Effects of Regenerant Wastewater Irrigation on Growth and Ion Uptake of Landscape Plants[1]

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Abstract

The effects of regenerant wastewater irrigation and high concentrations of Ca^{2+}, K^{+}, Mg^{2+}, and Cl^{-} on growth and ion uptake of nine species of landscape plants were studied. Significant differences in chloride tolerance were detected among the species. Generally, the species that had greater uptake of chloride grew less than species that took up less amounts of chloride. Lace fern (*Athyrium filix-femina* Roth.) had the highest tissue chlorine (Cl) concentration and was the most affected. Hydrangea (*Hydrangea macrophylla* Ser.) also had high tissue Cl concentration, but showed no growth reduction. Its tolerance was attributable to a high tissue calcium (Ca) concentration. The data suggest that in the species tested, higher tissue Ca concentrations were positively correlated with plant tolerance to Cl. Overall, the Cl^{-} concentration in the wastewater seems to be the factor most likely to create problems for the landscape plants. However, severe negative effects will probably be noticed only for very sensitive plant species, but it is important to determine this before applying regenerant irrigation water.

Index words: chloride tolerance, ion uptake, landscape plants, regenerant wastewater irrigation, tissue Ca concentration.

Species used in this study: Hydrangea (Hydrangea macrophylla Ser.), Nandina (Nandina domestica Compacta), Lace-fern (Athyrium filix-femina Roth.), Rhaphiolepis (Rhaphiolepis indica Lindl.), Hedge rose (Rosa semperirens L.), Pittosporum (Pittosporum tobira Ait.), Jasmine (Jasminum sambac Ait.), Japanese boxwood (Buxus japonica Muell. Arg.), and Azalea (Azalea formosa L.).

Significance to the Nursery Industry

In arid and semiarid regions in the United States, regenerant wastewater produced by water softeners and residences has been the greatest target for water recycling and landscape irrigation. The utilization of sodium chloride in water softeners has been prohibited by some local governments in California. The substitution of potassium chloride for sodium chloride has been proposed by both industry and local governments, and the wastewater generated by water softeners has been considered for use in landscape and home garden irrigation. So far, there has been no experimental information showing to what extent the high ion concentrations such as Ca^{2+}, K^{+}, Mg^{2+}, and Cl^{-} may affect the growth of landscape plants. This study discovered a differential ion uptake and chloride tolerance among the landscape plant species. This information is important for landscape management and the application of regenerant wastewater for landscape irrigation.

Introduction

Disposal of waste materials, including wastewater, on soil has been practiced for centuries. One of the earliest documented land disposal systems was initiated in 1531 at Bunzland, Germany, where a sewage irrigation system continued in operation for over 300 years (7). Land application of wastewater in the United States began in the early 1900s. However, interest increased in the 1970s as populations became more centralized in towns and cities. Because discharge wastes into waterways during the 1970s produced unacceptable pollutions in fresh waters of the United States, federal legislation and 'cleanup funds' for polluted waters were established, beginning with the Clean Water Act of 1972. This act proposed a 'zero discharge' of waste into waterways and encouraged a reuse and recovery philosophy.

Residential wastewater has been greatest target for water recycling. In arid and semiarid regions, wastewater produced by water softeners and residences is a major concern in wastewater disposal. In addition, it is a potentially useful water resource for landscape irrigation. Traditionally, sodium chloride has been used in water softeners for ion exchange. However, since wastewater discharged from water softeners contains high concentrations of Na (sodium) which is detrimental to both plants and soil, the utilization of sodium chloride in water softeners has been prohibited by some local governments in California. The substitution of potassium chloride (KCl) for sodium chloride (NaCl) has been proposed by both industry and local governments, and the wastewater generated by water softeners has been considered for use in turf and landscape irrigation. The ion concentrations in the wastewater produced by water softeners can be more than 30 mM for K^{+}, 100 mM for Ca^{2+} and Mg^{2+}, and 400 mM for Cl^{-} [preliminary water analysis based on 1.8 kg KCl (4 lb) regeneration rate]. These ion concentrations are also commonly found in so-called gray water produced by residences (9). So far, there has been no experimental information showing to what extent these ion concentrations affect growth of landscape plants. The objective of this study was to examine the effects of the regenerant wastewater and high concentrations of Cl^{-}, Mg^{2+}, Ca^{2+} and K^{+} on the growth and ion uptake of landscape plant species that are commonly found in California gardens.

