8 ± 0.5	5.5 ± 2.1	14.2 ± 1.2
Chinese Pistache	0.8 ± 0.2	5.1 ± 0.6	12.7 ± 0.3	0.6 ± 0.7	6.2 ± 1.5	17.0 ± 2.5
Japanese Boxwood	0.8 ± 0.1	4.0 ± 0.8	9.1 ± 0.0	0.4 ± 0.0	5.6 ± 1.1	9.3 ± 2.5
Jasmine	0.5 ± 0.0	12.3 ± 3.0	23.9 ± 2.4	0.3 ± 0.0	9.3 ± 2.5	22.6 ± 2.9
Liquidambar	1.5 ± 0.4	7.5 ± 2.3	16.5 ± 0.8	0.6 ± 0.3	6.5 ± 2.4	16.8 ± 1.1
Mexican Pinon Pine	0.6 ± 0.0	1.1 ± 0.5	4.0 ± 0.9	1.3 ± 0.3	2.0 ± 0.0	6.3 ± 7.9
Heavenly Bamboo	0.8 ± 0.0	3.5 ± 1.1	10.4 ± 1.4	0.6 ± 0.0	2.2 ± 1.2	6.6 ± 0.9
Oleander	1.4 ± 0.1	2.0 ± 0.7	6.2 ± 0.7	0.3 ± 0.0	3.0 ± 1.3	7.7 ± 4.6
Rose	0.3 ± 0.0	7.3 ± 3.2	19.3 ± 3.6	0.4 ± 0.1	7.8 ± 1.5	20.5 ± 3.8
Trumpet Vine	0.5 ± 0.4	11.0 ± 2.3	21.2 ± 1.4	0.6 ± 0.8	9.3 ± 1.4	15.6 ± 4.5
ANOVA						
Between plant species	F = 3.43	P < 0.001				
Between treatment	F = 3.43	P < 0.001				
Between plantings	F = 0.00	P > 0.05				

Table 5 along with the other 20 species and the California native grasses.

Discussion

Most recycled water irrigation studies have been conducted on agricultural crop plants (Bernstein and Francois, 1973; Day and Kirkpatrick, 1973; Pettygrove and Asano, 1984; Maas, 1985; Pepper and Mancino, 1994). Limited information is available about the response of landscape plants to recycled water. Among species and varieties of crop plants, there is considerable variation in salt tolerance (Francois and Mass, 1993; Maas, 1990). It is possible to select crops whose yields are only slightly affected by a particular level of salinity. An EC value of 10 dS m^{-1} appears to be the maximum tolerated by crops without suffering a loss in yield. Unlike the monoculture of agricultural crops, most landscape plantings include a variety of different plant species with different abilities to tolerate salt in irrigation water.

Most recycled waters contain less salt than the lower concentration (500 mg L^{-1}) used in this study. Plant response under these experimental conditions should be indicative of plant salt tolerance in the landscape. Although, in this study, salinity levels of soils irrigated by a drip system with salt laden waters were significantly higher than the soils irrigated by potable water, there were no detectable effects on plant growth or salt stress symptoms. This suggests that the soil salinity was not sufficient to cause salt damage to the plants. In addition, the seasonal fluctuation in soil salt concentration may prevent soil salinity from building up to damaging levels.

Salinity-induced growth reduction, in many cases, affects shoots more severely than roots (Munns and Termaat, 1968; Blits and Gallagher, 1990). Crop pants are more severely injured by saline water applied by sprinkler than by drip systems (Bernstin and Francois, 1975; Francois and Clark, 1979; Mass and Francois, 1982; Westcot and Ayers, 1984). Drip irrigation using recycled water was acceptable for nearly all the plant species used in this study. However, sprinkler irrigation is used for most California landscape settings, because it is lower maintenance and less vulnerable to traffic. Performance of landscape plants is judged by their physical appearance rather than their yield. Therefore, salt tolerance to leaf spread is a critical trait for selecting landscape plants for recycled water irrigation. In woody tree plants, injury to leaves can be minimized by sprinkler irrigation under the canopy. However, severe damage of lower leaves can occur even with under-canopy sprinkler irrigation. Very little information can be found in the literature regarding the relationship of salt tolerance for roots and shoots. Ashraf *et al*. (1986) found no correlation between salt tolerance tested on roots and tested on leaves in grass species. In this study, for the selected woody landscape plants, we used higher salt concentrations and found that there was a good positive correlation between salt tolerance tested by drip irrigation and by sprinkler irrigation (Wu *et al*., 2001). This study revealed that large differences in salt tolerance exist among landscape plant species under sprinkler irrigation. Nevertheless, salt tolerance of any given plant species may vary considerably with climate, irrigation management, genetic variation among varieties, soil texture and structure, and soil fertility (Maas, 1990). However, differences in tolerance to salt spray among the plant species tested were very clear. This study suggests that screening of landscape plant species for recycled water irrigation can be achieved in a simple and rapid fashion. A salt tolerance reference list for recycled water irrigation management for the 38 plant species and 10 California native grasses is presented in Table 5.

