沙漠研究 **24**-1, 213-221 (2014)
Journal of Arid Land Studies
－ DT11 Refereed Paper －

Effects of Saline Irrigation on Four Native Texas Plant Species with Ornamental Potential for Coastal and Arid Climate Landscapes

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Abstract: Effects of saline irrigation were tested on four taxa with potential as native landscape plants for saline or arid environments: *Borrichia frutescens* (L.) DC., *Erigeron procumbens* (Houst. ex Mill.) G.L. Nesom, *Oenothera drummondii* Hook., and *Sesuvium portulacastrum* (L.) L. In four separate experiments, plants were grown in 2.3 L containers and irrigated with four concentrations (0, 8.75,17.5, 35 and 70 g L^{-1}) of saline water, representing electrical conductivities (EC) of 0.8, 15.1, 23.8, 51.3 and 92.5 mS cm^{-1}, either applied sub-canopy or over the foliage. Salinity was derived from 2NaCl:1$CaCl_2$ and concentrations roughly represent the salinity of quarter, half, full and double the salinity of seawater. Treatments above half the salinity of seawater decreased most growth measures, with notable exceptions for *S. portulacastrum*. All four species tolerated regular irrigation with water containing salinity of as much as half or more of seawater and showed minimal damage with one quarter seawater. Growth responses, mineral nutrient content, Na content, and K/Na ratios were consistent with reports of the halophytic nature of *S. portulacastrum*. Research herein demonstrates that these potential new landscape plants can tolerate the application of saline water with salt concentrations of up to one quarter that of seawater with minimal aesthetic impacts and show potential for landscape testing in challenging coastal and arid region environments where the use of recycled water is necessary.

Key Words: *Borrichia frutescens*, *Erigeron procumbens*, Mineral nutrition, *Oenothera drummondii*, *Sesuvium portulacastrum*

1. Introduction

With the decreasing availability of high quality irrigation water in urban areas in arid environments new ornamental plants need to be developed for landscapes that will thrive with use of lower quality irrigation water. A strategy often employed in built environments in arid regions is to stretch water supplies via utilization of recycled or poorer quality non-potable water sources, which are often higher in salinity, for landscape irrigation (Miyamoto *et al*., 2001, 2002). An important ingredient in successfully implementing such a strategy will be the identification and development of suitable landscape taxa capable of thriving with saline irrigation water. Texas and the Southwestern USA have regions that are classic arid environments and even the more mesic portions are prone to extended droughts and limited water resources (Arnold, 2008). Demand for high quality water for human consumption may make the use of recycled water to irrigate urban landscapes inevitable (Niu and Rodriguez, 2006). The composition of treated waste water varies among communities and depends on composition of the original source of water, and type and number of industrial, commercial and residential users that are contributing to the source of treated waste water (Harivandi, 2000). With recycled water, such as treated effluent, the major concern is elevated salinity which can be as much as two to three times the level of potable water (Khurram and Miyamoto, 2005). After most recycled water treatment processes, sodium chloride is the most deleterious chemical remaining (Wu *et al*., 2001). Foliar necrosis and plant death are major concerns of using irrigation water with high concentrations of salts (Fox *et al*., 2005; Miyamoto *et al*., 2001, 2002).

Salts can induce a number of stress responses in plants: salts can affect general water balance, ion toxicity especially Na^+, Cl^-, or SO_4^{2-}, and inhibit nutrient uptake. Water balance in the plant is affected by the dissolved solutes in the root zone causing a low osmotic potential which reduces soil water potential. This results in an analogous situation to water deficit even when an otherwise sufficient amount of water is available (Taiz and Zeiger, 2006). Plants can adjust, to some extent, to prevent a loss of turgor pressure through a reduced osmotic potential, however growth may be slowed and often plants exhibit stress responses similar to adjustment to water deficit (Taiz and Zeiger, 2006). Ions of Na^+, Cl^-, or SO_4^{2-} can accumulate to toxic levels in plants in saline environments (Marschner, 1995). The accumulation of ions, especially a high ratio of Na^+ to K^+, can inhibit protein synthesis and

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(Received, September 14th, 2013; Accepted, December 10th, 2013)

Table 1. Transplant dates and mean greenhouse temperatures for each separate salinity experiment with the four species tested.

Species	Cuttings Rooted	Planted in 0.47 L Pots	Planted in 2.3 L pots	Treatment Started	Harvest	Max. Temp (ºC)	Min. Temp (ºC)	Mean Temp (ºC)
B. frutescens	13-Feb-11	2-Mar-11	1-Apr-11	9-Apr-11	5-Mar-11	31.6	17.2	24.7
E. procumbens	25-Apr-11	2-Mar-11	16-Mar-11	25-Mar-11	23-Jun-11	31.9	20.5	27.1
O. drummondii	9-Mar-11	16-Mar-11	31-Mar-11	9-Apr-11	29-Apr-11	31.6	18	24.6
S. portulacastrum	18-Mar-11	23-Mar-11	7-Jun-11	15-Jun-11	14-Jul-11	32.7	22.3	28

inactivate enzymes and may eventually lead to cell death (Taiz and Zeiger, 2006).

All of these responses to salt stress can lead to a loss of ornamental appeal. A buildup of ions from the transpirational stream can lead to leaves with necrotic margins, chlorosis, or leaf abscission giving the plant a general unhealthy appearance that is unacceptable for ornamental use (Maas, 1993; Marschner, 1995; Sykes, 1993). Salt ions interfering or interacting with nutrient absorption can also lead to chlorotic plants that are unacceptable in ornamental applications (Arnold, 2008; Maas, 1993; Marschner, 1995; Sykes, 1993).

