Saline Irrigation Affects Growth and Leaf Tissue Nutrient Concentration of Three Native Landscape Plant Species

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SUMMARY. Greywater is a renewable irrigation alternative to potable water; however, its use as an irrigation source is limited by the potential for salt injury to plants. Research was conducted to determine salt tolerance of three common landscape species, small anise tree (*Illicium parviflorum*), ‘Henry’s Garnet’ sweetspire (*Itea virginica*), and muhly grass (*Muhlenbergia capillaris*). Two experiments were performed, one with high sodium chloride (NaCl) concentrations and one with low NaCl concentrations. Plants received daily irrigation of tap water containing one of the following NaCl concentrations: 0 (tap water); 2000, 4000, 6000, 8000, or 10,000 mg·L⁻¹ (high NaCl); or 0 (tap water), 250, 500, or 1000 mg·L⁻¹ (low NaCl) for 15 weeks. Plants were harvested after 5, 10, or 15 weeks. Root dry weight (RDW) and shoot dry weight (SDW) were determined at each harvest; survival was determined at experiment termination. Leaf tissue was analyzed for tissue macronutrient [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg)], sodium (Na), and chlorine (Cl) concentrations in the high NaCl concentration experiment. With high NaCl, RDW and SDW decreased with increasing NaCl for all species. Anise and sweetspire had low or no survival, respectively, at the highest NaCl concentration; muhly grass had 100% survival regardless of treatment. In general, leaf macronutrient, Na, and Cl increased with increasing NaCl concentration. With low NaCl, there was no effect of NaCl concentration on RDW or SDW for all species. All three species continued to grow between harvest dates in the lower NaCl concentration experiment, whereas only anise and muhly grass continued to grow with high NaCl. Anise and muhly grass were tolerant of saline irrigation that could be expected from greywater. Sweetspire exhibited symptoms of salt stress (necrotic leaves and leaf drop, visual observation) at all NaCl concentrations including the lowest (250 mg·L⁻¹), and should not be irrigated with saline water.

Alternative water sources provide an opportunity to reduce the demand for potable water. Greywater could provide homeowners and municipalities with an alternative irrigation source. One common chemical characteristic of greywater is high salt content, usually in the form of NaCl. Reviews of several greywater studies indicate that Na concentrations

of greywater range from 7.4 to 480 mg·L⁻¹, whereas Cl concentrations range from 9 to 88 mg·L⁻¹ (Christova-Boal et al., 1996; Eriksson et al., 2002). Salinity tolerance research conducted on landscape plant species has commonly been conducted using simulated reclaimed wastewater (treated municipal effluent) (Marcotte et al., 2004; Miyamoto et al., 2004; Niu et al., 2007, 2012; Wu et al., 2000).

Limited information is available on salt tolerance of woody landscape

species native to the southeastern United States (Jordan et al., 2001; Wu et al., 2001). Previous evaluation of salt tolerance of woody landscape plant species commonly used in the southeastern United States has used both native and non-native species. For example, ‘Helleri’ holly (*Ilex crenata*), Japanese holly (*I. crenata*), yaupon holly (*Ilex vomitoria*), Chinese juniper (*Juniperus chinensis*), Mexican redbud (*Cercis canadensis* var. *mexicana*), and crapemyrtle (*Lagerstroemia* sp.) have all been screened and found to be tolerant of saline irrigation water (Cabrera, 2009; Niu et al., 2010; Valdez-Aguilar et al., 2011; Yeager et al., 2010). Evaluations of monocots have been mostly limited to palms and turf with few ornamental landscape grasses (Marcotte et al., 2004; Miyamoto et al., 2004; Wu et al., 2000). Evaluation of additional landscape species, native to the southeastern United States, for tolerance of greywater salinity could increase plant selection options for a greywater-irrigated landscape. Therefore, the objective of this research was to evaluate the tolerance of three landscape plant species, native to the southeastern United States, to saline irrigation water.

Materials and methods

HIGH SALT CONCENTRATIONS.