Literature Cited

Ashraf, M., T. McNeilly and A.D. Bradshaw. 1986. Tolerance of *Holcus lanatus* and *Agrostis stolonifera* to sodium chloride in soil solution and saline spray. Plant and Soil. 96:1, 77-84.

Bernstein, L. and L. E. Francois. 1973. Comparison of drip, furrow, and sprinkler irrigation. Soil Sci. 115: 73-86.

Bernstien, L. and L. E. Francois. 1975. Effects of frequency of sprinkling with saline waters compared with daily drip irrigation, Agron. J. 67:185-190.

Blits, K. C. and Gallagher, J. L. 1990. Salinity tolerance of *Kosteletzkya virginica*. 1. Shoot growth, ion and water relations, Plant Cell Environ. 13:409-418.

Day, A. D. and R. M. Kirkpatrick. 1973. Effects of treated municipal wastewater on oat forage and grain. J. Environ. Qual. 2:282-289.

Francois, L. E. and R. A. Clark. 1979. Accumulation of sodium and chloride in leaves of sprinkler irrigatied grapes, J. Am. Soc. Hort. Sci. 104:11-13.

Francois L. E., and E. V. Maas.1993. Crop response and management on salt-affected soils. In Mohmmad Pessarakli ed., Handbook of Plant and Crop Stress. Marcel Dekker, Inc., New York, NY, pp.149-181.

Hays, A. R., C. F. Mancino, and I. L. Pepper. 1990. Irrigation of turfgrass with secondary sewage effluents. 1. Soil and leachate quality, Agron. J. 82:939-943.

Maas E. V. 1990. Crop salt tolerance, In Agricultural Salinity Assessment and Management. K. K. Tanji (ed.). ASCE Manuals and Reports on Engineering Practice No. 71, 262 pp. New York.

Maas, E. V. and L. E. Francois. 1982. Sprinkler-induced foliar injury to pepper plants: Effects of irrigation frequency, duration and water composition, Irrig. Sci. 3:101-109.

Maas, E.V. 1985. Crop tolerance to saline sprinkling waters, Plant Soil, 89:273-284.

Munns, R. and A. Termaat. 1986. Whole-plant response to salinity, Aust. J. Plant. Physiol. 13:143-160.

Pepper, L., and C. F. Mancino. 1994. Irrigation of turf with effluent water. In Handbook of Plant and Crop Stress, M. Pessarakli, ed. Marcel Dekker, New York.

Pettygrove G. S., and T. Asano, 1984. Irrigation With Reclaimed Municipal Wastewater A Guidance Manual, G. S. Pettygrove, and T. Asano (ed.). California State Water Resources Control Board, Sacramento, CA.

Westcot D. W., and R. S. Ayers. 1984. Irrigation water quality criteria. In Irrigation With Reclaimed Municipal Wastewater A Guidance Manual. Ed. by G. Stuart Pettygrove, and Takashi Asano. pp. 3-1 to 3-37. California State Water Resources Control Board, Sacramento, CA.