The appearance of plants in the landscape is extremely important to landscape managers, designers, and people using the space (Fox *et al*., 2005). The use of salt tolerant or halophytic species could potentially reduce the ornamental liabilities of salt stress, allowing lower quality irrigation water to be used in production of plant materials and landscape irrigation without a loss of ornamental function.

Sesuvium portulacastrum (L.) L., *Borrichia frutescens* (L.) DC., *Oenothera drummondii* Hook. and *Erigeron procumbens* (Houst. ex Mill.) G.L. Nesom. are species native to Texas coastal regions (Richardson, 2002) and were selected for these studies because of their natural tolerance to salinity, especially in the form of sodium and chlorine ions, associated with seawater exposure in their coastal ranges. All of these species offer interesting foliage, form and/or flowering attributes which would make them potentially desirable landscape plants. Native plants were also selected because they pose a low potential for invasiveness compared to exotics. The purpose of this study is to quantify the salinity tolerances of these four potential landscape species in support of cultivar selection research.

2. Materials and Methods

Four separate experiments were conducted with the same general protocols but on different dates (**Table 1**). Tip cuttings, 4-6 cm long, were taken from containerized stock plants of single accessions maintained in a gravel nursery in College Station, TX. Basal ends of cuttings were dipped in talc based IBA at the concentration of 1 g·kg-1 (Hormodin® 1, OHP, Inc., Mainland, PA). Cuttings were placed in 36 cm × 51 cm × 10 cm deep flats (Kadon Corp., Dayton, Ohio) filled with coarse perlite (Sun Gro Horticulture Canada Ltd, Seba Beach, AB). Intermittent mist was applied at 16 min intervals for 15 sec duration using reverse osmosis water from 1 h before sunrise to 1 h after sunset. Rooted cuttings were potted in 0.47 L black plastic pots (Dillen Products, Middlefield, OH) containing calcined clay amended with 6.53 kg m^{-3} 15N-3.9P-9.9K controlled release fertilizer (Osmocote® Plus, Scotts Co., Marysville, Ohio), 0.89 kg m^{-3} micronutrient fertilizer (Micromax®, Scotts Co., Marysville, Ohio), 1.78 kg m^{-3} $CaSO_4$ (United States Gypsum Co., Chicago, Ill.) and 4.15 kg m^{-3} $CaMgCO_3$ as per the methods of Denny (2007). Liners were later potted into 2.3 L containers filled with the media described above and placed on greenhouse benches in a completely randomized design with five replicates of each treatment. Mean temperature, minimum, and maximum temperature were recorded for each experiment (Table 1).

Treatments were 2NaCl:1$CaCl_2$ (Denny, 2007; Solis-Perez, 2009) added at the rates of 0.00, 8.75, 17.50, 35.00, or 70.00 g L^{-1} to reverse osmosis water, representing electrical conductivities (EC) of 0.8, 15.1, 23.8, 51.3 and 92.5 mS cm^{-1}, applied either over the top of the canopy contacting the foliage or sub-canopy not contacting the foliage. Irrigation water with a salt concentration of 35 g L^{-1} roughly represents the salinity of seawater (Denny, 2007; Miyamoto *et al*., 2004; Southorn, 1995). All treatments were watered simultaneously as needed with 800 mL (> 25% leaching factor).

At the time of harvest, plant heights, widths, leaf count, leaf area and internode lengths were recorded. Chlorophyll content was sampled spectrophotmetrically by removing five leaf discs from each plant and extracting in 80% acetone (Bryan, 2008; Harborne, 1984). A foliar damage rating of 1-5 was taken by the same observer at harvest, with 1) representing a dead plant or plant near death (unacceptable for ornamental use), 2) plant with severe damage to the canopy but surviving (unacceptable for ornamental use with 50-90% of the foliage exhibiting necrotic regions), 3) plant with severe to mild damage to the canopy, (20-40% of the foliage exhibiting necrotic regions), 4) very mild damage to the plant canopy, canopy is full with <10% of the foliage having necrotic regions (acceptable ornamental landscape plant) and 5) no damage to the plant canopy (acceptable ornamental landscape plant). Fresh and dry shoot and root weights were recorded. Shoots

Table 2. Main effects of salinity on growth measures for individual species in individual studies.

