Relative Salt Tolerance of Seven Texas Superstar® Perennials

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Abstract. Salt tolerance of seven Texas Superstar® perennials [*Malvaviscus arboreus* var. *drummondii* (Turk's cap), *Phlox paniculata* 'John Fanick' ('John Fanick' phlox), *Phlox paniculata* 'Texas Pink' ('Texas Pink' phlox), *Ruellia brittoniana* 'Katie Blue' ('Katie Blue' ruellia), *Salvia farinacea* 'Henry Duelberg' ('Henry Duelberg' salvia), *Salvia leucantha* (mexican bush sage), and *Verbena ×hybrida* 'Blue Princess' ('Blue Princess' verben)] was evaluated in a greenhouse experiment. Plants were irrigated with a nutrient solution at electrical conductivity (EC) of 1.1 dS·m⁻¹ (control) or a salt solution at EC of 5.0 or 10.0 dS·m⁻¹ (EC 5 or EC 10) for 8 weeks. 'John Fanick' and 'Texas Pink' phlox plants in EC 5 had severe salt foliage damage, while those in EC 10 were died. Mexican bush sage in EC 10 had severe salt foliage damage. Turk's cap, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and 'Blue Princess' verben had minor foliar damage regardless of treatment. EC 5 reduced the shoot dry weight (DW) by 45% in 'Texas Pink' phlox and 11% to 18% in 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and mexican bush sage, but did not impact the shoot DW of Turk's cap and 'John Fanick' phlox. EC 10 further decreased the shoot DW of 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and mexican bush sage plants by 32%, 29%, and 56%, respectively. EC 5 decreased leaf net photosynthesis (P_n) of 'Texas Pink' phlox and mexican bush sage, while EC 10 reduced P_n of all species except 'Henry Duelberg' salvia and 'Blue Princess' verben. 'Katie Blue' ruellia and 'Blue Princess' verben had relatively lower leaf Na concentration and 'John Fanick' phlox, 'Texas Pink' phlox, and mexican bush sage had higher leaf Cl concentrations. In summary, Turk's cap, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and 'Blue Princess' verben were the most tolerant perennials, and 'John Fanick' phlox, 'Texas Pink' phlox, and mexican bush sage were the least tolerant to salinity.

Nursery growers and homeowners in arid and semiarid regions are facing ever-increasing pressure of limited supply of potable water for irrigating plants. This forces them to use alternative water sources such as municipal reclaimed water to irrigate nursery crops and landscapes (Wu et al., 2009). Reclaimed water contains beneficial nutrients for plant growth, but also contains relatively high levels of soluble salts, which adversely impact plant growth and development (Haering et al., 2009). Use of reclaimed water is not a widely acceptable practice for irrigating

nursery and landscape plants because of potential salt damage to sensitive plant species and lack of information on their salt tolerance. To enhance sustainable development and expand the usage of reclaimed water, salt-tolerant ornamental plants should be identified for nursery production and landscapes in areas where alternative waters may be used for irrigation.

Salinity decreases soil water potential and thereby makes water less available to plants. Typical plant responses to salinity include slower plant growth, smaller size of whole plants, and foliar injury such as leaf burn, scorch, necrosis, and premature defoliation (Munns, 2002). Salinity may also induce a series of metabolic dysfunctions in plants including absorption of excessive minerals, nutrient imbalance, and inhibition of plant photosynthesis and stomatal conductance (g_s) (Munns and Tester, 2008). The magnitude of the negative effects of salinity on plant growth and physiological processes often depends on salinity level and length of exposure. The actual response of a plant to salinity is highly variable depending on plant species or even cultivars. *Ratibida columnaris* is more salt tolerant than *Oenothera elata* and *S. farinacea*, followed by *Berlandiera lyrata* and *Monarda citriodora* in descending order (Niu et al., 2012a). Villarino and Mattson

(2011) reported that *Euphorbia hybrida* 'White Manaus', *Impatiens walleriana* 'Super Elfin XP White', *Salvia splendens* 'Vista Red', *Zinnia angustifolia* 'Star Gold', and *Viola tricolor* 'Delta Blue Blotch' were sensitive to salinity. They also found that *Tagetes patula* 'Crested Bonanza Bolero' and *Verbena ×hybrida* were moderately tolerant to salinity. Niu and Rodriguez (2006a) found that *Delosperma cooperi* and *Gazania rigens* had a relatively high tolerance to salinity; *Teucrium chamaedrys* and *Cerastostigma plumbaginoides* were moderately tolerant; and *Penstemon eatonii*, *P. strictus*, *P. pseudospectabilis*, and *Lavandula angustifolia* were the least tolerant to salinity. Niu and Rodriguez (2006b) also reported that *Achillea millefolium*, *Gaillardia aristata*, and *Salvia coccinea* had relatively high salt tolerance, while *Agastache cana* and *Echinacea purpurea* were not salt tolerant.

The Texas Superstar® is a special designation given to plants that show superb performance in the Texas landscape based on observations made at replicated demonstration trials across the state (Mackay et al., 2001; Texas AgriLife Research and Extension Service, 2015). During the field trials, plants receive minimal soil preparation, reasonable levels of water, and no pesticides. After several years of extensive field trials, those plants demonstrating superior pest tolerance combined with outstanding landscape performance are awarded the Texas Superstar® designation. However, salt tolerance is not one of the factors considered during the evaluation process.

By 2015, Texas AgriLife Research and Extension Service listed 16 perennial plants as Texas Superstar® plants. Among them, *Lantana ×hybrida* 'New Gold' ('New Gold' lantana), *Lantana montevidensis* (purple lantana) and *Plumbago auriculata* (plumbago) are moderately tolerant to salt (Niu et al., 2007, 2010). Salt tolerance of *M. arboreus* var. *drummondii* (Turk's cap), *P. paniculata* 'John Fanick' ('John Fanick' phlox), *P. paniculata* 'Texas Pink' ('Texas Pink' phlox), *R. brittoniana* 'Katie Blue' ('Katie Blue' ruellia), *S. farinacea* 'Henry Duelberg' ('Henry Duelberg' salvia), *S. leucantha* (mexican bush sage), and *Verbena ×hybrida* 'Blue Princess' ('Blue Princess' verben) remains unknown. Turk's cap is a drought-tolerant, rapidly growing, and a coarse-textured plant native to south Texas and produces a profusion of "turban-like" bright red, pink, or white flowers. 'John Fanick' phlox is a hardy perennial with compact growth habit, dark green foliage, and showy clusters of light pink blossoms with darker pink throats. This plant tolerates heat, drought, and powdery mildew. 'Texas Pink' phlox is a very hardy and disease-resistant phlox that forms clumps with upright multiple stems and provides fragrant blooms during hot summers. 'Katie Blue' ruellia is a perennial with a low, spreading mounds of narrow, dark green foliage and profusion of violet, light pink, or white flowers and is heat tolerant and highly pest resistant. 'Henry Duelberg' salvia is a native perennial with masses of showy blue flowers and is heat

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tolerant. Mexican bush sage is a drought-tolerant and a highly pest-resistant plant with showy spikes of purple and white, or solid purple blossoms. 'Blue Princess' verbena is a perennial with beautiful lavender blue flowers and has resistance to powdery mildew. The objective of this study was to evaluate salt tolerance of seven Texas Superstar® perennials described above in a greenhouse experiment based on their growth and physiological responses to different levels of salinity and the ion accumulation in their leaf tissue.

Materials and Methods

Plant materials and treatments

Rooted cuttings of Texas Superstar® perennials (Table 1) were received from Southwest Perennials Inc. (Dallas, TX). On 1 Feb. 2013, cuttings were transplanted into propagation cells (8.5 cm × 8.5 cm × 8.0 cm) filled with Metro-Mix 360 (SunGro® Horticulture, Agawam, MA). On 18 Feb., plants were transplanted into 2.3-L Poly-Tainer containers (16.5 cm × 16.5 cm, one plant per container) with Metro-Mix 360 (SunGro Horticulture, Bellevue, WA). All plants were watered with a nutrient solution until treatments were initiated. The nutrient solution at EC of 1.2 dS·m⁻¹ was prepared by adding 1 g·L⁻¹ of 15N-2.2P-12.5K (Peters 15-5-15; Scotts) to reverse osmosis (RO) water.

From 7 Mar. to 11 Apr., treatments were applied on a weekly basis by irrigating plants with 1 L nutrient solution (control) or saline solutions at EC of 5.0 or 10.0 dS·m⁻¹ with 10% to 20% leaching fraction. In addition, plants were watered with 500 mL nutrient solution whenever their substrate surface was dry between treatment solutions. On 22 Apr., all plants were watered with 1 L nutrient solution and experiment was ended on 29 Apr. The saline solution was prepared by adding sodium chloride (NaCl) and calcium chloride at 2:1 (molar ratio) to the nutrient solution, prepared as described above. All solutions were prepared in 100-L tanks with confirmed EC of 1.2 ± 0.1 (control, nutrient solution), 4.7 ± 0.3 (EC 5), and 9.0 ± 0.5 dS·m⁻¹ (EC 10) (mean and sd) for the nutrient and saline solutions, respectively. The pH of the solutions was adjusted to 6.0 ± 0.4.

Leachate was collected periodically, and the EC of the leachate was measured using an EC meter (Model B-173; Horiba, Ltd., Japan). To reduce salt accumulation, plants in EC 10 were flushed on 15 Mar. with RO water to lower the salinity in the root zone. The substrate EC was determined using the pour-through method (Cavins et al., 2000). During the experiment, aphids were observed on Turk's cap and 'Henry Duelberg' salvia plants, and mealybugs were observed on Mexican bush sage plants. To control aphids and mealybugs, AVID® 0.15 EC (2% Abamectin; Syngenta Crop Protection Inc., Greensboro, NC) at 5 mL per gallon was applied to all plants. The temperature in the greenhouse was maintained at 27.0 ± 6.4 °C (mean ± sd) during the day and 21.0 ± 2.6 °C at night. The daily light integral (photosynthetically active radiation) was 19.3 ± 4.6 mol·m⁻²·d⁻¹.

Experimental design and statistical analysis

The experiment followed a split-plot design with salinity (three levels) as the main plot and seven species as subplot with eight replications. One-way analysis of variance was performed separately for each species for all data because the species had different growth habits. When salinity effect was significant, means separation among treatments was conducted using Tukey's honestly significant difference multiple comparison. When comparing two treatments (plants all died in treatment EC 10, example), Student's *t* test was employed. All statistical analyses were performed using JMP 11 (SAS Institute Inc., Cary, NC).

Data collection and measurement

Growth parameters and visual quality. Plant growth parameters were taken at the initiation of treatments (i.e., 7 Mar.) and end of experiment (i.e., 29 Apr.). Height (centimeter) from the pot rim to the tallest growth point of the plant was measured for Turk's cap, 'Henry Duelberg' salvia, Mexican bush sage, 'John Fanick' phlox and 'Texas Pink' phlox. Due to their prostrate growth habits, the length of the longest shoot (centimeters) was recorded for 'Blue Princess' verbena and two perpendicular

widths (centimeters) for 'Katie Blue' ruellia. Number of shoots and number of flowers (or inflorescences) of Turk's cap, 'Henry Duelberg' salvia, Mexican bush sage, and 'Blue Princess' verbena were counted. During the experimental period, 'John Fanick' phlox, 'Texas Pink' phlox, and 'Katie Blue' ruellia had no flowers or secondary branches.

Upon termination of the experiment, shoots were severed at the substrate surface, and DW was determined after plants were oven-dried at 65 °C to constant weight. In addition, foliar salt damage (leaf edge burn, necrosis, and discoloration) was rated on a visual score of 0 to 5, where 0 = dead; 1 = severe (over 90%); 2 = moderate (50% to 90%); 3 = slight (less than 50%); 4 = good quality with minor foliar damage; and 5 = excellent with no visible foliar damage.

SPAD reading and gas exchange. Leaf greenness (or relative chlorophyll content) of all plants was measured using a handheld SPAD chlorophyll meter (Minolta Camera Co., Osaka, Japan) 1 week before harvest. For each plant, four leaves evenly distributed from the top of shoot to the bottom were chosen.

Leaf P_n, transpiration (E), and g_s of four plants per species (or cultivar) per treatment were measured 1 week before harvest using a CIRAS-2 portable photosynthesis system with an automatic universal PLC6 broad leaf cuvette (PP Systems, Amesbury, MA). Fully expanded healthy leaves were chosen for the measurements. The environmental conditions in the cuvette were controlled at leaf temperature = 25 °C, photosynthetic photon flux = 1000 μmol·m⁻²·s⁻¹, and carbon dioxide concentration = 375 μmol·mol⁻¹. Data were recorded when the environmental conditions and gas exchange parameters in the cuvette became stable. These measurements were taken on sunny days between 1000 HR and 1400 HR, and the plants were well watered to avoid water stress.

Mineral analysis. Four leaf samples per treatment per cultivar were randomly selected for mineral analysis. Dried tissue samples were ground to pass a 40-mesh screen with a stainless Wiley mill (Thomas Scientific, Swedesboro, NJ). Plant powder samples were extracted with 2% acetic acid

Table 1. Visual score, height, and shoot dry weight of Texas Superstar® perennials irrigated with nutrient solution [control, electrical conductivity (EC) = 1.2 dS·m⁻¹] or saline solutions (EC = 5.0 or 10.0 dS·m⁻¹, EC 5 or EC 10) in the greenhouse (*n* = 8).

Common name	Visual score ^a			Ht (cm)			Dry wt (g)		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Turk's cap	5.0 a ^b	5.0 a	4.9 a	45.0 a	35.8 b	26.0 c	52.0 a	46.7 ab	29.3 b
'John Fanick' phlox	4.0 a	2.6 a	0.0 b	9.0 a	7.0 a	— ^x	3.2 a	2.5 a	— ^x
'Texas Pink' phlox	4.0 a	2.9 b	1.0 c	24.4 a	22.1 a	15.3 b	5.0 a	2.8 b	2.1 b
'Katie Blue' ruellia ^w	4.7 a	4.3 b	4.1 b	17.3 a	8.7 b	10.3 b	28.3 a	23.2 b	19.2 c
'Henry Duelberg' salvia	5.0 a	5.0 a	4.4 b	123.4 a	104.1 b	91.9 b	92.2 a	80.7 b	65.2 c
Mexican bush sage	5.0 a	5.0 a	1.8 b	53.1 a	45.9 a	20.3 b	83.8 a	64.5 b	37.1 c
'Blue Princess' verbena ^v	5.0 a	5.0 a	4.4 b	80.1 a	74.0 a	56.0 b	93.8 a	83.4 b	73.3 b

^aVisual score: 0 = dead; 1 = over 90% foliar salt damage (burning, necrosis, and discoloration); 2 = moderate (50% to 90%) foliar salt damage; 3 = slight (less than 50%) foliar salt damage; 4 = good quality with minor foliar salt damage; and 5 = excellent with no visible foliar salt damage.

^bFor each species, same letters among treatments are not significantly different by Tukey's honestly significant difference multiple comparison or Student's *t* test at *P* < 0.05.

^xAll plants died when a saline solution at EC of 10.0 dS·m⁻¹ applied.

^wDue to the growth habit of 'Katie Blue' ruellia, two perpendicular width instead of height were taken, and their averages are presented.

^vThe mean length of the longest shoot is presented for 'Blue Princess' verbena.

(EM Science, Gibbstown, NJ) for determining anions (Cl^-) using methods described in Gavlak et al. (1994). The anions (Cl^-) were determined by M926 Chloride Analyzer (Cole Parmer Instrument Company, Vernon Hills, IL). Plant powder samples were submitted to the Soil, Water and Forage Testing Laboratory at Texas A&M University (College Station, TX) for determining alkaline earth metals (Na, Ca, K). In brief, plant powder samples were digested in nitric acid following the protocol described by Havlin and Soltanpour (1989). Na, Ca, and K in digested samples were analyzed by SPECTROBLUE inductively coupled plasma-optical emission spectrometry (SPECTRO Analytical Instruments Inc., Mahwah, NJ) and reported on a dry plant basis as described by Isaac and Johnson (1975).

Results and Discussion

Leachate EC. During the period of the experiment, the leachate EC increased from 4.2 to 8.4 $\text{dS}\cdot\text{m}^{-1}$ for plants irrigated with a nutrient solution (control) (Fig. 1). When plants were watered with a saline solution at EC of 5.0 or 10.0 $\text{dS}\cdot\text{m}^{-1}$, the leachate EC increased from 5.8 to 14.2 $\text{dS}\cdot\text{m}^{-1}$ and from 9.4 to 15.3 $\text{dS}\cdot\text{m}^{-1}$, respectively. In peat-based substrates such as the one used in this study, salt often accumulates in the substrate, which is reflected in the increasing leachate EC. In this study, saline solution was applied on a weekly basis, that is, not at every irrigation. When saline solution is applied with every irrigation, salt accumulates rapidly as reported in Niu et al. (2010).

Visual quality and growth. No significant foliage salt damage was observed on Turk's cap plants in EC 5 and EC 10 treatments (Table 1). 'John Fanick' and 'Texas Pink' phlox plants were sensitive to salinity. Phlox plants in the control had minor foliar salt damage with visual scores of 4.0. This might result from salt accumulation in the growing substrate as reflected in the leachate EC at around 4.0 $\text{dS}\cdot\text{m}^{-1}$ or higher throughout the experiment (Fig. 1). In EC 5, 'John Fanick' and 'Texas Pink' phlox plants experienced moderate foliar salt damage with visual

scores of 2.6 and 2.9, respectively. Most plants of 'John Fanick' and 'