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Salinity Effects on Emergence, Survival, and Ion Accumulation of *Limonium perezii*

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ABSTRACT

Saline wastewaters may provide a valuable water source for the irrigation of selected salt-tolerant floriculture crops as water quality and quantity becomes limited and as demand for quality water increases. A 2×7 factorial design with three replications was used to test the effects of water ionic composition and salinity, respectively, on emergence, survival, and mineral accumulation of the salt-tolerant cut flower *Limonium perezii* (Stapf) F. T. Hubb cv. 'Blue Seas.' Seeds ($n = 100$) were sown in each of 42 presalinized greenhouse sand tanks. Irrigation water composition represented saline drainage waters typically present in either the San Joaquin Valley (SJV) or the Imperial/Coachella Valleys (ICV) of California. Electrical conductivity levels of the treatment waters were 2.5 (control), 6, 8, 10, 12, 16, and 20 dS m^{-1} , respectively. Seedling emergence was monitored daily and leaf mineral concentrations (total sulfur (S), total phosphorus (P), Ca^{2+} , Mg^{2+} , Na^+ , K^+ , and Cl^-) were determined three months after planting. A two-way ANOVA revealed that salinity had a significant effect on seedling emergence ($F = 27.56$; $P < 0.01$). Cumulative emergence showed a marked decrease above 12 dS m^{-1} for both water treatments and tended to be greater from 6–10 dS m^{-1} than at 2.5 dS m^{-1} . A significant interaction of salinity and water composition was found for survival ($F = 2.90$; $P < 0.05$). Survival approximated 90% in ICV and SJV treatments up to 8 and 10 dS m^{-1} , respectively, yet continued to decrease below 70% in both water treatments at 12 dS m^{-1} and higher. Differences in leaf-mineral concentrations between ICV and SJV water composition can be attributed to differences in composition of irrigation waters. As salinity increased, leaf Ca^{2+} , K^+ , and total P decreased, whereas Mg^{2+} , Na^+ , Cl^- , and total S increased. Stem length showed a marked decrease above 2.5 and 6 dS m^{-1} under ICV and SJV treatments, respectively, with SJV waters producing ~30% more

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marketable flowers at salinities up to 6 dS m⁻¹. Thus, *Limonium perezii* may be produced commercially with moderately saline wastewaters.

Keywords: ion accumulation, salinity stress, seedling emergence, seed germination, statice, wastewater

INTRODUCTION

Management of water resources has become an important and necessary practice as overall demands for water quantity and quality rise due to increasing population and irrigation for agriculture. For several years, many areas have been reclaiming municipal wastewaters for reuse in agricultural systems to address these needs. Likewise, saline wastewaters may also function as an additional and useful source of irrigation water for selected salt-tolerant floriculture crops. This may prove useful for the San Joaquin Valley (SJV) and Imperial and Coachella Valleys (ICV) of California, where many crops are grown. In recent years in the SJV, both physical hydrogeochemistry and regulations limiting off-site drainage water disposal have promoted increases in soil salinity (Bassil and Kaffka, 2002). Drainage from irrigated croplands often returns to rivers, carrying with it salts and nutrients and thereby increasing eutrophication potential. This is especially true in the Colorado River as it approaches the southeastern corner of the state, and in the Salton Sea.

Many horticultural crops and their wild relatives are tolerant of varying levels of salinity. *Limonium* (common name statice), in particular, occurs worldwide (Aronson, 1989) and has been reported to occur naturally in coastal salt-marsh plant communities (Gleason and Cronquist, 1991). Morales et al. (2001) found that the wild type *Limonium pectinatum* was unaffected after four months of irrigation with a 200 mM NaCl solution. However, studies have shown that wild-type species tend to be more salt tolerant than related cultivated species (Morales et al., 2001; Alarcón et al., 1999). Pasternak and Nerd (1996) reported that wild relatives of *Limonium* sp. showed no reduction in yield when irrigation waters reached electrical conductivities of up to 15 dS m⁻¹.

Tolerance to salinity at later stages of development, however, does not always correlate with tolerance at earlier stages of development under similar environmental conditions (Waisel, 1989). Most seeds of salt-tolerant species demonstrate their greatest germination in freshwater (Ungar, 1991). Under saline conditions, seeds show a threefold response to salt stress: (1) germination at high salinities; (2) enforced dormancy; and (3) the capacity to remain viable when exposed to hypersaline conditions (Ungar, 1995). Successful germination (or radicle emergence) does not always ensure successful development or survival at later stages. Adam (1990) recognizes that newly germinated seedlings are particularly vulnerable in that they may not have developed the physiological mechanisms to withstand high salinities. Alternatively, Stumpf

et al. (1986) suggests that halophytic seedlings such as *Salicornia bigelovii* require moderate-to-high salinities in order to promote cotyledon expansion.

