Fig. 1. Local residents help with transplanting of landscape plants in the demonstration garden.

Studies of Recycled Water Irrigation and Performance of Landscape Plants under Urban Landscape Conditions

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Introduction

The objective of this cooperative project with the City of San Jose is to establish a field demonstration garden for the public and landscape industry with irrigation supplied by recycled water. The choice of plant material and watering regime is based on previous landscape screening studies conducted at UC, Davis, and partially funded by the Slosson Endowment.

Recycled water has been recommended for crop irrigation (Asano, 1981; Asano et al., 1984). It is also strongly recommended for landscape irrigation in California. The term "recycled water" refers to water that has been previously used and suffered a loss in quality but has been treated to a point where it is suitable for additional use. The first wastewater treatment plant used solely for recycling water was built in San Francisco in 1932. Today, wastewater is recycled at over 300 locations throughout California and used for agricultural and landscape irrigation, ground water recharge, and industrial applications. The California Water Resources Board estimates that by the year 2010, landscape irrigation will be the second largest use of recycled water after ground water recharge. Information about the tolerance of landscape plants to irrigation by recycled water is needed before such methods can be widely used in California landscapes (Wu *et al*. 1995, 1996). After most water treatment processes, sodium chloride is the only chemical compound remaining in recycled water that can be potentially detrimental to landscape plants (Day and Kirkpatrick, 1973; Hayes *et al*., 1990; Harivandi, 1991; Pepper and Mancino, 1994). Other elements such as boron, selenium, magnesium, and cadmium are rarely found to be above safe levels.

A reference list of the salt tolerance of 38 landscape plant species was developed as a result of Slosson-sponsored research (Wu *et al*., 1999). Substantial differences in salt tolerance were found among the 38 landscape plant species studied. Plants were more susceptible to salt stress by sprinkler irrigation than by drip irrigation due to direct contact of salt on the leaves. No apparent salt stress symptom was detected when the plants were irrigated by drip irrigation at the designated salt concentration. Therefore, drip irrigation may be acceptable for most landscape plants in California. Nevertheless, sprinkler irrigation has been used in most California landscape settings because it has fewer maintenance problems and is less vulnerable to damage by public activities.

Considerable resistance to the use of recycled water for landscape irrigation still exists among the public and landscape maintenance industries in California because of the perceived negative impact on plants and degradation of soil conditions. Therefore, a field demonstration using recycled-water irrigation under landscape conditions was conducted as a cooperative effort between the Department of Environmental Horticulture, UC Davis and the City of San Jose. Plant performance after one year of irrigation with recycled water is presented in this report.

Materials and Methods

Study site and plant species

The recycled-water irrigation demonstration garden, about 150 m x 80 m, is located on the south side of Taylor Street, at Spring Street, within Guadalupe River Park and Gardens in San Jose. About half of the designated area is covered by turfgrass. The rest of the area, designated for landscape plant installation (Fig. 1), is called the "Courtyard Garden". It had been planted with some perennials, including Japanese cherry trees, several rose varieties and shrubs. For the recycled-water irrigation project, plant species were selected from both the landscape plant list provided by

Table 1. List of landscape plant species used in the San Jose recycled-water irrigation demonstration garden

Scientific name	Common name
Baccharis pilularis	Dwarf Coyote Brush
Camellia sasanqua	Sasanqua Camellia
Campanuula carpatica	'Blue Clips' Bellflower
Camellia japonica	Camellia
Clematis armandii	Evergreen Clematis
Cymbidium grandiflorum	Terrestrial Orchid
Dicksonia antarctica	Tasmanian Tree Fern
Erigeron karvinskianus	Mexican Daisy
Festuca ovina 'Glauca'	Blue Fescue
Gazania 'Chansonette'	Hybrid Gazania
Griselinia littoralis	Griselinia
Hardenbergia comptoniana	Lilac Vine
Hypericum calycinum	Creeping St. Johnswort
Iris reticulata	Violet-scented Iris
Lavandula angustifolia	English Lavender
Liriope muscari	Blue Lily Turf
Pennisetum setaceum	Tender Purple Fountain Grass)
Philadelphus coronarius	Sweet Mock Orange
Photina fraseri	Red Tip Photinia
Pieris forrestii	Chinese Pieris
Rosa sp. 'America Tripadora'	Rose
Vaccinium ovatum	Evergreen Huckleberry
Vinca major 'Variegata'	Variegated Periwinkle
Vinca minor	Dwarf Periwinkle

Jerry Brown, Landscape Specialist for the City of San Jose, and the salt-tolerant plant list developed by Lin Wu of UC, Davis. The 24 plant species selected included woody shrubs, herbaceous monocotyledon and dicotyledon species, and ornamental grasses (Table 1). The plants were monitored during the course of the year-long study for salt stress symptoms.

An existing Heritage Rose Garden next to the demonstration garden and irrigated with potable water served as a control site.

Irrigation and recycled water supplies

Recycled water was supplied by the South Bay Water Recycling treatment facility. The salinity, pH, nitrate, phosphate, and boron concentrations of the recycled water used in the study are presented in Table 2. Sprinkler irrigation, the most common method of application in California, was used for the demonstration garden.

Plant and soil analysis

Plant tissues were analyzed for sodium and chloride. Sodium, chloride and sulfate concentrations, electrical conductivity (EC), and pH were measured for the soil samples.

Results and Discussion

The sodium and chloride concentrations in the San Jose recycled water were considerably lower than those previously reported for the recycled water of the Marin Municipal Water District (Wu *et al.*, 1999) which contained 225 mg·L^{-1} sodium and 320 mg·L^{-1} chloride (Table 2). The rest of the chemical constituents were comparable in both waters. No salt stress symptoms were observed for any of the 24 landscape plant species in the demonstration planting. Previous studies have revealed that rose is salt-sensitive, especially when irrigated by sprinklers (Wu *et al*. 1999). The roses grown in the current study, however, were healthy and had no symptoms of salt stress (Fig. 2). This result suggests that the salt levels of the recycled water were below the concentration that may cause visually detectable salt stress symptoms in the plant species used.

Sodium and chloride concentrations were measured for leaf tissues of 13 species (Table 3) randomly selected from the 24 landscape plant species that had been irrigated with recycled water for a year. The tissue sodium concentrations ranged from 423 mg·kg^{-1} in *Photina fraseri* to 7010 mg·kg^{-1} in *Erigeron faciculatum*. The tissue chloride concentrations ranged from 604 mg·kg^{-1} in *Photina fraseri* to 11571 mg·kg^{-1} in *Erigeron faciculatum*. Generally, the tissue chloride concentrations were two to three times higher than tissue sodium concentrations when presented on a dry weight basis (mg·kg^{-1}). Among the different plant species, both sodium and chloride concentrations were highly significantly different ($P<0.001$). The control sample, rose, collected from the adjacent rose garden irrigated with potable water, had a mean tissue sodium concentration of 350 mg·kg^{-1} and a chloride tissue level of 741 mg·kg^{-1}. The rose plants irrigated with recycled water had sodium and chloride concentrations 3 and 5 times greater than the control plants.

In crop plants, the response to water salinity was found to depend on the method of irrigation and the

Table 2. Analysis of the recycled water used for irrigation of the demonstration garden

Sodium	151 mg·L^{-1}
Chloride	160 mg·L^{-1}
Sulfate	123 mg·L^{-1}
Nitrate	41 mg·L^{-1}
Boron	0.54 mg·L^{-1}
Phosphate	6 mg·L^{-1}
EC	1.30 dS·m^{-1}
pH	8.0

frequency of water application (Bernstein and Francois, 1973, 1975; Goldberg and Shumeli, 1971; Maas and Francois, 1982; Maas, 1985; Ehlig and Bernstein, 1959; Francois and Clark, 1979). Crop plants irrigated with sprinkler irrigation are subject to injury not only from salts in the soil but also from salts absorbed directly through wetted leaves (Mass, 1985; Westcot and Ayers, 1984). In woody tree plants the injury of leaves can be minimized by sprinkler application under the canopy. However, even with under-canopy sprinkler irrigation, severe damage of the lower leaves can occur. Therefore, selection of salt-tolerant landscape plants for recycled-water irrigation is a viable approach for landscape management. In addition, good water management such as infrequent heavy irrigation and avoiding irrigation on hot, windy days can substantially reduce plant injury. In the present study, even though the tissue sodium and chloride concentrations were significantly higher ($P < 0.001$) than those of the control plants, no salt stress symptoms were observed. This suggests that the salt concentrations in the plants did not reach levels high enough to induce salt stress symptoms.

Table 3. Sodium and chloride concentrations detected in leaf tissues of 13 landscape plant species irrigated with recycled water for one year.

Landscape plant species	Sodium ($mg \cdot kg^{-1}$)	Chloride ($mg \cdot kg^{-1}$)
Plants irrigated with recycled water		
Baccharis pilularis (Coyote Brush)	5147 ± 76	6699 ± 60
Campanuula carpatica 'Blue Clips'	5389 ± 112	8308 ± 30
Erigeron faciculatum (Mexican Daisy)	7010 ± 30	11571 ± 26
Festuca ovina (Blue Fescue)	1663 ± 21	5516 ± 26
Gazania sp. 'Chansonette'	6555 ± 116	1124 ± 130
Hypericum calycnium (Creeping St. Johnswort)	1832 ± 21	1661 ± 50
Iris reticulata (Violet-scented Iris)	778 ± 24	1177 ± 24
Pennisetum setaceum (Purple Fountain Grass)	1875 ± 25	5161 ± 56
Philadelphus coronarius (Sweet Mock Orange)	778 ± 24	1177 ± 34
Photina fraseri (Red-tip Photinia)	423 ± 25	604 ± 30
Rosa sp. 'American Tripadora'	1108 ± 25	3616 ± 55
Vinca major 'Variegata' (Periwinkle)	2498 ± 17	7897 ± 55
Vinca minor (Dwarf Periwinkle)	2180 ± 30	5180 ± 40
Control (plants irrigated with potable water)		
Rosa sp. 'American Tripadora'	350 ± 35	741 ± 52

The soil irrigated with recycled water had significantly higher salt and sulfate concentrations than the soil irrigated with potable water (Table 4), but the soil salt concentrations did not induce salt stress symptoms in the plants. Nevertheless, long term monitoring of soil and plant salt accumulations is needed in order to predict possible effects of recycled-water irrigation on soil physical and chemical properties and performance of landscape plants.

Fig.2. Healthy blooming rose plants in the demonstration garden after one year of irrigation with recycled water.

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Table 4. Chemical characteristics of soil collected from the demonstration garden after one year of irrigation with recycled water.

	Chloride ($mg \cdot kg^{-1}$)	Sodium ($mg \cdot kg^{-1}$)	Sulfate ($mg \cdot kg^{-1}$)	pH	EC ($dS \cdot m^{-1}$)
Soil samples from the demonstration garden					
1	549	502	1700	7.6	1.7
2	626	418	7500	7.8	7.4
3	206	288	800	7.9	0.7
4	403	426	800	7.8	1.7
5	161	250	600	8.0	0.6
6	145	309	700	8.2	0.6
7	275	357	1200	8.1	1.2
Soil samples from adjacent control site					
1	107	128	700	7.6	0.7
2	120	123	900	7.6	0.9
3	86	123	500	7.7	0.4

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