Liners (2 inches) of small anise tree (propagated at Auburn University), sweetspire (Spring Meadow Nursery, Grand Haven, MI), and muhly grass (Magnolia Gardens Nursery, Magnolia, TX) were planted in trade gallon (0.75 gal) containers in a 5:3:1 pinebark:peat:perlite, by volume, substrate. Substrate was preplant amended with 9.1 lb/yd³ controlled-release fertilizer (Polyon with micros 17N-2.2P-9.1K; Harrell’s, Lakeland, FL) and dolomitic limestone (4 lb/yd³). Plants were irrigated by hand daily with 300 mL of tap water to which one of the

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.5933	lb/yd ³	kg·m ⁻³	1.6856
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Table 1. Effect of high sodium chloride (NaCl) concentration added to irrigation water (simulated greywater) and harvest date [weeks after treatment (WAT)] on root dry weight (RDW) and shoot dry weight (SDW) of small anise tree, 'Henry's Garnet' sweetspire, and muhly grass.

NaCl (mg·L ⁻¹) ^z	Anise								Sweetspire								Muhly grass	
	RDW (g) ^y				SDW (g)				RDW (g)				SDW (g)					
	WAT				WAT				WAT				WAT					
	5	10	15	Sig. ^y	5	10	15	Sig.	5	10	15	Sig.	5	10	15	Sig.	RDW (g)	SDW (g)
0	2.5	6.4	14.1	L**	9.9	24.2	45.2	L**	13.4	21.1	36.4	L***	37.1	39.0	61.8	L**	26.7	54.6
2,000	2.1	4.3	7.1	L**	7.1	19.7	26.3	L**	8.9	19.8	24.1	L***	29.8	40.7	45.5	L**	18.5	56.6
4,000	2.0	3.5	5.0	L*	6.4	11.5	19.4	L**	7.4	15.4	15.1	L***	20.4	31.5	23.3	Q**	16.6	53.5
6,000	1.6	2.6	3.2	L**	5.6	11.9	15.1	L**	6.8	8.0	6.9	Q*	16.8	11.3	7.4	L***	10.7	45.0
8,000	1.9	2.8	3.0	NS	6.3	8.1	13.1	NS	5.0	8.4	0.0	Q**	9.8	9.4	0.0	L**	10.1	41.3
10,000	1.2	1.9	1.4	NS	2.7	6.4	6.0	NS	4.8	7.4	0.0	Q***	6.6	3.1	0.0	L***	9.3	38.9
Sig.	L**	L**	L***		L***	L**	L***		L***	L***	Q***		L***	L***	Q***		L***	L***

^z1 mg·L⁻¹ = 1 ppm; 1 g = 0.0353 oz.

^ySignificance (SAS version 9.2; SAS Institute, Cary, NC) of linear (L) or quadratic (Q) trend associated with effect of NaCl concentration and harvest date on RDW and SDW; trends were significant at $P \leq 0.05$ (*), 0.01 (**), 0.001 (***), or nonsignificant (NS). For anise, $n = 6$ for 5 and 10 WAT, and $n = 8$ for 15 WAT. For muhly grass, $n = 20$ (data pooled over WAT). Data were pooled over two runs for anise and muhly grass. For sweetspire, $n = 3$ for 5 and 10 WAT, and $n = 4$ for 15 WAT. There was only one run for sweetspire.

following amounts (treatments) of NaCl were added: 0 (tap water), 2000, 4000, 8000, or 10,000 mg·L⁻¹ resulting in $\approx 10\%$ to 15% leachate (Southern Nursery Association, 2007). Although these rates are much higher than those normally found in greywater, they were used so that results could be applicable to other more saline irrigation sources (Christova-Boal et al., 1996; Eriksson et al., 2002). Plants received tap water irrigation (no added NaCl) on weekends. Plants were grown under natural photoperiods on raised benches in a polycarbonate greenhouse at Paterson Horticulture Teaching and Research Greenhouse Complex at Auburn University in Auburn, AL. Temperatures ranged from 67 to 80 °F during the day and 65 to 72 °F at night.

There were 10 single container replications per treatment per species. Experimental design was a completely randomized design with each species as a separate experiment. Three plants of each species in each treatment were harvested 5 and 10 weeks after treatment (WAT) initiation, and the remaining plants ($n = 4$) were harvested 15 WAT initiation (experiment termination). Survival was determined at experiment termination. RDW and SDW were determined at each harvest. Recently matured leaf tissue samples were collected from SDW samples of three plants per treatment per species at experiment termination and analyzed for tissue macronutrient (N, P, K, Ca, and Mg), Na, and Cl concentrations using inductively

coupled plasma analysis (Brookside Laboratories, New Bremen, OH). Treatments were initiated on 20 June 2011, and experiments were ended on 30 Sept. 2011. On 12 Sept. 2011, experiments were repeated with the same procedures described above with only anise and muhly grass, and with the omission of leaf tissue nutrient analysis. Sweetspire was omitted based on its lack of tolerance to NaCl concentrations applied in the first run; the second run was ended on 19 Dec. 2011. Data were subjected to analysis of variance and regression analysis using PROC MIXED in SAS (version 9.2; SAS Institute, Cary, NC). The effect of run was not significant, thus data were pooled over runs.

LOW SALT CONCENTRATIONS. On 10 July 2012, an experiment similar to the high salt concentration experiment described above was initiated. On the basis of results from the high salt concentration experiment, NaCl treatments were lowered to 0 (tap water), 250, 500, or 1000 mg·L⁻¹ NaCl added to irrigation water to evaluate seemingly less salt tolerant sweetspire and anise (based on results from high NaCl concentration experiments). Muhly grass was also evaluated for comparison. Substrate electrical conductivity (EC) was measured on 25 Oct. 2012 (termination) from leachate collected using the pour-through nutrient extraction procedure (Wright, 1986) with a handheld Beckman Coulter 460 m and conductivity probe. All other materials and methods and

analyses were the same as described above with the omission of tissue analysis. The low salt concentration experiment was repeated with the same procedures on 15 Oct. 2012; experiment termination (second run) was on 30 Jan. 2013.

Results and discussion

ROOT AND SHOOT DRY WEIGHT. RDW and SDW of anise decreased linearly with increasing high NaCl concentration at each harvest date (Table 1). Within high NaCl concentration, anise RDW and SDW increased linearly over time up to 6000 mg·L⁻¹ with no increases in growth over time at 8000 or 10,000 mg·L⁻¹ (Table 1). Sweetspire RDW and SDW decreased linearly with increasing high NaCl concentration at 5 and 10 WAT (Table 1). At 15 WAT, sweetspire RDW and SDW decreased quadratically with increasing high NaCl concentration (Table 1). Muhly grass RDW and SDW decreased linearly with increasing high NaCl concentration (WAT not significant, Table 1). There was no effect of low NaCl concentration on RDW or SDW for any of the species (Table 2). At low NaCl, RDW and SDW increased linearly over time for all species with the exception of sweetspire SDW, which did not change over time (Table 2).

SURVIVAL AND VISUAL QUALITY. Anise had 100% survival in all experiments, with the exception of one run (fall), where it had survival rates of 90% at 6000 mg·L⁻¹, 80% at 8000 mg·L⁻¹,

Table 2. Effect of low sodium chloride (NaCl) concentration added to irrigation water (simulated greywater) and harvest date [weeks after treatment (WAT)] on root dry weight (RDW) and shoot dry weight (SDW) of small anise tree, ‘Henry’s Garnet’ sweetspire, and muhly grass.

NaCl (mg·L ⁻¹) ^z	Anise		Sweetspire		Muhly grass	
	RDW (g) ^z	SDW (g)	RDW (g)	SDW (g)	RDW (g)	SDW (g)
0	4.0	8.1	3.9	3.5	41.1	54.9
250	3.7	7.6	3.3	2.9	50.5	56.6
500	3.4	7.1	3.1	2.7	51.6	55.9
1,000	6.7	7.1	3.0	2.5	44.8	55.4
Sig. ^y	NS	NS	NS	NS	NS	NS
WAT						
5	1.9	3.9	2.1	2.8	22.0	27.2
10	3.6	8.0	3.0	3.2	37.8	55.6
15	5.7	10.5	4.9	2.8	81.2	84.3
Sig.	L***	L***	L***	NS	L***	L***

^z1 mg·L⁻¹ = 1 ppm, 1 g = 0.0353 oz.

^ySignificance (SAS version 9.2; SAS Institute, Cary, NC) of linear (L) trend associated with effect of NaCl concentration or harvest date on RDW and SDW; trends were significant at $P \leq 0.001$ (***) or nonsignificant (ns). For 5 and 10 WAT, n = 24; for 15 WAT, n = 32 (data pooled over two runs and over NaCl treatment). For NaCl treatment, n = 20 (data pooled over two runs and harvest date).

Table 3. Effect of sodium chloride (NaCl) concentration added to irrigation water (simulated greywater) on concentration of macronutrients^z, sodium (Na), and chlorine (Cl) in leaves of small anise tree, ‘Henry’s Garnet’ sweetspire, and muhly grass.

NaCl (mg·L ⁻¹) ^y	Leaf tissue element concn (%)						
	Anise						
	N	P	K	Ca	Mg	Na	Cl
0	1.11	0.10	0.74	0.17	0.12	0.01	0.07
2,000	1.23	0.12	0.82	0.15	0.11	0.11	0.32
4,000	1.85	0.19	0.96	0.24	0.12	0.50	0.88
6,000	2.19	0.20	0.87	0.18	0.09	0.60	0.96
8,000	1.96	0.19	0.95	0.16	0.11	0.96	1.63
10,000	2.27	0.19	1.10	0.18	0.12	2.26	4.07
Sig. ^x	L***	L***	L**	Q*	Q*	L***	L***
Sufficiency ^w	0.99–2.08	0.12–0.18	0.67–0.95	0.20–0.28	0.11–0.15	0.006–0.011	N/A
NaCl (mg·L ⁻¹)	Sweetspire						
	N	P	K	Ca	Mg	Na	Cl
0	1.13	0.09	0.51	0.53	0.22	0.04	0.21
2,000	1.28	0.15	1.06	0.79	0.32	0.17	1.99
4,000	1.66	0.23	1.07	0.94	0.35	0.68	3.26
Sig.	L**	L***	L***	L***	L***	L***	L***
Sufficiency	1.64–4.50	0.10–0.24	0.36–0.80	0.38–1.09	0.13–0.20	0.003–0.014	N/A
NaCl (mg·L ⁻¹)	Muhly grass						
	N	P	K	Ca	Mg	Na	Cl
0	0.64	0.16	0.77	0.18	0.12	0.24	0.54
2,000	0.79	0.16	0.68	0.18	0.11	0.96	1.56
4,000	0.65	0.15	0.54	0.11	0.08	1.17	1.74
6,000	0.89	0.23	0.76	0.17	0.11	2.66	4.76
8,000	0.91	0.22	0.82	0.18	0.11	3.39	6.07
10,000	0.87	0.20	0.70	0.16	0.10	3.14	5.93
	L**	L**	NS	NS	NS	L***	L***
Sufficiency ^w	1.61	0.18	0.60	0.53	0.11	0.0046	N/A

^zNitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg).

^y1 mg·L⁻¹ = 1 ppm.

^xSignificance (SAS version 9.2; SAS Institute, Cary, NC) of linear (L) or quadratic (Q) trend associated with effect of NaCl concentration on leaf tissue element concentration (n = 3); trends were significant at $P \leq 0.05$ (*), 0.01 (**), 0.001 (***), or nonsignificant (ns).

^wSufficiency ranges (Mills and Jones, 1996). Values listed under muhly grass are for maiden grass (*Miscanthus sinensis*). Sufficiency ranges for muhly grass not available.

and 20% at 10,000 mg·L⁻¹. There was 0% sweetspire survival at NaCl concentrations of 8000 and 10,000 mg·L⁻¹ at experiment termination. Muhly grass

had 100% survival even at NaCl irrigation rates of up to 20 times higher than generally found in greywater (Christova-Boal et al., 1996; Eriksson et al.,

2002). Sweetspire foliar damage was observed visually at NaCl concentration of 2000 mg·L⁻¹ and higher. Generally, plants that can tolerate

Table 4. Effect of sodium chloride (NaCl) concentration added to irrigation water (simulated greywater) on leachate electrical conductivity (EC) of small anise tree, 'Henry's Garnet' sweetspire, and gulf muhly grass.

NaCl (mg·L ⁻¹) ^z	EC (dS·m ⁻¹)		
	Anise	Sweetspire	Muhly grass
0	2.71	3.64	0.80
250	3.46	4.85	1.24
500	4.22	4.91	2.79
1,000	6.19	6.04	4.64
Sig. ^y	L***	L***	L***

^z1 mg·L⁻¹ = 1 ppm, 1 dS·m⁻¹ = 1 mmho/cm.

^ySignificance (SAS version 9.2; SAS Institute, Cary, NC) of linear (L) trend associated with effect of NaCl concentration on leachate EC (n = 8, data pooled over two runs); trends were significant at $P \leq 0.001$ (***).

saline irrigation levels of 2000 to 3000 mg·L⁻¹ are considered to be salt tolerant (Watling, 2007). High survival rates of anise and muhly grass are probably due to their native habitats' proximity to saline environments (Dirr, 1998; Schroeder et al., 1976). Anise and muhly grass continued to grow despite prolonged (15 weeks) application of NaCl suggesting these species would be appropriate candidates for use in greywater-irrigated landscapes. In addition, despite growth reductions, anise and muhly grass still appeared "marketable" (healthy foliage and roots) by the end of each experiment, indicating they could also be irrigated with saline water during production. Conversely, even at low concentrations of NaCl, sweetspire exhibited growth reductions and tissue damage, indicating it may not be suitable for inclusion in a landscape receiving frequent greywater irrigation or for highly saline landscapes. Symptoms of salt stress observed in sweetspire included wilting, chlorosis, leaf necrosis, defoliation, and root damage.

TISSUE NUTRIENT CONCENTRATIONS. Anise leaf N, P, K, Na, and Cl concentrations increased linearly with increasing NaCl concentration (Table 3). Anise leaf Ca concentration responded quadratically, initially increasing then decreasing, with increasing NaCl concentration (Table 3). Anise leaf Mg concentration also responded quadratically, initially decreasing then increasing with increasing NaCl concentration (Table 3). Sweetspire irrigated with NaCl concentrations higher than 4000 mg·L⁻¹ lacked sufficient leaf tissue for nutrient analysis. Sweetspire leaf macronutrient, Na, and Cl concentrations increased linearly with increasing NaCl concentration (Table 3).

Muhly grass leaf N, P, Na, and Cl concentrations increased linearly with increasing NaCl concentration, whereas there was no effect on leaf K, Ca, and Mg concentrations (Table 3). With some minor exceptions, leaf tissue macronutrient concentrations were within sufficiency ranges for all species (Table 3).

Increasing leaf macronutrient, Na, and Cl concentrations with increasing NaCl concentration are probably attributed to a reduction in SDW with increasing NaCl concentration (Table 3). Muhly grass leaf Na and Cl concentrations were up to 10 times higher in plants irrigated with the highest NaCl concentrations than in plants irrigated with tap water (Table 3). Likewise, anise irrigated with 10,000 mg·L⁻¹ had leaf Na and Cl concentrations 200 and 58 times higher, respectively, than plants irrigated with tap water (Table 3). Sweetspire leaf concentrations of Na and Cl were 17 and 15 times higher, respectively, in plants irrigated with 4000 mg·L⁻¹ NaCl than in plants irrigated with tap water (Table 3). The tolerance (or lack thereof) of these three species to saline irrigation may be related, at least in part, to their ability to accumulate Na and Cl in leaf tissue without toxicity as suggested by foliar damage of sweetspire, but not anise or muhly grass.

ELECTRICAL CONDUCTIVITY. Substrate leachate EC increased linearly ($P < 0.0001$) with increasing NaCl concentration in all species (Table 4). Elevations in EC of substrate leachate with increasing NaCl concentrations were expected. Substrate leachate EC above 6 dS·m⁻¹ are considered highly saline, whereas 2–6 dS·m⁻¹ are considered moderately saline (Watling, 2007). EC in the lower NaCl concentration experiments were within the range of moderately saline,

with the exception of 1000 mg·L⁻¹, which were highly saline.

Weekend irrigation of all plants with tap water (no added NaCl, EC = 0.2 dS·m⁻¹) was used to mimic rain events or an irrigation cycle of tap water and appeared (visually) to aid in the prevention of NaCl accumulation in substrate. This technique could be used as a management tool in greywater-irrigated landscapes. Periodically irrigating with tap water could reduce salt accumulation in soil or substrate. Likewise, less salt-tolerant plants could still be used in greywater-irrigated landscapes if frequency of application is reduced.

Conclusions

This research evaluated plant tolerance of a range of NaCl concentrations even higher than those observed in greywater application. Responses to NaCl concentrations used in these experiments could also be applied to conditions that could occur when irrigating with reclaimed wastewater or collected stormwater, or in landscapes in coastal regions and perhaps even arid environments. Alternating saline and nonsaline irrigation water may prevent salt buildup in soil and mitigate salt stress in plants. Although plant growth may be reduced as a result of saline irrigation, plant visual quality is not necessarily compromised as demonstrated by muhly grass and small anise tree in this research. Identifying native landscape plant species that are salt tolerant has application for using greywater for landscape irrigation as well as using saline irrigation water in general. Potential plant species for future evaluation for use in greywater-irrigated landscapes could be identified from those species native to coastal environments and species with drought tolerance.

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