When compared with agronomic crops, horticultural crops have been identified as being better adapted for use with newer water-efficient technologies due to their higher monetary value and controlled growing conditions (Parsons, 2000). Statice (*Limonium* sp.) is commonly used in water-efficient irrigated landscape designs where salinization potential increases over time. Not only is *Limonium* tolerant to salinity, but it has also become an economically important cut flower. In 1998, 234 operations in the United States sold 3.7 million bunches of statice at \$4.3 million. Of these operations, 75 were located in California, where annual sales approached \$3.7 million (Census of Horticultural Specialties, 1998).

The purpose of this study was to determine whether marketable *Limonium perezii* cut flowers could be produced from seeds exposed to saline conditions. Specifically, the goals of this investigation were (1) to determine emergence of *L. perezii* seedlings when seeds were exposed to differing saline water ionic compositions and increasing salinity; (2) to assess survival of *L. perezii*; (3) to evaluate marketability of flowering stems based on plant height; and (4) to compare mineral uptake of *L. perezii* when exposed to differing water ionic compositions and salinity levels.

MATERIALS AND METHODS

Native to the Canary Islands, *Limonium perezii* (Stapf) F. T. Hubb. cv. 'Blue Seas' (Plumbaginaceae) is a perennial herb that has become a widely cultivated floral crop. Flowering stems of *L. perezii* arise from basal leaves. Pale-yellow flowers surrounded by a purplish-blue calyx are produced from March to September in the wild (Munz, 1973).

A 2×7 factorial design with three replications was used to test the effects of water ionic composition and salinity on emergence, survival, and mineral composition of *L. perezii*. Seeds of *L. perezii* were sown in greenhouse sand tanks. Ten seeds were placed between two strips of MicroporeTM (3M Company) surgical tape (1.25 cm wide \times 33 cm long) at 3.0 cm spacings. Ten strips were buried to a 1.0 cm depth at 10 cm intervals in each of 42 greenhouse sand tanks on January 18, 2002 at the George E. Brown, Jr., Salinity Laboratory in Riverside, CA yielding 300 seeds per treatment (3×100 seeds per replicate). Sand tanks were presalinized to one of seven target conductivities [2.5 (control), 6, 8, 10, 12, 16, and 20 dS m^{-1}] made by adding salts to City of Riverside municipal water (Table 1). Two water ionic compositions representing saline drainage waters typically present in the Imperial/Coachella Valleys (ICV) or San Joaquin Valley (SJV) of California were used (Table 1). Micronutrient concentrations based on Hoagland's micronutrient solution were as follows (in mmol) for both water ionic compositions: 0.34 KH_2PO_4 , 0.10 Fe as

Table 1
Target concentrations (mM) of salinizing salts in water solutions used to irrigate *Limonium perezii*

EC (dS m ⁻¹)	Ca ²⁺	Mg ²⁺	Na ⁺ (mM)	SO ₄ ²⁻	Cl ⁻
Imperial/Coachella Valleys					
2.5	2.3	2.6	10.5	3.3	13.3
6	5.7	9.4	32.3	10.0	42.0
8	7.6	12.7	43.6	13.6	57.2
10	9.4	16.3	55.0	17.3	72.5
12	11.4	19.4	66.9	20.9	87.8
16	15.6	27.5	93.8	29.3	124.0
20	19.0	35.0	121.0	36.75	160.0
San Joaquin Valley					
2.5	2.6	1.6	13.8	6.5	4.2
6	6.4	5.0	30.0	14.65	14.1
8	8.3	6.6	44.5	22.5	28.2
10	10.4	8.3	73.3	37.25	35.5
12	12.6	10.0	88.5	44.9	42.9
16	13.0	15.5	123.0	63.5	66.4
20	13.5	20.1	178.0	79.0	86.3

sodium ferric diethylenetriamine pentacetate (NaFeDTPA), 0.046 H₃BO₃, 0.01 MnSO₄, 0.0008 ZnSO₄, 0.0004 CuSO₄, and 0.0002 H₂MoO₄. An additional 6.0 mmol of KNO₃ was also included.

Sand tanks (1.2 × 0.6 × 0.5 m deep) contained washed sand with an average bulk density of 1.54 Mg m⁻³. Volumetric water content was 0.34 m³ m⁻³ and 0.1 m³ m⁻³ at saturation and after the cessation of drainage, respectively. Tanks were flood irrigated with treatment waters for ~15 min twice daily, after which water drained into 765 L subsurface reservoirs for reuse in the next irrigation. Water lost to evapotranspiration was automatically replenished daily to ensure that target electrical conductivity (EC_i) levels were maintained. Treatment waters were measured with an Orion model 126 conductivity meter (Orion Research, Inc.; Beverly, MA) to confirm target EC_i levels. Water was also analyzed with inductively coupled plasma optical emission spectrometry (ICPOES) to validate ion concentrations. Coulometric-amprometric titration was used to determine chloride concentrations. Adjustments to ion compositions were made as necessary to maintain target ion concentrations of the treatment waters. Water pH ranged from 7.5 to 7.9.