PART II

Studies of Salt Stress Response and Root Depth Potential of California Native Grass Species For Recycled Water Irrigation

Introduction

In California, there are 478 species of grasses, 303 of which are native and 175 which have been introduced (Crampton, 1974). Two thirds of these species are perennial. Perennial grasses are of two kinds, bunchgrasses and sod forming grasses. Sod forming grasses are used mainly for turf, groundcover, or for erosion control. In the landscape and garden, bunchgrasses are preferred for ornamental purposes and/or for creating buffer zones between landscapes and watersheds. California perennial bunchgrass species occur in a wide range of geographic habitats ranging from the humid Coast Range to the Central Valley to high elevations in the Sierra Nevada Mountains to the Mohave Desert. Therefore, substantial differences in response to salt and salinity stress among them are expected. Less than twenty California

Plate 5. Soil column set-up for the California native grass root depth potential and salt stress response studies.

native perennial bunchgrass species are considered to be good candidates for landscape and garden use.

In California, the competition and cost for increasingly limited water resources has forced the use of recycled water for landscape irrigation, particularly in urban areas. The chemical properties of reclaimed or recycled water vary greatly among different water treatment facilities. However, the major chemical compound remaining in the water after treatment that is potentially detrimental to plants is sodium chloride. For example, the chemical characteristics of the reclaimed water reported by Marin County Water District (MMWD) and the City San Jose from 1993 to 1995 indicated that the principal chemical compound found in concentrations potentially detrimental to landscape plants was sodium chloride. The average sodium (Na) concentrations ranged from 155 mg L^{-1} to 225 mg L^{-1}, and the average chloride (Cl) concentrations ranged from 175 mg L^{-1} to 319 mg L^{-1}. Other elements, such as boron, cadmium, and magnesium were not exceptionally high. Therefore, for this study, sodium chloride was the target chemical compound to be tested. The salt levels commonly encountered in recycled water are too low to induce salt stress on the root systems of many grasses which can tolerate up to 5000 mg L^{-1} of salt (Rogers *et al.*, 1996; Marcum, 1999). However, plants are more sensitive to salt spray on leaves than exposure of roots to salt solutions (Bernstein and Francois, 1973, 1975). Therefore, for the present study, salt concentrations slightly above those found in recycled waters were considered.

Salinization of soil and water usually occurs in areas with arid and semiarid climates such as the Central Valley and most parts of southern California. In addition, salts in coastal regions are transported by groundwater, precipitation, and aerial spray. Therefore, elevated salt levels in the environment have been a widespread problem in California landscapes. Furthermore, the morphology, phenology, growth habit, and management of grasses are, generally, quite different from most landscape plants, and their response to salt stress may also be different. In this project, we tested California native grass species potentially suitable for California landscapes and gardens. Information generated from this project may be useful for managing California native grasses in landscapes and gardens where recycled water may be used and/or in areas where elevated salt and salinity concentrations exist in irrigation waters.

Two experiments were conducted: (1) testing the response of grass species to sprinkler irrigation with salt concentrations slightly above those found in recycled waters, and (2) measuring the effects of salt treatment on root depth potential. The first experiment was completed and the results are presented here. In order to obtain results of the full potential of root growth a complete life cycle is required. Therefore, the second experiment will be finalized by the end of September 2001, and the results will be summarized and submitted for publication by the end of 2001.

Materials and Methods

A. Salt tolerance testing

Eight native grass species and four ecotypes including *Bromus carinatus* (California Brome), *Deschampsia caespitosa* (California Hairgrass), *Deschampsia elongata* (Slender Hairgrass), *Elymus glaucus* (Anderson valley ecotype), *Elymus glaucus* (Blue Wildrye, coast range ecotype), *Elymus glaucus* (Stainslaus, 2000 ft elevation), *Elymus glaucus* (Stainslaus, 5000 ft. elevation), *Festuca californica* (California Fescue), *Melica californica* (California Melic), and *Poa scabrella* (Pine Bluegrass) were established from seeds (100 seeds per pot) in sand culture in pots (20 cm diameter and 20 cm deep). Irrigation and salt treatment started in the fifth week after the seeds were planted. Three salt (NaCl) levels of irrigation waters, control (potable water), low salt concentration (500 mg salt L^{-1}), and high salt concentration (1500 mg salt L^{-1}), were used for this study. The average Na concentration in recycled water reported by the MMWD was approximately 225 mg L^{-1} and Cl concentration was approximately 320 mg L^{-1}. The 500 mg salt L^{-1} supplied about 200 mg L^{-1} Na and 300 mg L^{-1} Cl, thus approximating the