Materials and Methods

Simulated water softener regenerant wastewater was prepared, using a mix of 2.20 g/liter KCl, 9.15 g/liter $MgCl_2$, and 11.08 g/liter $CaCl_2$ to attain a final ion concentration of 30 mM of K^{+}, 100 mM of Ca^{2+}, 100 mM of Mg^{2+}, and 420

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mM of Cl^-. It was diluted 10 times with deionized water before it was used for the irrigation studies. The diluted wastewater had the ion concentrations of Ca^{2+} 400, Mg^{2+} 243, K^+ 117, and Cl^- 1,484 mg /liter with pH 6.03 and EC 3.50 ds m^{-1}. Deionized water was used for the control treatment.

Nine landscape plant species that are commonly grown in the gardens of California were used for this study. The selected plant species were Hydrangea (*Hydrangea macrophylla* Ser.), Nandina (*Nandina domestica* Thunb.), Lace-fern (*Athyrium filix-femina* Roth.), Rhaphiolepis (*Rhaphiolepis indica* Lindl.), Hedge rose (*Rosa sempervirens* L.), Pittosporum (*Pittosporum Tobira* Ait.), Jasmine (*Jasminum sambac* Ait.), Japanese boxwood (*Buxus japonica* Muell. Arg.), and Azalea (*Azalea formosa* L.). Plants of comparable size (depending on the species ramged from 30 to 60 cm (1 to 2 ft) high) of each species were grown in equal portions of sand, peatmoss, and redwood sawdust in containers 20 cm (8 in) in diameter and 30 cm (1 ft) high. The plants were placed on a greenhouse bench in a randomized block design with each block [120 × 240 cm (4 × 8 ft)] consisting of one plant of each species. Three replications were used, and the plants were kept in a temperature-controlled greenhouse at 21C (68F) day 18C (66F) night, day length 15 h, with a minimum photon flux density of 200 quanta µmol/sq m/sec. The plants were irrigated with 0.1 concentration wastewater twice a week and once a week with 0.25 concentration modified Hoagland nutrient solution (5). A control treatment was irrigated with deionized water twice a week and once with nutrient solution. In a landscape, the plants are likely to be irrigated by sprinkler systems and expose leaves and shoot tissues to the irrigation water. Therefore, irrigattion water was applied over the leaves of the plants. Two-and-one-half cm (1 in) water were applied per irrigation. Twelve weeks after irrigation treatment initiation, plants were examined for symptoms of leaf chlorosis, leaf tissues were collected for mineral element concentration analysis, and cut back to 5 cm (2 in) from the soil surface. Identical irrigation treatments were continued for another 12 weeks. At the end of the second 12 weeks of growth, all areial plant tissues were harvested, oven dried at 60C (39F) for one week, and weighed. Growth responses to the wastewater treatment of the nine plant species are presented as tolerance ratios which are the percentage of growth under wastewater irrigation to the growth produced under the control treatment. Soil samples were collected from each pot through the whole soil profile using a 2.5 cm (1 in) diameter soil probe. The soil samples were air dried at room temperature for at least four weeks.

For plant tissue analysis, 5 ml of concentrated HNO_3 and 2.5 ml of $HClO_4$ were added to 50 mg of dry plant material in a volumetric digestion tube and allowed to digest overnight at room temperature (11). Further digestion was conducted at 150–210C (300–410F) for 1 h. The plant tissue digests were diluted with double distilled water to a final volume of 25 ml. Ca, K, and Mg were measured with a Perkin-Elmer atomic absorption spectroscope. For Cl extraction, 50 mg dry plant tissue was incubated and extracted overnight at room temperature in 10 ml 0.1 M HNO_3. Chloride was measured with a Buchler Cotlove automatic titrator (Buchler Instruments, Fort Lee, NJ). For soil-exchangeable Ca, Mg, and K measurement, the ammonium acetate extraction method was used (3). Ten grams of dried soil were extracted with 40 ml ammonium acetate. Calcium, K, and Mg were measured with an atomic absorption spectroscope and chlorine was measured with a Buchler Coltove automatic titrator.

Data were subjected to analysis of variance to test for differences between wastewater irrigation treatments and between plant species. The means were separated using Duncan's New Mulple Range Test.

Results and Discussion

Plant shoot regrowth and tolerance ratio after 12 weeks irrigation with the wastewater showed (Table 1) that five species, Azalea, Japanese boxwood, Hydrangea, Rhaphiolepis, and Jasmine, were not affected by the wastewater irrigation. Pittosporum showed a slight dry weight reduction with a tolerance ratio of 73%, but no visible symptoms were detected. Dry weight of Nandina was reduced by 75%, with a tolerance ratio of 25%. It had no apparent symptoms of any toxic effect, and its growth was normal. The growth of lace fern was severely inhibited. The plants displayed severe chlorosis and had very little regrowth after they were cut back (Table 1).

Table 1. Plant shoot regrowth and tolerance ratio represented by dry weight of the greenhouse grown landscape plant species after 10 weeks growth and irrigated with regenerant wastewater.

Plant species	Mean shoot dry weight (g) (wastewater treatment)	Mean shoot dry weight (g) (control treatment)	Tolerance ratio (%) (response to treatment)
Azalea	21.50	23.07	91a[z]
Japanese boxwood	40.33	39.15	103a
Hydrangea	51.83	52.00	100a
Lace fern	0.50	58.23	0.08e
Nadina	6.83	27.32	25d
Pittosporum	26.83	36.75	73 b
Hedge rose	51.16	88.20	58c
Rhaphiolepis	38.83	32.63	119a
Jasmine	44.66	38.84	115a
ANOVA			
Between species	***[y]	***	***

[z]Means followed by the same letter are not significantly different at P = 0.01, according to Duncan's new multiple range test.

[y]*** Significantly different at 1% level.

Table 2. **Mean values of the soil chemical characteristics of the greenhouse grown landscape plant species after 12 weeks irrigation with regenerant wastewater.**

Soil of different plant species	Mineral element concentrations (mg/g)					
	Cl	Ca	K	Mg	pH	EC (ds/m)
Regular water irrigation	0.024	0.147	0.250	0.036	6.9	6.5
Waste water irrigation	0.957	0.786	0.302	0.340	6.9	13.07
ANOVA						
Between species	NS[z]	NS	NS	NS	NS	NS
Between treatment	***	***	***	***	NS	***
Species x Treatment	NS	NS	NS	NS	NS	NS

[z]NS, *** Not significantly different, significantly different at 1% level, respectively.

For the soil irrigated with deionized water and Hoagland nutrient solution (control treatment), no significant difference was detected for the soils of the nine plant species. The average concentration of Cl was 0.024 mg/g, Ca was 0.147 mg/g, K was 0.250, and Mg was 0.036 mg/g (Table 2). The average soil pH was about 6.9 and EC (electrical conductivity) was 6.5 ds/m. The soil chemical characters of the soils irrigated with diluted wastewater had a mean Cl concentration 39.5 times those of the control treatment. Mg was10 times, Ca was 5 times, and K was about the same as the control treatment. pH was not different from the control treatment, but EC was about two times that of the control treatment.

The plant tissue analyses indicated that water significantly increased Cl uptake, and the magnitude of increase was different among the nine plant species and between wastewater irrigation treatment (Table 3). For example, the tissue Cl concentration of the Lace fern increased from 0.577 mg/g with the control treatment to 35.957 mg/g with the wastewater treatment, a 65-fold increase, but the tissue Cl concentration of the Rhaphiolepis only had a two-fold increase, from 0.623 to 1.509 mg/g. The tissue Cl concentration increases of the other 7 species by the wastewater irrigation treatment were within a range from a 4-fold increase in Jasminum to 28-fold increase in Hydrangea. For the control treatment, the tissue Ca concentrations ranged from 3.007

Table 3. **Plant tissue chemical concentrations of the greenhouse grown landscape plant species after 12 weeks irrigation with regenerant wastewater.**

Plant species	Tissue mineral element concentrations (mg/g)			
	Cl	Ca	K	Mg
Regular water irrigation				
Azalea	0.832e[z]	10.534d	34.217b	2.508bc
Japanese boxwood	0.835e	10.859d	16.748d	2.373bc
Hydrangea	1.141d	20.898ab	39.080ab	5.877b
Lace fern	0.577e	3.007e	43.559a	2.582bc
Nadina	0.614e	6.519e	9.518d	1.297d
Pittosporum	0.749e	14.093cd	41.320a	1.259d
Hedge rose	1.150d	13.053cd	25.643c	3.244bc
Rhaphiolepis	0.623e	14.646c	20.972c	1.826cd
Jasmine	0.575e	17.146c	33.321b	2.204c
Wastewater irrigation				
Azalea	12.350c	14.790c	31.786bc	5.391b
Japanese boxwood	11.113c	12.650cd	14.637d	3.615bc
Hydrangea	31.734a	24.820a	45.927a	6.944b
Lace fern	35.957a	16.642c	29.482bc	10.191a
Nadina	12.173c	10.174d	7.982d	3.534bc
Pittosporum	7.537d	17.555bc	37.928ab	3.339bc
Hedge rose	19.686b	13.924c	24.683c	4.338bc
Rhaphiolepis	1.509d	14.213c	21.548c	2.157c
Jasmine	2.597d	14.622c	30.689bc	2.373c
ANOVA				
Between species	***[y]	***	***	***
Between treatment	***	NS	NS	***
Species x treatment	***	NS	NS	***

[z]Within colums (including control and waste water treatment data) means followed by the same letter are not significantly different at P = 0.01, according to Duncan's new multiple range test.

[y]NS, *** Not significantly different, significantly different at 1% level, respectively.

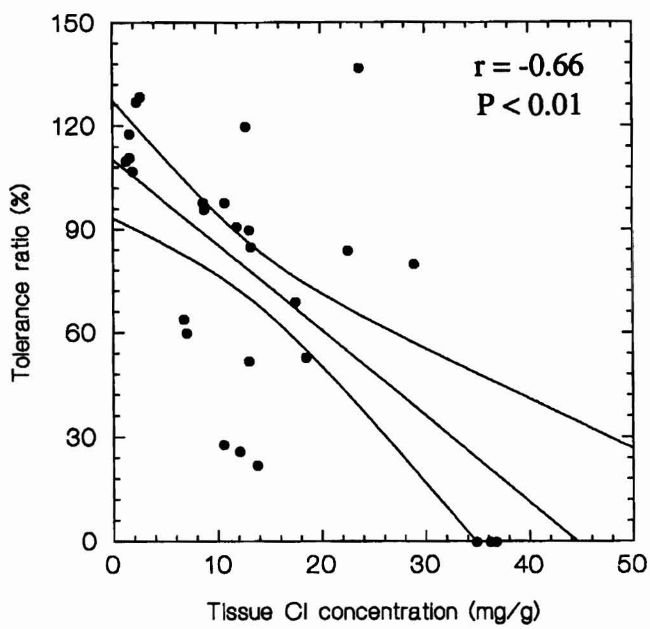

Fig. 1. **Joint distribution and correlation between the tolerance ratios represented by percentage of dry weight produced by the wastewater irrigation to regular water irrigation and tissue Ca concentrations detected from plants irrigated with 10 times dilution of the wastewater.**

mg/g in Lace fern to 20.898 mg/g in Hydrangea. The tissue K concentrations ranged from 9.518 in Nandina to 41.320 mg/g in Pittosporum. The tissue Mg concentrations ranged from 1.259 in Pittosporum to 5.877 mg/g in Hydrangèa, and was significantly different both between the plant species and wastewater treatment. Calcium and K was not increased significantly by the wastewater treatment. Magnesium uptake was slightly increased by wastewater treatment and was significantly different both between species and betreen treatment. Significant difference was also found in species and wastewater treatment interactions. This result indicates that the patterns of Mg uptake responded to the wastewater treatment are different among the plant species.

Generally, the species that accumulated greater amounts of Cl were the ones that had a greater reduction of growth. Fig. 1 shows that a negative correlation was found between the tissue Cl concentration and the tolerance ratio ($P < 0.01$, $r = -0.63$). The Lace fern had the highest tissue Cl concentration and was the most affected. Rhaphiolepis and Jasmine had the least tissue Cl concentrations (Table 3), and no growth reduction was detected (Table 1 and 3). Hydrangea also had a high tissue Cl concentration, but it showed no growth reduction. Its chloride tolerance might be attributable to its high tissue Ca concentration. The correlation analysis showed that the chloride tolerance ratios were positively correlated with the tissue Ca concentrations (Fig. 2). This relationship suggests that in the species tested, higher tissue Ca concentrations were able to alleviate the chloride toxicity. In addition, the tolerance ratio was positively correlated with the tissue Ca to Cl ratio (Fig. 3). Calcium is essential in the structural and functional integrity of plant cell membranes (6), stabilization of cell wall structure, regulation of ion transport, and control of ion-exchange behavior, as well as cell wall enzyme activities (4). The present study suggests that a differential ion uptake mechanism for Ca^{2+} and Cl^- exists among the nine plant species.

The requirement of Cl as a mineral nutrient for plants was first demonstrated by Broyer et al. (2). Because chloride is commonly supplied to plants from various sources, such as soil reserves, rain, fertilizers, and air pollution, there is more concern about toxic levels in plants than about deficiency. Assuming a minimal requirement for optimal growth of 1 g/kg dry weight, one would expect, on average, a crop requirement of between 4 and 8 kg chloride per hectare. This is the amount of chloride supplied by rain (9). If the concentration of chloride in the external culture solution is more than 20 mM, it can lead to chloride toxicity in sensitive plant species (1). For tolerant species the external chloride concentration can be four to five times higher without a reduction in growth. Differences in chloride toxicity in plants are related mainly to differences in the sensitivity of leaf tissue to excessive chloride levels. Most fruit trees, bean (*Ricinus communis* L.), and cotton (*Gossypium hirsutum*) may show chloride toxicity under 10 mM Cl– (9). In contrast, 20 to 30 g chloride per kg dry leaf tissue may have no toxic effect on tolerant species such as barley (*Hordium vugare*), spinach (*Spinacia oleracea*), lettuce (*Lactuca sativa*), and sugar beet (*Beat vuglaris*). Irrigation of Baccara roses (*Rosa cathayensis*) with water containing chlorides was more detrimental than irrigation with water containing nitrates at the same level of salinity (10). Overall, the Cl^- concentration in the wastewater tested seemed to be the factor most likely to create problems for landscape plants. Severe negative effects will probably be noticeable only for a few sensitive plant species, but it is important to determine this before applying regenerant irrigation water.

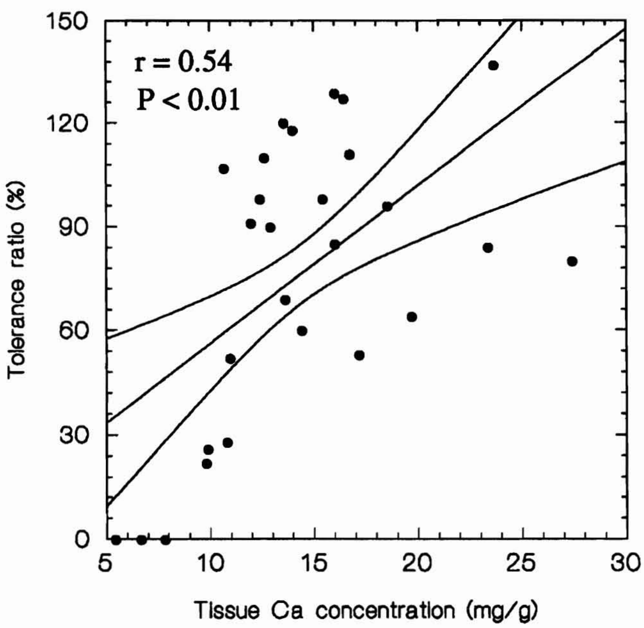

Fig. 2. **Joint distribution and correlation between the tolerance ratios represented by percentage of dry weight produced by the wastewater irrigation to regular water irrigation and tissue Cl concentrations detected from plants irrigated with 10 times dilution of the wastewater.**

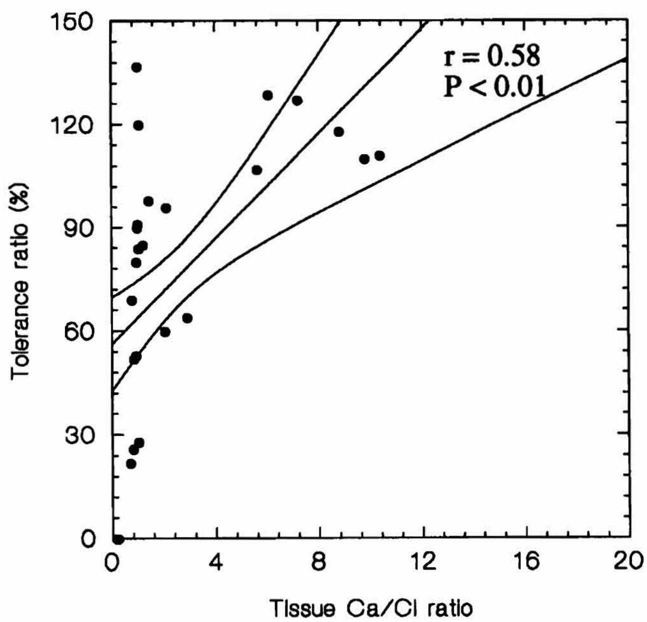

Fig. 3. **Joint distribution and correlation between the tolerance ratios represented by percentage of dry weight produced under the wastewater irrigation to regular water irrigation and tissue Ca/Cl concentration ratios detected from plants irrigated with 10 times dilution of the wastewater.**

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