Environmental conditions in the greenhouse were recorded with an automated system at hourly intervals at a single point above the plant canopy from March 28, 2002 to July 19, 2002. Daily air temperatures ranged from 11.4°C–41.4°C with a mean of 30.1°C, whereas night temperatures ranged from 11.6°C

to 30.1°C with a mean of 22.1°C. Minimum and maximum values for relative humidity approximated 41% and 48%, respectively for both periods, with a mean relative humidity of 45%. Data were not recorded from January 18, 2002 to March 27, 2002 due to a system upgrade that temporarily prevented data collection. Data collected from January 2001 through March 2001, however, have shown that day temperatures during these months ranged from 11.7°C–34.9°C with a mean of 27.1°C and night temperatures ranged from 11.1°C–30°C with a mean of 19.6°C. Daytime relative humidity values ranged from 41%–48% with a mean of 45.1%, whereas nighttime relative humidity values ranged from 39%–48% with a mean of 43.1%.

Two to six plants in each tank were harvested for ion analysis on April 19, 2002. Leaves were collected to provide at least 1.0 g dry plant material. Fresh plant material was weighed, triple washed with deionized water, and dried at 70°C in a forced air oven for at least 72 h. Dried plant material was reweighed and ground in a Wiley mill to pass a 60 mesh screen. Nitric-perchloric acid digests of dried plant material were used to determine concentrations of total sulfur (S), total phosphorus (P), Ca²⁺, Mg²⁺, Na⁺, and K⁺ with ICPOES. Nitric-acetic acid extracts were used to determine Cl⁻ concentrations with coulometric-amperometric titration.

A two-way, fixed-effects general linear model (GLM) analysis of variance (ANOVA) was performed based on tank means to test for effects of water composition and salinity on emergence, survival, and mineral concentrations of *Limonium perezii*. A Tukey post-hoc multiple comparison procedure was used to compare individual means when significant differences were found. An α -level of 0.05 with double precision was used for both ANOVA and Tukey procedures. All statistical analyses were performed using SAS v. 8.2 (SAS Institute, 2001).

RESULTS

A two-way ANOVA showed that salinity had a significant effect ($F = 27.56$; $P < 0.01$) on the emergence of *Limonium perezii* seeds. No significant effect was found for water composition ($F = 1.08$; $P = 0.31$) and no interaction of salinity and water composition was found ($F = 2.09$; $P = 0.09$). Emergence percentages declined as salinity increased in both water compositions in the 12, 16, and 20 dS m⁻¹ treatments (Figures 1a, 1b). Even though not significantly different, emergence was greater in treatments exposed to 6 and 8 dS m⁻¹ (74.3% and 74%, respectively) when compared with the control treatment (69%) for the ICV composition (Figure 1a). For the SJV composition, emergence was greater in treatments exposed to 10, 8, and 6 dS m⁻¹ (76%, 74%, and 70%, respectively) when compared with the control treatment (64%), even though these four treatments were not found to differ significantly (Figure 1b). An overall delay in emergence was also found under both water compositions

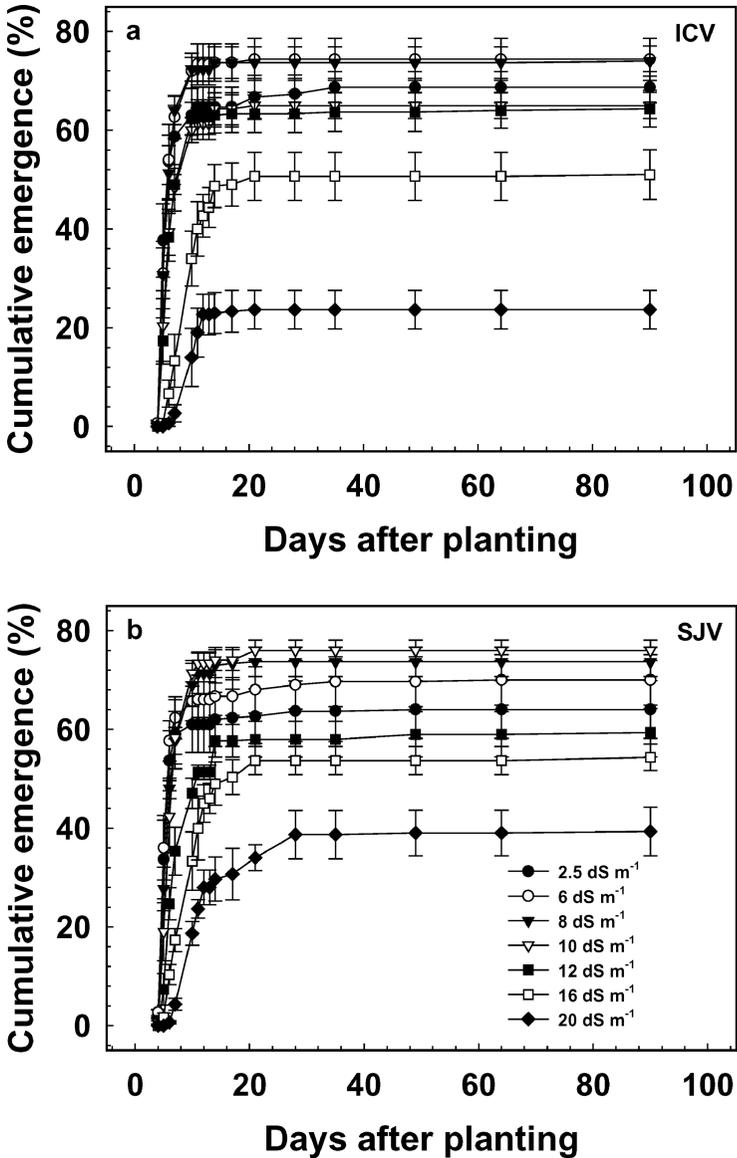


Figure 1. Percent cumulative emergence (mean \pm SE) of *Limonium perezii* seeds exposed to seven salinity treatments in Imperial/Coachella Valley water (ICV) (a) and San Joaquin Valley water (SJV) (b) compositions after 90 d.

as salinity increased, but most seedlings emerged within 20 d for all salinity treatments with each water composition (Figures 1a, 1b).

There was a significant interaction of salinity and water composition on survival percentage of *L. perezii* ($F = 2.90$; $P < 0.05$). For plants grown under

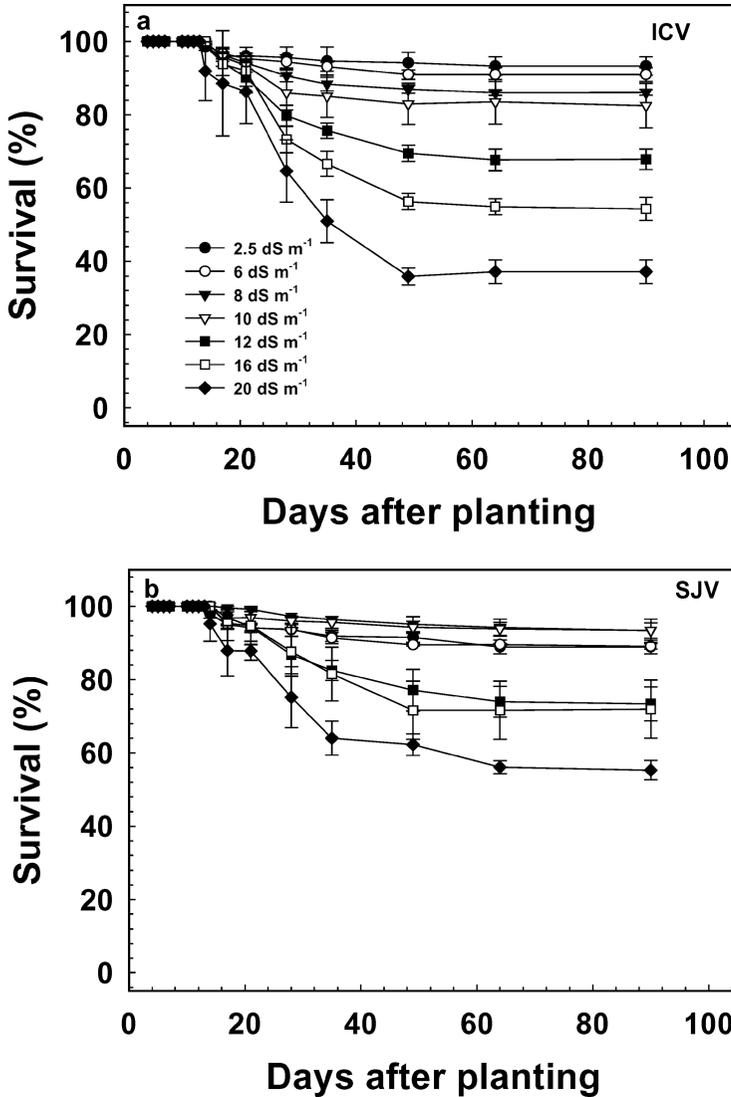


Figure 2. Percent survival (mean \pm SE) of *Limonium perezii* exposed to seven salinity treatments in Imperial/Coachella Valley water (ICV) (a) and San Joaquin Valley water (SJV) (b) compositions after 90 d.

ICV, survival was greatest with 2.5 dS m⁻¹ (93%) and was 91%, 86%, and 83% in 6, 8, and 10 dS m⁻¹, respectively (Figure 2a). Survival decreased from 68% to 37% when salinity increased from 10 to 20 dS m⁻¹, respectively (Figure 2a). Plants exposed to 8 and 10 dS m⁻¹ under SJV had survival rates of 93.4%, whereas those exposed to the control and 6 dS m⁻¹ had 89%

survival (Figure 2b). Survival decreased from 73.4% with 12 dS m⁻¹ to 55.3% with 20 dS m⁻¹ under SJV (Figure 2b).

Barr (1992) suggests 41 cm as the minimum stem length for cut-flower marketability. Length of stems showed an overall decline as salinity increased. Stem length showed a marked decrease above 3 and 6 dS m⁻¹ under ICV and SJV treatments, respectively, with SJV waters producing ~30% more marketable flowers at salinities up to 6 dS m⁻¹ (Figure 3). Once salinities reached 8 dS m⁻¹, 57% of flowering stems under ICV treatments were longer than 41 cm, whereas 24% under SJV were longer than 41 cm. When exposed to 12 dS m⁻¹, 96% and 100% of flowering stems were found to be less than 41 cm in length for both ICV and SJV treatments, respectively (Figure 3).

Significant interactions of salinity and water composition were found for concentrations of Ca²⁺ ($F = 4.44$; $P = 0.003$), Mg²⁺ ($F = 2.48$; $P = 0.048$), Na⁺ ($F = 4.71$; $P = 0.002$), Cl⁻ ($F = 3.57$; $P = 0.009$), total P ($F = 8.89$; $P < 0.01$), and total S ($F = 13.7$; $P < 0.01$) in *L. perezii* leaves. There was no significant interaction of salinity and water composition for K⁺ concentrations ($F = 1.49$; $P = 0.22$), even though salinity and water composition were both found to be statistically significant ($F = 60.1$, $P < 0.01$; $F = 6.29$, $P = 0.18$; respectively).

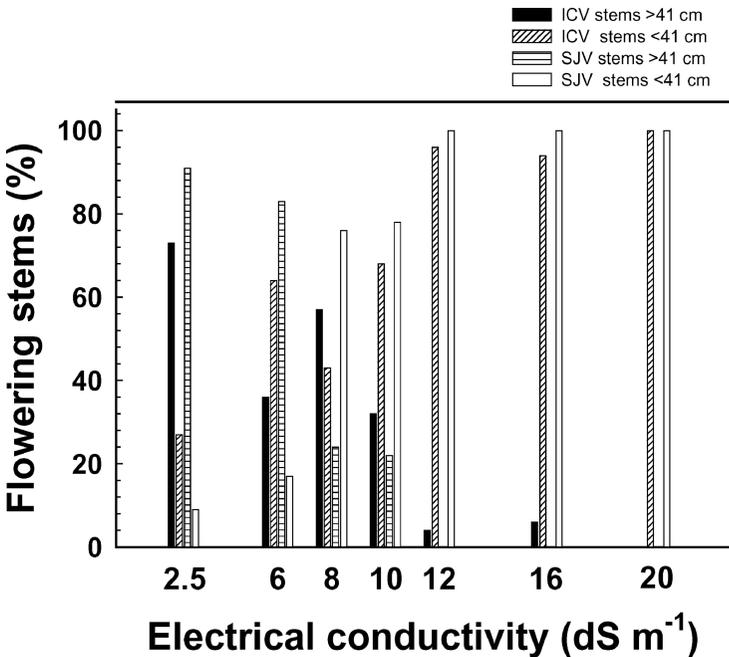


Figure 3. Percentage (mean \pm SE) of *Limonium perezii* flowering stems above and below 41 cm height for plants grown in Imperial/Coachella Valley water (ICV) and San Joaquin Valley water (SJV) and exposed to seven salinity treatments.

Calcium (Ca) concentrations were higher, overall, under ICV treatments than SJV treatments. Calcium concentrations declined under the ICV treatments from 177 mmol kg⁻¹ dwt in the control to 106.1 mmol kg⁻¹ dwt in 12 dS m⁻¹ and increased to 153.5 mmol kg⁻¹ dwt in 20 dS m⁻¹. Under SJV treatments, Ca concentrations declined from 188 mmol kg⁻¹ dwt in the control to 77.5 mmol kg⁻¹ dwt in 16 dS m⁻¹ and increased to 98.7 mmol kg⁻¹ dwt in 20 dS m⁻¹ (Figure 4a). Magnesium (Mg) concentrations were also higher in ICV treatments when compared with SJV treatments. In ICV, Mg²⁺ concentrations ranged from 501.3 mmol kg⁻¹ dwt in the control to 586 mmol kg⁻¹ dwt in 20 dS m⁻¹. Magnesium concentrations also increased in SJV treatments and ranged from 327.3 mmol kg⁻¹ dwt in the control to 419.3 mmol kg⁻¹ dwt in 20 dS m⁻¹ (Figure 4b). Sodium (Na) concentrations increased with increasing salinity and were higher under SJV treatments than ICV treatments. Concentrations ranged from 712 mmol kg⁻¹ dwt in the control to 1504.5 mmol kg⁻¹ dwt in 20 dS m⁻¹ for ICV and from 805.3 mmol kg⁻¹ dwt in the control to 1938.7 mmol kg⁻¹ dwt in 20 dS m⁻¹ for SJV (Figure 4c).

Unlike Na, chloride concentrations showed different responses between the two water compositions and were higher under ICV treatments than SJV treatments. Chloride concentrations ranged from 1177.7 mmol kg⁻¹ dwt in the control to 1655 mmol kg⁻¹ dwt in 20 dS m⁻¹ in ICV and from 1019 mmol kg⁻¹ dwt in the control to 1043.3 mmol kg⁻¹ dwt in 20 dS m⁻¹ in SJV (Figure 4d).

Potassium K concentrations declined with increasing salinity. Values ranged from 1173.3 mmol kg⁻¹ dwt in the control to 493.5 mmol kg⁻¹ dwt in 20 dS m⁻¹ for ICV and from 1205.3 mmol kg⁻¹ dwt in the control to 459.3 mmol kg⁻¹ dwt in 20 dS m⁻¹ for SJV (Figure 4e). Total P concentrations declined as salinity increased. Under ICV, concentrations ranged from 214.3 mmol kg⁻¹ dwt in the control to 120 mmol kg⁻¹ dwt in 20 dS m⁻¹. Under SJV, concentrations ranged from 233 mmol kg⁻¹ dwt in the control to 113.7 mmol kg⁻¹ dwt in 20 dS m⁻¹ (Figure 4f). Total S concentrations were higher, overall, under SJV than ICV treatments. Values increased from 249.3 mmol kg⁻¹ dwt in the control to 358 mmol kg⁻¹ dwt in 20 dS m⁻¹ for ICV. Under SJV, concentrations ranged from 235.3 mmol kg⁻¹ dwt in the control to 651.3 mmol kg⁻¹ dwt in 20 dS m⁻¹ (Figure 4g).

DISCUSSION

As indicated by the seed supplier, expected germination percentage for seeds of *L. perezii* was 78% under ideal environmental conditions. These findings show that seeds exposed to moderately saline treatments in both water compositions approximated 75% emergence compared with the controls, where emergence was found to be less than 70%. Even though the control treatments did not differ statistically from the moderately saline treatments, emergence of *L. perezii* was seemingly enhanced by moderate levels of salinity. Likewise, Keiffer and Ungar

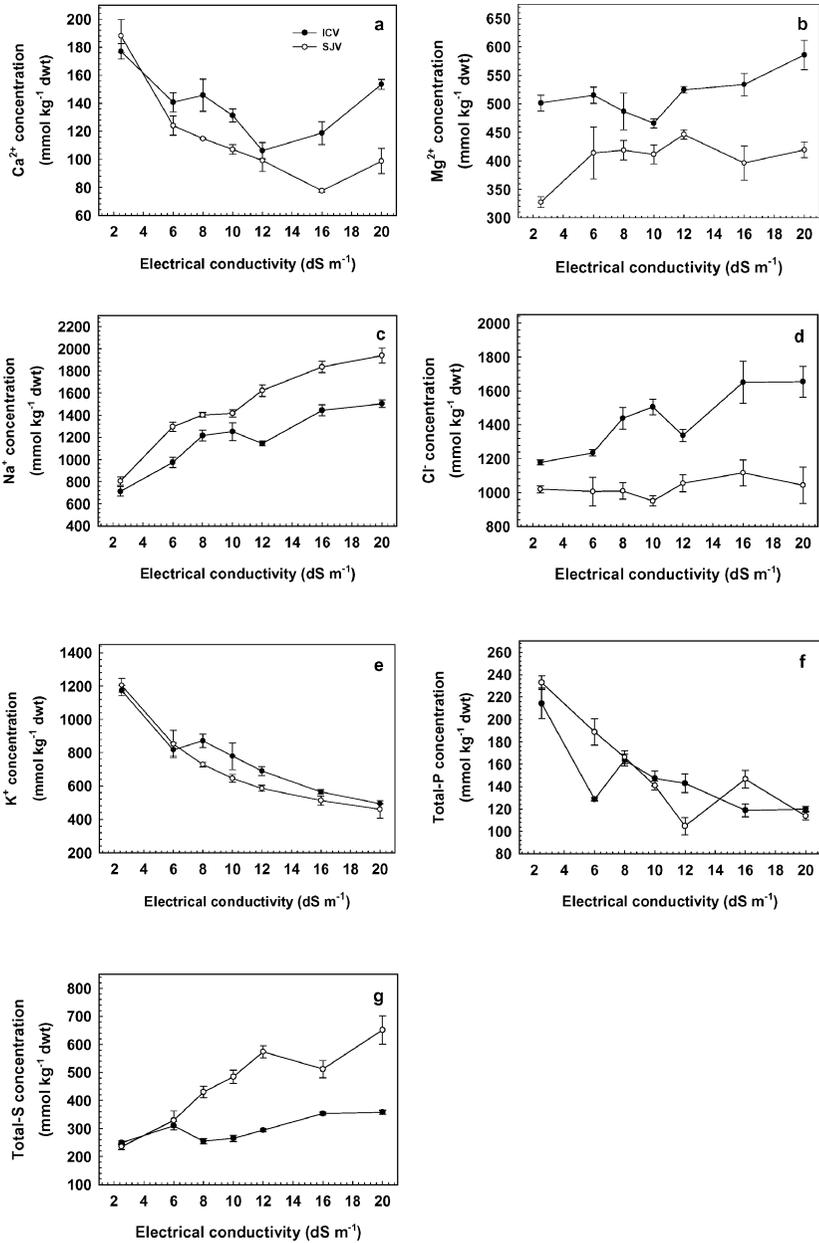


Figure 4. Ion concentrations (mean \pm SE) for Ca²⁺ (a), Mg²⁺ (b), Na⁺ (c), Cl⁻ (d), K⁺ (e), total P (f), and total S (g) of *Limonium perezii* leaves when exposed to seven salinity treatments and Imperial/Coachella Valley water (ICV) or San Joaquin Valley water (SJV) after 90 d.

(1997) found that seed germination of the halophytes *Salicornia europaea* and *Suaeda calceoliformis* was stimulated when seeds were exposed to high-salinity pre-treatments. Zia and Khan (2004) also found that seed germination of *Limonium stocksii* was not inhibited under salinities of up to 200 mM/L NaCl, but inhibition did occur at higher salinities.

Seedlings exposed to moderate salinities also demonstrated high survival rates (>90%), but performed better under SJV treatments overall when compared with ICV treatments. This may be attributed to the lower Cl^- and higher SO_4^{2-} content of SJV water treatments when compared with ICV water treatments. The concentration of Cl^- in ICV was nearly twice that of SJV and the concentration of SO_4^{2-} in ICV was approximately half that of SJV. In an investigation of salinity effects on four genetically diverse cultivars of wheat, Datta et al. (1995) found that sulfate salinity was more injurious when compared with chloride salinity.

The ability of a plant to maintain a high K^+/Na^+ ratio is a determining factor of its salt tolerance (Maathuis and Amtmann, 1999). Yet as Na^+ concentrations increase in solution, essential nutrients, such as K^+ , are replaced by Na^+ as it also competes for K^+ binding sites in the plant (Maathuis and Amtmann, 1999; Tester and Davenport, 2003). These results indicate that as Na^+ increased in both water treatments, Na^+ uptake by *L. perezii* increased and K^+ decreased.

Even though plant Na^+ concentrations increased with increasing salinity under both water treatments, plant Cl^- concentrations increased only for the ICV treatment. This result may be attributed to the Cl^- concentration of ICV treatment waters, which was nearly twice that of SJV waters. Differences in Cl^- concentrations in plants treated with these two water compositions can also be related to their respective SO_4^{2-} concentrations. White and Broadley (2001) reported that plant selectivity for SO_4^{2-} is greater than selectivity for Cl^- . As the amount of SO_4^{2-} increased in the SJV water, Cl^- uptake in *L. perezii* remained relatively uniform across all salinity levels as total-S concentrations increased, thereby indicating plant selectivity for SO_4^{2-} . Even though plant total-S concentrations showed a slight increase as salinity increased under ICV treatments, Cl^- concentrations showed a greater increase. Sulfate concentrations may not have been great enough in ICV to offset an increase in Cl^- accumulation, given that the SO_4^{2-} concentrations in ICV waters were nearly half those in SJV waters. Similar results were reported by Grieve et al. (2001) in a study conducted on nine leafy vegetables. In their investigation, SO_4^{2-} concentrations in the treatment water ranged from 10.9 mol m^{-3} at 3.0 dS m^{-1} to 93.5 mol m^{-3} at 23 dS m^{-1} . As salinity increased, they found that total-S concentrations increased in leaves of *Beta vulgaris* (Swiss chard), *Cichorium endivia* (curly endive), and *Cichorium intybus* (radicchio) but leaf Cl^- concentrations did not differ statistically.

Concentrations of Ca^{2+} in leaves of *L. perezii* showed an overall decline as salinity increased in both water compositions and were more reduced under SJV treatments than ICV treatments. Suarez and Grieve (1988) reported

that plant selectivity for Ca^{2+} at high salinities is inhibited as root-zone concentrations of Na^+ increase and root membranes lose their ability to discriminate between Ca^{2+} and Na^+ . Differences between SJV and ICV treatments would be expected, as the Na^+ concentrations in SJV water treatments were greater than in the ICV water treatments. Increases in Ca^{2+} in plant tissues at 20 dS m^{-1} may be explained by an overall increase of Ca^{2+} in the treatment solutions.

Magnesium concentrations in plant tissues tend to decrease as salinity increases (Grattan and Grieve, 1999), yet plant Mg^{2+} concentrations increased in plant tissues as salinity increased in the external medium. Marschner (1995) reported that Ca^{2+} outcompetes Mg^{2+} on root-plasma membrane-binding sites when Ca^{2+} concentrations are high in substrate solutions. Given that the $\text{Ca}^{2+}/\text{Mg}^{2+}$ ratio was 1:2 under ICV treatments and approximately 1:1 under SJV treatments, the overall increase of Mg^{2+} in plant tissues and the higher concentration in plants exposed to ICV treatment waters may be attributed to the higher concentration of Mg^{2+} relative to Ca^{2+} in treatment waters and the relative increase of Mg^{2+} in solution as salinity increased.

Phosphorus concentrations in plant tissues have been tied to Ca^{2+} concentrations in soils (Grattan and Grieve, 1999). Sharpley et al. (1992) reported that as salinity increases, P concentrations in plant tissues decrease, and this decline of total P has been attributed to increases in Ca^{2+} in the substrate (Papadopoulos and Rendig, 1983). This phenomenon may be explained by the possible precipitation of P as calcium phosphate in solution as Ca^{2+} increases (Grattan and Grieve, 1999; Sharpley et al., 1992). Yet Champagnol (1979) reported conflicting results depending on the species. Tomatoes, barley, and onions decreased in concentration of total P with increasing substrate salinity, whereas total P concentration in sesame, sorghum, and corn increased with an increase in salinity.

Seed product information provided on the packaging envelope of the seed supplier for this cultivar indicated that expected plant height should range from 61–76 cm under ideal environmental conditions. Others have found a range of results depending on the cultivar. Armitage (1993) reported that plant height for *L. perezii* averaged 49.25 cm in trials conducted on first-year plants at the University of Georgia, whereas Whipker and Hammer (1994) found stem length of *L. sinuatum* to range from 40.6 to 52.1 cm depending on the cultivar. Findings for stem length for plants that have been exposed to salinity differ, however, based on species and cultivar. Morales et al. (2001) found that stem length of the wild type *L. pectinatum* was not affected by exposure to 200 mM NaCl (20.4 dS m^{-1}) for four months but that the hybrid showed a significant decrease in stem length (80.8 cm to 57.5 cm) when exposed to salinity. Similarly, *L. perezii* growing in the wild has been reported to have a maximum salinity tolerance of 56 dS m^{-1} (Aronson, 1989), but cultivated *L. perezii* is seemingly more sensitive, in this case, to sulfate-dominated salinity and is less salt tolerant, overall, when compared with other species of cultivated *Limonium*.

CONCLUSIONS

Saline wastewaters may be used to produce *L. perezii* commercially. Moderately saline irrigation water of up to 10 dS m⁻¹ stimulates germination at rates, especially those waters that mimic the composition of waters in the San Joaquin Valley. Not only can seeds germinate in saline irrigation water, but seedlings also demonstrate high survival percentages and complete their life cycles under similar environmental conditions. Saline wastewaters that have an electrical conductivity up to 6 dS m⁻¹ with a composition similar to that of the San Joaquin Valley are best used to produce plants with an adequate stem length with regard to industry standards. Differences in mineral uptake and composition in plant tissues exposed to different treatment solutions may be attributed to ion interactions and quantitative differences in ionic composition of the solutions themselves. Essential nutrients, such as Ca²⁺, K⁺, and total P, in plant tissues tend to decline with an increase in substrate salinity, whereas Cl⁻, Na⁺, Mg²⁺, and total S tend to increase.

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