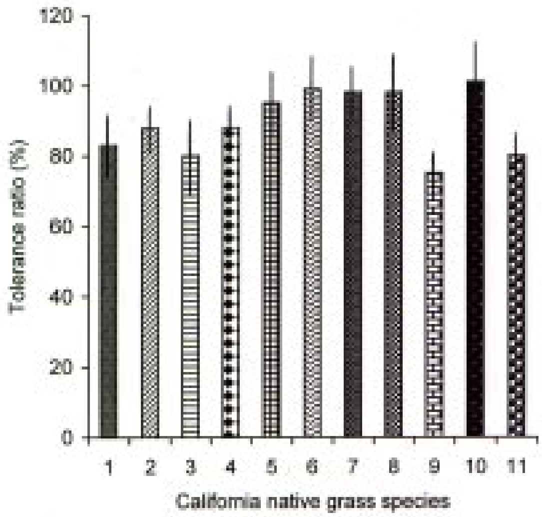

Fig. 2. Salt Tolerance ratios of 8 California native grass species and 4 ecotypes after received 12 weeks of sprinkler irrigation with 500 mg L^{-1} NaCl. Patterns represent: California Brome ( ), California Hairgrass ( ), Slender Hairgrass ( ), Blue Wildrye (Anderson valley) ( ), Blue Wildrye (costal range) ( ), Blue Wildrey (Stanislaus 2000 ft) ( ), Blue Wuldrey (Stanislaus 5000 ft) ( ), California Fescue ( ), California Melic ( ), Deergrass ( ), Pine Bluegrass ( ).

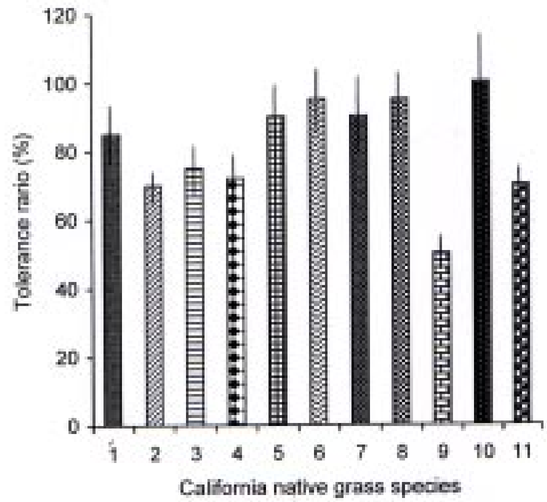

Fig. 3. Salt tolerance ratios of 8 California native grass species and 4 ecotypes after received12 weeks of sprinkler irrigation with 1500 mg L^{-1} NaCl. Patterns represent: California Brome ( ), California Hairgrass ( ), Slender Hairgrass ( ), Blue Wildrye (Anderson valley) ( ), Blue Wildrye (costal range) ( ), Blue Wildrey (Stanislaus 2000 ft) ( ), Blue Wuldrey (Stanislaus 5000 ft) ( ), California Fescue ( ), California Melic ( ), Deergrass ( ), Pine Bluegrass ( ).

highest Na and Cl concentrations found in recycled waters. In order to establish a treatment that will induce a relatively higher salt stress, 1500 mg L^{-1} salt was chosen for the high salt concentration treatment. This salt concentration provides 600 mg L^{-1} Na and 900 mg L^{-1} Cl. Each salt concentration treatment was replicated three times. The plants were irrigated every other day and 2.5 cm water were applied by a sprinkler system at each irrigation. Two grams of slow release Apex Polyon Coated Fertilizer (21-5-6) were applied per pot. After 12 weeks of growth and salt treatment, plant tissue above the soil level was harvested. Fresh leaves were briefly rinsed with distilled water (about 30 seconds) and dried in a drying oven for 72 hours. Leaf tissue was 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 spectroscopy.

B. Effects of salt stress on root depth potential

Grasses have fibrous root systems and tend to grow downward. Root depth of a grass species determines such management decisions as frequency and intensity of irrigation. Different species of California native grasses may have inherited differences in root depths. Therefore, the potential depth of root distribution for each of the grass species will be measured. Soil and water salinity may affect dry weight distribution in roots, shoots and leaves differently among species (Philipp, 1988). The effects of salt and salinity stress on root dry weight distribution along the soil profile and root/shoot dry weight partitioning will be measured, because these factors may affect irrigation management strategies. Plants irrigated with overhead sprinklers are subject to injury not only from salts in the soil but also from salts absorbed directly by the wetted leaves (Gornat *et al.*, 1973). For landscape plant species, the application of saline water with sprinkler irrigation was found to be a feasible method for screening salt tolerant plants (Wu, *et al.*, 2001). For the present study, sprinkler irrigation was used.

Six species of bunch type perennial California native grasses that have been grown in California landscapes and gardens were chosen for this study. The six species were *Deschampsia caespitosa* (California Hairgrass), *Festuca californica* (California fescue), *Melica californica* (California Melic), *Muhlenbergia rigens* (Deergrass), *Sporobolus airoides* (Alkali Sacaton), and *Stipa pulchra* (Purple Needlegrass). The plants were established from vegetative tillers taken from two year old field established plants. Grass tillers (10 to

15 tillers) of comparable size within a species were collected from three or more individual plants and were transplanted to plastic pots (15 cm diameter and 20 cm deep) containing sand for initial establishment. The plants were kept in a greenhouse and irrigated three times a week with quarter strength Hoagland nutrient solution (Hoagland and Arnon, 1950). After 8 weeks of initial establishment, in the first week of January 2001, the plants were transplanted to plastic columns 15 cm diameter and 115 cm deep (Plate 5.) The plastic columns were filled with sand up to the top. Two grams of slow release Apex Polyon Coated Fertilizer (21-5-6) were applied to each column. The plants were grown under a regime of 21^{o}C day and 18^{o}C night under natural sunlight with extended light for 15 h day length. Irrigation and salt treatment started right after transplant. The experimental design and salt concentration treatments were identical to those previously described.

Results and Discussion

The results of irrigation and salt tolerance testing on eight grass species and four ecotypes are presented in Figures 2 and 3. Of the plants irrigated with 500 mg L^{-1} salt, 7 species and 4 ecotypes of *Elymus glaucus* had tolerance ratios ranging from 80% to over 100 %, and California Melic had a tolerance ratio of 75%. When irrigated with 1500 mg L^{-1} salt, the tolerance ratio of California Melic was reduced to about 50%. The tolerance ratios of California Hairgrass, Pine Bluegrass, and Slender Hairgrass ranged from 70 to 75% under the 1500 mg L^{-1} salt irrigation regime, and the remaining 4 species had tolerance ratios over 85%. Ecotype differences in salinity tolerance within a grass species have been reported (Wu, 1981; Chetelat and Wu, 1986; Wang and Nobel, 1996), but the four ecotypes of Blue Wildrye that came from quite distinct habitats had similar salt tolerance ratios. Most salt tolerance studies on grasses have involved treating the plants with salt at the root environment and have found that most grasses are not affected by up to 100 mM NaCl (5000 mg L^{-1}) (Rogers, 1996; Marcum, 1999). The salt levels used for this study were only 10 and 25 mM, but they were sufficient to induce salt stress in the plants. This result suggests that when grasses are subjected to salt exposure on leaves from overhead sprinkler irrigation differences in salt stress sensitivity can be detected. Chlorosis induced by salt stress appeared on leaves of California Melic and California Hairgrass (Plates 6 and 7). For landscape management, acceptable salt concentrations in irrigation water are much lower than those considered acceptable for agricultural crop irrigation.

Plates 6 and 7. Leaf chlorosis on California Melic (Melica californica) and California Hairgrass (Deschampsia caespitosa) after sprinkler irrigation with 500 mg L^{-1} salt.

Salinity-induced growth reduction, in many cases, affects shoots more severely than roots (Munns and Termaat, 1986; Blits and Gallagher, 1990). Crop pants are more severely injured by saline water applied by sprinklers than by drip systems (Bernstein and Francois, 1975; Francois and Clark, 1979; Mass and Francois, 1982; Westcot and Ayers, 1984). Drip irrigation using recycled water may be acceptable for most native grass species. However, sprinkler irrigation is used for most California landscape settings, because it is lower maintenance and less vulnerable to traffic. Therefore, salt tolerance to leaf spread is a critical trait for selecting grasses for landscape irrigation. Nevertheless, salt tolerance of any given plant species may vary considerably with climate, irrigation management, genetic variation among varieties, soil texture and structure, and soil fertility (Maas, 1990). However, differences of tolerance to salt spray among the grass species tested were very clear. This study suggests that screening of California native grass species for recycled water irrigation can be achieved in a simple and rapid fashion.

Leaf tissue Na and Cl concentrations are presented in Table 4. Plants irrigated with 1500 mg salt L^{-1} had Na concentrations ranging from 2515 (in deergrass) to 6346 (in Pine Bluegrass) mg kg^{-1} dry weight which is about 3 times greater than the tissue Na concentrations detected for the plants irrigated by 500 mg salt L^{-1} and is about 15 times greater than the concentrations detected for the

Table 4. Sodium and chloride concentration in plant tissue of eleven California native grass species and ecotypes after twelve weeks of sprinkler irrigation with three salt concentrations.

Grass species	Salt treatment (mg L^{-1})	Tissue Na (mg kg^{-1})	Tissue Cl (mg kg^{-1})
Bromus carinatus (California Brome)	Potable water	233 ± 21	711 ± 33
Deschampsia caespitosa (California Hairgrass)	Potable water	166 ± 18	446 ± 59
Deschampisa elongata (Slender Hairgrass)	Potable water	240 ± 15	546 ± 44
Elymus glaucus (Blue Wildrye), Anderson Valley	Potable water	110 ± 10	348 ± 50
Elymus glaucus (Blue Wildrye), Berkeley (Coast Range)	Potable water	120 ± 9	330 ± 62
Elymus glaucus (Blue Wildrye) Stanislaus (2000 ft elev)	Potable water	131 ± 14	393 ± 75
Elymus glaucus (Blue Wildrye) Stanislaus (5000 ft elev)	Potable water	100 ± 9	306 ± 51
Festuca californica (California Fescue)	Potable water	106 ± 16	346 ± 35
Melica californica (California Melic)	Potable water	100 ± 8	236 ± 27
Muhlenbergia rigens (Deergrass)	Potable water	100 ± 8	299 ± 36
Poa scabrella (Pine Bluegrass)	Potable water	250 ± 26	762 ± 47
Bromus carinatus (California Brome)	500	1729 ± 200	5189 ± 204
Deschampsia caespitosa (California Hairgrass)	500	2100 ± 120	5802 ± 162
Deschampsia elongata (Slender Hairgrass)	500	1744 ± 180	5233 ± 238
Elymus glaucus (Blue Wildrye), Anderson Valley	500	1167 ± 110	3503 ± 150
Elymus glaucus (Blue Wildrye), Berkeley (Coast Range)	500	1540 ± 100	3129 ± 219
Elymus glaucus (Blue Wildrye) Stanislaus (2000 ft elev)	500	1246 ± 120	3738 ± 206
Elymus glaucus (Blue Wildrye) Stanislaus (5000 ft elev)	500	1033 ± 120	3097 ± 144
Festuca californica (California Fescue)	500	1526 ± 154	4585 ± 180
Melica californica (California Melic)	500	1848 ± 120	4344 ± 189
Muhlenbergia rigens (Deergrass)	500	1560 ± 180	3488 ± 250
Poa scabrella (Pine Bluegrass)	500	2203 ± 201	6610 ± 200
Bromus carinatus (California Brome)	1500	3846 ± 250	14539 ± 952
Deschampsia caespitosa (California Hairgrass)	1500	4993 ± 480	14980 ± 793
Deschampsia elongata (Slender Hairgrass)	1500	5203 ± 500	15609 ± 8228
Elymus glaucus (Blue Wildrye), Anderson Valley	1500	4500 ± 280	11316 ± 827
Elymus glaucus (Blue Wildrye), Berkeley (Coast Range)	1500	2900 ± 390	10833 ± 973
Elymus glaucus (Blue Wildrye) Stanislaus (2000 ft elev)	1500	3398 ± 260	10195 ± 8596
Elymus glaucus (Blue Wildrye) Stanislaus (5000 ft elev)	1500	3868 ± 250	11606 ± 420
Festuca californica (California Fescue)	1500	3046 ± 270	10038 ± 752
Melica californica (California Melic)	1500	4829 ± 300	15488 ± 830
Muhlenbergia rigens (Deergrass)	1500	2515 ± 360	9390 ± 711
Poa scabrella (Pine Bluegrass)	1500	6346 ± 540	14145 ± 913

plants irrigated by potable water. Salinity tolerance of some turfgrass species, tested at the root environment, was found to be associated with an exclusion mechanism in which the tolerant plants tend to exclude Na and Cl from being taken up and transported to the shoots (Greenway and Munns, 1980; Gorham *et al*., 1986; Marcum and Murdoch, 1990; Marcum, 1999; Wu and Lin, 1994). The present study indicates that among the eight native grass species a salt exclusion mechanism is involved. For example, Deergrass and Blue Wildrye were the most salt tolerant and had the smallest tissue Na and Cl concentrations. California Hairgrass and Pine Bluegrass were the least salt tolerant and had the highest tissue Na and Cl concentrations.

The last part of this research project on root depth potential is still in progress, and it will be completed at the end of September 2001. It will be written for publication by the end of 2001. Nevertheless, among the 6 species, salt stress symptoms were apparent, and found on California Melic irrigated by both 500 and 1500 mg L^{-1} salt and on California Hairgrass irrigated by 1500 mg L^{-1} salt. The rest of the four species showed no salt stress response. The results of salt stress response of the ten California native grass species were added to the final landscape reference list (Table 5).

Literature Cited

Bernstein, L. and L. E. Francois. 1973. Comparison of drip, furrow, and sprinkler irrigation. Soil Sci.115: 73-86.

Bernstien, L. and L. E. Francois. 1975. Effects of frequency of sprinkling with saline waters compared with daily drip irrigation, Agron. J. 67:185-190.

Blits, K. C. and J. L. Gallagher, 1990. Salinity tolerance of *Kosteletzkya virginica*. 1. Shoot growth, ion and water relations, Plant Cell Environ.13: 409-418.

Chetelat, R., and L. Wu. 1986. Contrasting response to salt stress of two salinity tolerant creeping grass clones. Journal of Plant Nutrition, 9: 1185-1197.

Crampton, B. 1974. Grasses in California. University of California Press, Berkeley, Los Angeles, London.

Francois, L. E. and R. A. Clark. 1979. Accumulation of sodium and chloride in leaves of sprinkler irrigated grapes, J. Am. Soc. Hort. Sci. 104:11-13.

Gorham, J., E. Budrewicz, E. McDonnell, and R.G. Wyn Jones. 1986. Salt tolerance in the Triticaceae. J. Exp. Bot. 37:1114-1128.

Gornat, B., D. Goldberg, R. Rimon, and J. Ben-Asher. 1973. The physiological effect of water quality and method of application on tomato, cucumber, and pepper. J. Am. Soc. Hort. Sci., 98: 202-205.

Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Annual Review of Plant Physiology 31:149-190.

Hoagland, D.R., and D.I. Arnon. 1950. The water-culture method for growing plants without soil. California Agric. Exp. Stn. Circular 347.

Maas, E. V. 1990. Crop salt tolerance, In Agricultural Salinity Assessment and Management. K. K. Tanji (ed.). ASCE Manuals and Reports on Engineering Practice No. 71, 262 pp., New York.

Maas, E. V. and L. E. Francois. 1982. Sprinkler-induced foliar injury to pepper plants: Effects of irrigation frequency, duration and water composition, Irrig. Sci. 3:101-109.

Maas, E.V., and C.M. Grieve, 1987. Sodium-induced calcium deficiency in salt-stressed corn, Plant Cell Environment, 10: 559-564.

Marcum, K.B. and C.L. Murdoch. 1990. Growth responses, ion relations, and osmotic adaptations of eleven C4 turfgrasses to salinity. Agron. J. 85:892-896.

Marcum, K.B. 1999. Salinity tolerance mechanism of grasses in the subfamily Chloridoidese. Crop Sci. 39:1153-1160.

Munns, R. and A. Termaat. 1986. Whole-plant response to salinity, Aust. J. Plant. Physiol. 13:143-160.

Philipp, K.R. 1988. Water and salt budgets of selected halophytes. Dissertation, University of Delaware, Lewes.

Rogers, M.E., C.L. Noble and R.J. Pederick.1996. Identifying suitable grass species for saline areas. Australian J. Exp. Agri. 36:197-202.

Wang, X.Y., C.G. Suhayda and Redmann. 1992. Identification of physiological ecotypes in *Hordium jubatum* based on responses to salinity stress. Canadian Journal of Botany, 70:1123-1130.

Westcot D. W., and R. S. Ayers. 1984. Irrigation water quality criteria. In Irrigation With Reclaimed Municipal Wastewater A Guidance Manual. Ed. by G. Stuart Pettygrove, and Takashi Asano. p.3-1- 3-37. California State Water Resources Control Board, Sacramento,CA.

Wu, L. and H. Lin. 1994. Salt tolerance and salt uptake in diploid and polyploid Buffalograss (*Buchloe dactyloides*). Plant Nutrition, 17:1905 – 1928.

Wu, L. 1981. The potential for evolution of salinity tolerance in *Agrostis stolonifera* L. and *Agrostis tenuis* Sibth. New Phytol. 89:471-486.

Wu L., X. Guo and A. Harivandi. 2001. Salt tolerance and salt accumulation of landscape plants irrigated by sprinkler. Journal of Plant Nutrition. 24: (in press).

PART III

Conclusions

Field trials tested salt tolerance of landscape plants for recycled water irrigation. Salt (NaCl) concentration levels used for this study were slightly above those found in recycled waters. Thirty-eight landscape woody plant species and ten California native grass species exhibited substantial differences in salt tolerance when the salt-laden waters were applied by overhead sprinklers. Plants were more susceptible to salt stress by sprinkler irrigation than by drip irrigation. Twelve (31%) of the 38 woody plant species and 5 (50%) of the 10 native grass species were salt tolerant when they were irrigated with 1500 mg L^{-1} salt and 21 (55%) woody species and 7 (70%) native grass species were salt tolerant when irrigated with 500 mg L^{-1} salt. This study suggests that testing salt tolerance of landscape plants for recycled water irrigation can be simple and rapid. No salt stress symptoms were detected on plants irrigated by drip irrigation either with 500 mg L^{-1} or 1500 mg L^{-1} salt. Drip irrigation is acceptable for most landscape plants in California. A salt tolerance reference list of 38 woody landscape plant species and 10 California native grass species was developed (Table 5), and is useful for both landscape and nursery irrigation management. Seasonal fluctuation in soil EC (electrical conductivity), highest in the fall and lowest in the spring, may prevent soil salinity build up to damaging levels.

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Table 5. Reference list of salt tolerance of 38 landscape woody plant species and 10 California native grass species grown under sprinkler irrigation with two salt (NaCl) concentrations.

Plant species	Sprinkler irrigation with 1500 $mg \cdot L^{-1}$ salt	Sprinkler irrigation with 500 $mg \cdot L^{-1}$ salt
Woody landscape plants		
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 (Janpanese Boxwood)	HIGH	HIGH
Ceanothus thrysiforus (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' (Cotoneaster)	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)	MODERATE	HIGH
Juniperus virginiana 'Skyrocket' (Juniper)	HIGH	HIGH
Koelreuteria paniculata (Goldenrain Tree)	LOW	MODERATE
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 Pinon Pine)	HIGH	HIGH
Pistacia chinesis (Chinese Pistache)	LOW	LOW
Pittosporum tobria (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
California native grasses		
Bomus carinatus (California Brome)	MODERATE	HIGH
Deschampsia caespitosa (California Hairgrass)	LOW	MODERATE
Deschampsia elongata (Slender Hairgrass)	MODERATE	HIGH
Elymus glaucus (Blue Wildrye)	HIGH	HIGH
Festuca californica (California fescue)	HIGH	HIGH
Melica californica (California Melic)	LOW	LOW
Muhlenbergia rigens (Deergrass)	HIGH	HIGH
Poa scabrelld (Pine Bluegrass)	LOW	MODERATE
Sporobolus airodies (Alkali Sacaton)	HIGH	HIGH
Stipa pulchra (Purple Needlegrass)	HIGH	HIGH