		Leaf Area (cm^2)	Leaf Count	Height (cm)	Internode (cm)	Shoot Mass (g)	Foliar Damage Rating (1-5)	E. C. of Media ($mS{\cdot}cm^{-1}$)
B. frutescens	Control (0 $g{\cdot}L^{-1}$)	521.3±44.3[x]	125.3±8.9	36.0±1.2	65.7±1.6	7.9±0.8	5.0±0.0[y]	0.5±0.2
	Low (8.75 $g{\cdot}L^{-1}$)	498.0±46.0	132.4±12.1	33.4±1.1	54.8±1.5	7.9±0.8	5.0±0.0	4.3±0.9
	Medium (17.5 $g{\cdot}L^{-1}$)	307.4±29.0	111.3±10.6	29.2±1.0	42.7±1.6	5.4±0.5	5.0±0.0	7.7±0.4
	Med-High (35 $g{\cdot}L^{-1}$)	123.5±18.8	42.7±6.1	18.6±1.4	28.0±1.5	2.4±0.3	5.0±0.0	12.2±1.5
	High (70 $g{\cdot}L^{-1}$)	-	-	-	-	-	-	16.1±1.8
	Linear	***[z]	***	***	***	***	-	***
	Quadratic	***	***	***	***	***	-	***
E. procumbens	Control (0 $g{\cdot}L^{-1}$)	684.8±59.5	614.5±52.0	6.1±0.3	22.8±1.0	9.1±0.6	4.9±0.1	2.2±0.2
	Low (8.75 $g{\cdot}L^{-1}$)	232.5±25.6	238.5±28.3	5.6±0.4	19.9±1.0	3.3±0.5	4.5±0.2	7.7±1.1
	Medium (17.5 $g{\cdot}L^{-1}$)	121.9±20.7	131.9±21.4	5.1±0.3	12.5±0.6	2.4±0.4	3.7±0.2	10.5±1.1
	Med-High (35 $g{\cdot}L^{-1}$)	26.2±8.5	28.5±9.2	5.2±1.24	8.9±1.0	0.7±0.2	2.8±0.6	15.7±2.1
	High (70 $g{\cdot}L^{-1}$)	-	-	-	-	-	-	32.3±1.8
	Linear	***	***	n.s.	***	***	-	***
	Quadratic	***	***	n.s.	***	***	-	**
O. drummondii	Control (0 $g{\cdot}L^{-1}$)	1033.2±41.1	565.0±26.7	12.6±1.0	12.2±0.6	7.9±0.8	5.0±0.0	0.9±0.1
	Low (8.75 $g{\cdot}L^{-1}$)	491.5±39.0	275.1±18.7	17.8±1.0	9.0±0.4	7.9±0.8	4.5±0.5	6.6±0.5
	Medium (17.5 $g{\cdot}L^{-1}$)	192.6±28.5	99.2±12.1	11.7±0.9	6.6±0.6	5.4±0.5	3.6±0.3	8.9±0.6
	Med-High (35 $g{\cdot}L^{-1}$)	-	-	-	-	2.4±0.3	-	14.2±1.0
	High (70 $g{\cdot}L^{-1}$)	-	-	-	-	-	-	25.6±1.3
	Linear	***	***	n.s.	***	***	-	***
	Quadratic	***	***	**	***	***	-	**
S. portulacastrum	Control (0 $g{\cdot}L^{-1}$)	607.7±26.3	288.1±20.2	23.5±2.5	68.2±2.6	26.4±1.1	5.0±0	1.0±0.2
	Low (8.75 $g{\cdot}L^{-1}$)	837.7±32.1	331±18.2	15.6±0.8	69.7±1.8	33.1±1.1	5.0±0	8.1±0.3
	Medium (17.5 $g{\cdot}L^{-1}$)	617.2±21.1	278.6±12.7	18.5±0.8	63.5±1.9	29.5±0.8	4.9±0.1	15.0±1.2
	Med-High (35 $g{\cdot}L^{-1}$)	357.5±9.2	153.6±8.3	19.8±1.3	63.5±1.7	19.3±0.4	4.9±0.1	18.4±1.4
	High (70 $g{\cdot}L^{-1}$)	75.0±8.9	54.8±5.5	9.6±0.8	33.7±1.8	8.0±0.4	1.8±0.2	27.8±1.7
	Linear	***	***	***	***	***	-	**
	Quadratic	***	***	***	***	***	-	*

[x] Values represent means (± standard errors) of 10 observations. Lack of observations indicates mortality.
[y] Foliar damage ratings range from a 1 (most severe damage) to a 5 (no observable damage). Unable to apply linear or quadratic regression due to non-normal data.
[z] *,**,***, or n.s. indicates significance of the linear or quadradic regression component at $P \leq 0.05$, 0.01, 0.001, or not significant, respectively.

from three plants in each treatment were rinsed in distilled water to remove external salts and analyzed for N, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu and B content (Texas A&M AgriLife Ext. Ser. Soil, Water and Forage Testing Laboratory, College Station, TX). Electrical conductivity of the media was determined using the 1:5 method described by Lang (1996).

An analysis of variance for the interactions among application methods and salinity level treatments within each study was conducted using JMP 2009 and SAS 9.3 (SAS Institute Inc., Cary, NC) for continuous variables. If interactions were not significant, then data were pooled into the main effects and they were analyzed for significance. All non-normal data was analyzed using permutations in the lmPerm package (Wheeler, 2010) in R (R Core Team, 2013), set to defaults.

3. Results and Discussion

3.1. Growth responses

Interactions among application modes and salinity levels were not significant ($P \leq 0.05$) for any of the growth measures, thus only main effects are presented. The main effects of salinity level were significant ($P \leq 0.05$) for all growth measures and media EC (**Table 2**). Increasing salinity levels generally resulted in progressive decreases in all growth measures recorded except for those of *S. portulacastrum* and height of *O. drummondii* (Table 2). *Sesuvium portulacastrum* leaf area, leaf number, and shoot mass were stimulated by the lowest salinity exposure (38%, 15% and 25%, respectively, compared to the controls), consistent with reports that it is a halophyte (Lonard and Judd, 1997). *Sesuvium portulacastrum* was able to survive regular irrigation with salinity at 70 g L^{-1}, equivalent to nearly twice the salinity of seawater, which resulted in an elevated mean substrate EC of 27.8 mS cm^{-1}. This is consistent with the natural occurrence of *S. portulacastrum* immediately adjacent to the ocean on dunes. The mean height of *O. drummondii* was increased 41% by low levels of salt in the irrigation solution, but other measurements decreased with increasing salinity exposure and *O. drummondii* typically succumbed to salinity of 35 g L^{-1} or greater (Table 2). Treating *B. frutescens* and *E. procumbens* with salt concentrations of 70 g L^{-1} killed them, but they survived regular irrigation with salinity equivalent to that of seawater. However, *E. procumbens* plants treated with 35 g L^{-1} foliar applied died while plants treated with same concentration applied sub-canopy survived.

Internode length was reduced 51% at 70 g L^{-1} and only 7% at 35 g L^{-1} for *S. portulacastrum* (Table 2). Salt treatments also reduced internode length for *E. procumbens* (61% at 35 g L^{-1}), *O. drummondii* (46% at 17.5 g L^{-1}) and *B. frutescens* (57% at 35 g L^{-1}). The reduction in internode extension could be beneficial during nursery or greenhouse production by reducing the need for plant growth retardants. The interaction among application modes and salinity levels for *O. drummondii* was significant ($P \leq 0.001$) for chlorophyll concentrations, but only the main effects of salinity were significant ($P \leq 0.05$) for *B. frutescens*, *E. procumbens* and *S. portulacastrum*. For all four species tested, chlorophyll content increased with increasing salinity then declined (**Fig. 1**). At the highest salinity level tested chlorophyll concentration for *S. portulacastrum* was reduced 36% compared to controls at 70 g L^{-1}. In *O. drummondii* there was an interaction among the concentrations of total salts and modes of application in which chlorophyll concentration was reduced 4% at 17.5 g L^{-1} when applied foliarly but increased 67% when applied sub-canopy at the same concentration. In all cases initial treatment with saline water was accompanied by an increase in the concentration of chlorophyll per unit of leaf area (Fig. 1). This increase might be due to the decrease in leaf area and a possible increase in leaf thickness (Poljakoff-Mayber, 1975; Longstreth and Strain, 1977).

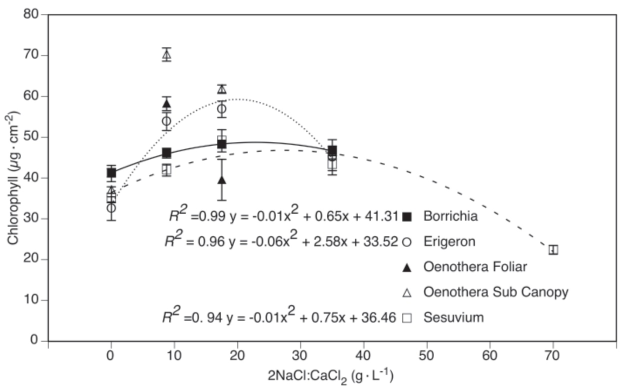

Fig. 1. Chlorophyll Concentration. Interactions among salt (0, 8.75 and 17.5 g L^{-1}) levels and application methods for *O. drummondii* and main effects of salt levels for *B. frutescens*, *E. procumbens* and *S. portulacastrum*. Symbols for *O. drummondii* represent means (± s.e.) of n=5. Symbols for *B. frutescens*, *E. procumbens* and *S. portulacastrum* represent means (± s.e.) of n=10. Regressions equations are based on means and are presented when significant at $P \leq 0.05$. Equations were not included for *O. drummondii* due to mortality of the two most saline treatments.

3.2. *Sesuvium portulacastrum* mineral content

Phosphorus was not affected by the application of salt solution in *S. portulacastrum* (**Table 3**). For all other mineral concentrations tested there was not an interaction among the modes of application and amounts of salt solutions (Table 3). In *S. portulacastrum* the application of salt solutions resulted in an increase in the concentrations of N, K, Ca, Cu and Na at all levels tested (Table 3). This is in contrast to results of Teixeira and Carvalho (2009) in the salt tolerant *Portulaca oleracea* L., Kachout *et al*. (2011) in the halophyte *Atriplex* L., and Carter and Grieve (2010) in *Zinnia elegans* Jacq. where decreases were found in K and Ca concentrations when plants were treated with saline irrigation water. Tissue levels of Na were elevated in all salinity treatments compared to the controls for *S. portulacastrum* (Table 3) as was the case for *O. drummondii* (**Table 4**), *E. procumbens* (**Table 5**) and *B. frutescens* (**Table 6**). However, salinity levels in tissues of *S. portulacastrum* were greatest at the lower salinity levels (Table 3), rather than at the greater salinity levels as was seen with the other three species (Tables 4, 5 and 6). This suggests some Na accumulation may have taken place at lower salinity levels. The K/Na ratios for *S. portulacastrum* were also different from that of the other three species (**Fig. 2A, B, C** versus **D**). Foliar applied salinity resulted in a more rapid and severe drop in the K/Na ratio for the other three species (Fig. 2A, B, C) than for *S. portulacastrum* in which the interaction was not significant indicating similar effects for either foliar or substrate exposure to elevated salinity (Fig. 2D). Competition between Na and K uptake has been reported for a number of plants (Marschner, 1995).

Nitrogen concentration was increased 38% by the application of a salt solution of 70 g L^{-1} to *S. portulacastrum*. Concentrations of Fe, Mg and S were decreased at all levels tested (Table 3). Boron, Mn and Zn shoot contents decreased with low levels of salt then increased with the application of more concentrated salt solutions, as compared to controls (Table 3). In *S. portulacastrum*, Zn showed a decrease in shoot content at all levels except 70 g L^{-1} where Zn concentration was increased 62% (Table 3). This was similar to Teixeira and Carvalho (2008) who also found a decrease in

Table 3. Mean shoot concentrations for minerals with significant interaction between mode of application and salt concentration for *S. portulacastrum* grown in 2.3 L containers irrigated with varied concentrations of 2NaCl:CaCl$_2$ solutions.

		Macronutrients					
		N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)
Sub-Canopy	0 g·L^{-1}	2.6±0.1^y	4285.7±334.8	30680.7±557.6	7731.3±870.5	4023±405.8	6019±495.5
	8.75 g·L^{-1}	2.4±0.1	4748.7±334.1	40327±702.9	9954±1192.4	2603±159.2	5125.7±627.4
	17.5 g·L^{-1}	2.5±0.0	4676.3±420.2	39953.3±1342.9	10678.3±1011.7	2459.3±177	4408.3±219.7
	35 g·L^{-1}	2.8±0.1	4637±391.1	32051±406.5	11234±377	2153±24.8	4125.3±245.4
	70 g·L^{-1}	3.9±0.3	5415.3±203	42433.3±1280.1	17855±1770.8	3981.3±68.7	5617.7±50.2
Foliar	0 g·L^{-1}	2.7±0.1	4910±167.1	33271.3±932.2	8499.3±1147.3	3876.3±168.8	6291.7±455.1
	8.75 g·L^{-1}	2.4±0.1	3910.7±259.8	39273.3±2750.8	7892±135.2	2275.7±274.2	4327.7±402.7
	17.5 g·L^{-1}	2.4±0.1	5006±157.9	37207±1812	11473.7±1154.5	2361.7±131.7	4181.7±403.1
	35 g·L^{-1}	2.8±0.1	5340.7±609.1	31920±798.8	11229.3±276.6	2182.7±40.6	3835.7±139.6
	70 g·L^{-1}	3.6±0.1	5266.7±222.7	37707.3±1234.4	21959±586.4	3792.3±104	4987±371.9
ANOVA Effects	Irrigation mode	0.583^z	0.401	0.172	0.322	0.165	0.192
	Salt concentration	<0.0001***	0.057	<0.0001***	<0.0001***	<0.0001***	<0.0001***
	Mode x salt concentration	0.786	0.182	0.132	0.065	0.937	0.669
		Micronutrients					
		Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Na (ppm)	B (ppm)
Sub-Canopy	0 g·L^{-1}	15.3±0.9	43.3±8.8	5.7±0.3	153.3±11.6	46860.7±476.6	85±2.5
	8.75 g·L^{-1}	14.3±2.4	33.7±5.5	7±0.6	133±10.5	82387.3±10881.1	68.7±6.2
	17.5 g·L^{-1}	12.3±2.4	25±3	7.7±0.9	106.3±15.4	81218.7±7270.3	58.3±4.1
	35 g·L^{-1}	11.7±1.5	21.3±0.9	6.3±0.7	101±15	79868.3±4983.7	58.3±4.7
	70 g·L^{-1}	24±0.6	26.7±2.7	9.7±0.7	184±9.7	69476.7±1665.7	96.3±6
Foliar	0 g·L^{-1}	16±1.5	39±4.6	5.7±0.3	137.7±19.8	47433.7±1106.4	88±3.6
	8.75 g·L^{-1}	15.3±2	22±3.6	6.7±0.3	114.3±10.4	80804±8616.8	61±3.6
	17.5 g·L^{-1}	13.3±1.5	30±1.5	7±0.6	93.3±8.4	78715±4696.5	61±2
	35 g·L^{-1}	14.3±0.9	27.3±3	7±0	94.3±8.6	80388±6802.2	58.7±0.3
	70 g·L^{-1}	26.7±1.5	24.3±3	9±0.6	187.3±20.7	69478.7±4904	100.3±5.8
ANOVA Effects	Irrigation mode	0.177	0.824	0.686	0.31	0.804	0.98
	Salt concentration	<0.0001***	0.006	<0.0001***	<0.0001***	<0.0001***	<0.0001***
	Mode x salt concentration	1	0.239	0.913	1	1	0.665

^{y} Values represent means (± standard errors) of 3 observations.
^{z} NS,*,**,***Non significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively. Mode of application either foliar or sub-canopy. Level is 0, 8.75, 17.5, 35 and 70 g L^{-1} of 2NaCl:CaCl$_2$. P values are permutation test p-values.

Zn, however they did not treat plants with irrigation water having a total salt concentration near the greatest concentration in this study.

3.3. *Oenothera drummondii* mineral content

For *O. drummondii* all mineral concentrations had significant effects except for B (Table 4). There were interactions among the modes of application and salt concentrations for N, Ca, Mg, Na, Zn, Fe and Cu in *O. drummondii* (Table 4). Concentrations of Ca, Cu, Na and Zn increased as compared to controls for both modes of application and all salt concentrations tested. Potassium, Mg and P had decreased mineral concentrations compared to controls for all salt concentrations in *O. drummondii*. This suggests Ca, Cu and Na were preferentially taken up by the plants as salt concentrations increased (Table 4). This is similar to studies with *Antirrhinum majus* L., considered tolerant of saline irrigation, which also showed increasing concentrations of Ca and Na with decreasing concentrations of K and P (Carter and Grieve, 2008) and *Zinnia elegans* which also showed decreasing K with increasing salt concentrations (Carter and Grieve 2010). Nitrogen was decreased 17% by the foliar application of irrigation water with a total salt concentration of 8.75 g L^{-1}, but increased 63% by sub-canopy application of irrigation water at the same concentration with *O. drummondii* (Table 4).

3.4. *Erigeron procumbens* mineral content

Treatments did not have effect on N, Mg, Cu, S or B in *E. procumbens*. There were interactions among the modes of application and salt concentrations for Na, Ca and P (Table 5). Mode of application was only significant for P and Zn. Zinc

Table 4. Mean shoot concentrations for minerals with significant interaction between mode of application and salt concentration for *O. drummondii* grown in 2.3 L containers irrigated with varied concentrations of 2NaCl:$CaCl_2$ solutions.

		Macronutrients					
		N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)
Sub-Canopy	0 g·L^{-1}	2.6±0.3^{y}	5402.7±501.5	29439±1234.7	17240.3±1229.9	3597±92.5	6568.7±261.2
	8.75 g·L^{-1}	4.2±0.2	5097.3±181.8	24035±260.7	22062.3±668.8	2518.3±128.7	7005.3±305.2
	17.5 g·L^{-1}	4.0±0.2	5047.3±153.7	23667.3±837.6	26425.3±897.8	2661±53.2	5366±420.1
Foliar	0 g·L^{-1}	3.4±0.4	5019.3±12.7	30272.3±483.5	15585.7±652.4	2984±162.3	7258.7±549.9
	8.75 g·L^{-1}	2.8±0.2	4573.3±277.1	24509.7±583.6	24090±761.9	2160.3±150	5159.3±529.2
	17.5 g·L^{-1}	3.0±0.2	3966.3±298.8	22500.7±980.3	31809±1930.5	2892.3±76.2	5070±644
ANOVA Effects	Irrigation mode	0.028*^{Z}	0.003**	0.922	0.055	0.018*	0.198
	Salt concentration	0.097	0.058	<0.0001***	<0.0001***	<0.0001***	0.007**
	Mode x salt concentration	0.002**	0.77	0.5	0.026	0.009	0.073

		Micronutrients					
		Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Na (ppm)	B (ppm)
Sub-Canopy	0 g·L^{-1}	47.3±1.8	112±11.2	13.7±1.2	312.7±53.5	8045±868.3	71±0.6
	8.75 g·L^{-1}	108±8	80.3±15.7	32±3.6	306±32.8	15523.3±1259.1	69.3±3.3
	17.5 g·L^{-1}	91.7±12.2	125.7±25.7	22±2.5	226.3±6.3	17995.7±1801.1	67.3±3.8
Foliar	0 g·L^{-1}	55.7±6.7	80.7±1.9	15.3±2.3	258.7±20.7	10033.3±339.1	68±4.2
	8.75 g·L^{-1}	68.7±1.2	97±33.5	19±1	220.7±23.7	16485.7±304.2	58.3±1.9
	17.5 g·L^{-1}	85.7±10.2	25.7±1.2	21±2.3	260.7±34	36851.7±5320.5	72±9
ANOVA Effects	Irrigation mode	0.075	0.028	0.047	0.143	0.002**	0.37
	Salt concentration	0.001**	0.55	0.001**	0.449	<0.0001***	0.329
	Mode x salt concentration	0.039*	0.038*	0.020*	0.153	0.003**	0.287

^{y} Values represent means (± standard errors) of 3 observations.

^{z} NS,*,**,***Non significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively. Mode of application either foliar or sub-canopy. Level is 0, 8.75, 17.5, 35 and 70 g L^{-1} of 2NaCl:$CaCl_2$. P values are permutation test p-values.

Table 5. Mean shoot concentrations for minerals with significant interaction between mode of application and salt concentration for *E. procumbens* grown in 2.3 L containers irrigated with varied concentrations of 2NaCl:$CaCl_2$ solutions.

		Macronutrients					
		N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)
Sub-Canopy	0 g·L^{-1}	3.2±0.1^{x}	3907±272	20921.3±502.6	7973.7±540.8	2455.7±222.6	4838±221
	8.75 g·L^{-1}	3.4±0.2	4958.7±130.2	15611.7±311.3	13652±521.4	2819.3±65	5445.3±174
	17.5 g·L^{-1}	3.3±0.3	4318.7±199.4	19063.3±2066	14393.7±362.7	2634.7±217	4829.7±268.4
	35 g·L^{-1}	3.3±0.3^{y}	3978.3±80.4	16050.0±281.6	25918.3±1253.0	3382.0±73.1	5723.0±223.3
Foliar	0 g·L^{-1}	3.4±0.1	4438±151.5	20806±128	8174.3±258.4	2849±123.8	5615.7±120.7
	8.75 g·L^{-1}	3.2±0.1	4067.3±196.5	15202.7±1811.3	16233±3302.6	2667±165.7	5743.3±586
	17.5 g·L^{-1}	3.3±0.1	4609.7±250.7	16396.3±1953.1	24873.3±1526	2558.7±87.2	4643±165.5
ANOVA Effects	Irrig. mode	0.784^{z}	0.014*	0.667	0.302	0.563	0.534
	Salt concentration	0.697	0.013*	0.002**	<0.0001***	0.172	0.076
	Mode x salt concentration	0.578	0.015*	0.635	0.015	0.21	0.295

		Micronutrients					
		Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Na (ppm)	B (ppm)
Sub-Canopy	0 g·L^{-1}	41.3±1.5	74±16.1	19.7±0.7	302.7±15.6	16917.3±1392.5	80.7±3.2
	8.75 g·L^{-1}	77±7.1	115.7±33	21.7±1.7	359.3±26.6	29346.3±466.7	75±2.3
	17.5 g·L^{-1}	53.3±2.9	58.3±4.4	19.7±1.2	344.3±38.1	26757±1325.4	80.3±7.3
	35 g·L^{-1}	61.0±7.1	252.7±38.6	26.3±2.0	475.3±56.0	41780.0±1167.5	84.7±2.2
Foliar	0 g·L^{-1}	38.3±0.9	79.3±17.3	20.3±0.3	293±10.6	19410±549.9	84±2.6
	8.75 g·L^{-1}	56.3±9.8	138.3±10.7	20.3±0.9	349.7±44.8	30932.7±5329.2	83±9
	17.5 g·L^{-1}	55.3±3.5	91±25.4	21±1.5	334.3±14.2	43436±2140.1	75.3±2
ANOVA Effects	Irrig. mode	0.021	0.332	0.583	0.643	0.473	0.312
	Salt concentration	0.005	0.045*	0.544	0.010*	<0.0001***	0.593
	Mode x salt concentration	0.127	0.778	0.468	1	0.018*	0.579

^{x} Values represent means (± standard errors) of 3 observations.

^{y} *E. procumbens* treated with 35 g L^{-1} foliar did not survive.

^{z} NS,*,**,***Non significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively. Mode of application either foliar or sub-canopy. Level is 0, 8.75, 17.5, 35 and 70 g L^{-1} of 2NaCl:$CaCl_2$. P values are permutation test p-values.

Table 6. Mean shoot concentrations for minerals with significant interaction between mode of application and salt concentration for *B. frutescens* grown in 2.3 L containers irrigated with varied concentrations of 2NaCl:$CaCl_2$ solutions.

		Macronutrients					
		N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)
Sub-Canopy	0 g·L^{-1}	2.7±0.2^y	2292.3±176	33226±1924	8721.7±599.2	3773±213	18024.3±717.4
	8.75 g·L^{-1}	2.7±0.1	3326.7±320.2	38315.7±420.3	10765±461	3209.3±93.6	16770±557
	17.5 g·L^{-1}	2.8±0.1	3579±222.7	38057±859.2	10899±421.3	2536.7±170.1	17052.7±1366.8
	35 g·L^{-1}	3±0.3	2810.7±305.6	25893.7±1637.1	11212.7±372.7	2628.7±144.7	14537±1317.7
Foliar	0 g·L^{-1}	3.0±0.4	2543.3±203.4	32554.7±2596.3	9883.7±1492.4	4025.3±332.6	16885.3±449.1
	8.75 g·L^{-1}	2.2±0.1	2602.3±108.7	35874.3±1817	10115.7±916.5	2860±102.1	13112.3±746.6
	17.5 g·L^{-1}	2.5±0.1	3115.7±209.1	33544.3±1176.5	11547.3±215.2	2798.3±34.4	15702.7±266.6
	35 g·L^{-1}	3.2±0.1	3056.7±164.2	29400.3±2370.2	18296±1977.7	3629±603.6	17444.3±2183.9
ANOVA Effects	Irrig. mode	0.583^z	0.564	0.47	0.006	0.115	0.205
	Salt concetration	0.029*	0.002**	<0.0001***	<0.0001***	0.005**	0.179
	Mode x salt concentration	0.153	0.128	0.184	0.01	0.159	0.052

		Micronutrients					
		Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Na (ppm)	B (ppm)
Sub-Canopy	0 g·L^{-1}	13.3±0.3	26.3±1.2	11.3±0.7	194.3±13.9	24046±1414.1	120±11.0
	8.75 g·L^{-1}	24.3±0.3	43.3±23.8	15.3±0.7	201±8.1	28007.7±828.8	86.7±0.7
	17.5 g·L^{-1}	31±4.7	28.3±4.1	15.7±0.7	212.7±39.9	28653.7±2323.2	83.7±9.8
	35 g·L^{-1}	21.7±1.9	34±9.6	13±0.6	202.7±27.3	34355.7±3063.4	108.7±5.2
Foliar	0 g·L^{-1}	13.7±0.7	24.3±1.2	11.7±0.3	179.0±8.7	24222.7±2317.4	111.3±5.2
	8.75 g·L^{-1}	16.7±0.9	21.7±0.9	12.7±0.3	162.7±20.3	30419.7±2950.7	82±6.5
	17.5 g·L^{-1}	18.7±2	22.3±1.8	13±0.6	172.3±6.3	32994.7±1726.1	93.7±3.8
	35 g·L^{-1}	45.3±5.8	30.7±1.5	17±1.5	388.7±45	38137.3±3541.1	137±19.1
ANOVA Effects	Irrig. mode	0.706	0.451	0.522	0.002**	0.706	0.451
	Salt concentration	<0.0001***	0.842	0.001	<0.0001***	<0.0001***	0.842
	Mode x salt concentration	<0.0001***	0.875	0.002	0.003**	<0.0001***	0.875

^{y} Values represent means (± standard errors) of 3 observations.

^{z} NS,*,**,***Non significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively. Mode of application either foliar or sub-canopy. Level is 0, 8.75, 17.5, 35 and 70 g L^{-1} of 2NaCl:$CaCl_2$. P values are permutation test p-values.

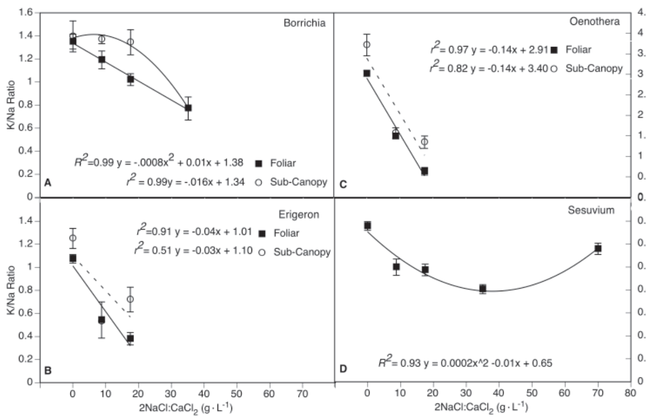

Fig. 2. Ratios of K/Na. Ratios of K/Na with significant (P≤0.05) interactions among application modes and salt levels for *B. frutescens* (A), *O. drummondii* (B) and *E. procumbens* (C). There was not a significant interaction or main effect of modes of application for *S. portulacastrum* (D). Symbols for *B. frutescens*, *O. drummondii* and *E. procumbens* represent means (± s.e.) for n=3; those for *S. portulacastrum* represent means (± s.e.) for n=6. Absence of symbols indicates mortality. All regression equations were generated from the means.

and P were increased by as much as 86% and 27%, respectively, in sub-canopy irrigation treatments of *E. procumbens* at 8.75 g L^{-1} total salts. With foliar applications at the same concentrations Zn was only increased 46% and P was unaffected (Table 5).

3.5. *Borrichia frutescens* mineral content

Shoot concentrations of Fe and S of *B. frutescens* were not affected by any of the treatments. There were interactions among modes of application and salt concentrations for Ca, Zn and Cu in *B. frutescens*, with Zn concentrations increasing by as much as 230% at 35 g L^{-1} of salinity as compared to controls (Table 6). The increase in Zn could be the result of a defense mechanism to elevated levels of Na in the irrigation water and substrate (Tavallali *et al.*, 2009). Zinc has been shown to mitigate some effects of Na and Zn concentrations in tissues have been shown to increase in other plants such as *Capsicum annuum* L. (Cornillon and Palloix, 1997) and *Pistacia vera* L. (Tavallali *et al.*, 2009) in response to Na application. Mode of application did not affect all other minerals tested in *B. frutescens*.

3.6. Foliar damage ratings

Sesuvium portulacastrum only had foliar damage ratings at the highest level (70 g L^{-1}), but exhibited essentially no signs of damage at levels equivalent to the salinity of seawater (Table 2). *Oenothera drummondii* had increasing amounts of damaged foliage with increasing salt concentrations with mean foliar damage ratings decreased from 5 for controls to 3.5 at 17.5 g L^{-1}. Treatments with salt concentrations greater than 17.5 g L^{-1} resulted in mortality of *O. drummondii*. The lesser salinity tolerance of *O. drummondii* compared to *S. portulacastrum* is consistent with its occurrence typically associated with the landward side of the dunes, whereas *S. portulacastrum* is often found on the seaward side of the dunes. Surviving *B. frutescens*, while stunted, did not exhibit any foliar damage up to 35 g L^{-1} salinity exposure, but were killed by treatments with salt concentrations of 70 g L^{-1}. Mode of application (either foliar application or sub canopy) only had effect on *E. procumbens*. Increasing levels of salt in the irrigation water decreased the mean damage rating from 4.8 to 3.25 at 17.5 g L^{-1} for sub-canopy applications and from 5 to 2.8 at 35 g L^{-1}. *Erigeron procumbens* was killed at concentrations greater than 35 g L^{-1}.

4. Conclusions

Sesuvium portulacastrum had increasing levels of K while other species treated with similar levels of saline irrigation water either had decreasing concentrations of K or unchanged concentrations of K while tissue concentrations of Na increased. Salt tolerance seems to be linked with the ability of the plant to maintain a high K/Na ratio (Navarro *et al*., 2008; Taiz and Zeiger, 2006). As shown in Figure 2, *S. portulacastrum* has a relatively steady K/Na ratio while all other species show a decrease in the ratio with treatment of salty irrigation water and death occurring with K/Na ratios between 0.2-0.8 (Fig. 2). Continued growth and survival of *S. portulacastrum* when irrigated with water containing salinity approximately twice seawater, lack of adverse responses to foliar application of salinity, and its enhanced growth at milder elevations in substrate salinity are consistent with its designation as a halophyte.

Although less tolerant to irrigation with saline water than *S. portulacastrum*, the other three species included in these studies tolerated chronic exposure to irrigation water with salinity half as salty as seawater and in some cases survived even greater concentrations. *Borrichia frutescens*, *E. procumbens* and *S. portulacastrum* may use the accumulation of Zn as a method to mitigate increasing amounts on Na in shoot tissues.

A slight decrease in growth from the shortening of internodes could be a beneficial aspect of using saline irrigation water on these species. The reduction in growth could eliminate or reduce the amount of plant growth regulators needed during a commercial production cycle where plant retardants are regularly used to increase compactness of plants.

All four species in this study can be irrigated with water resulting in a substrate EC of 15 mS cm^{-1} without affecting their ability to perform as ornamentals in container production, permitting the use of low quality irrigation water. Tolerance of these salinity levels may prove useful in landscape settings with recycled irrigation water, in coastal restoration or landscape development, and in areas where highway runoff or splash of deicing salts would be encountered.

Acknowledgement

This study is to be included as part of a dissertation in partial fulfillment of the requirements for the PhD. degree by S. T. Carver. This work was supported in part by funds from Texas A&M AgriLife Research. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the authors, Texas A&M University, or Texas A&M AgriLife Research and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

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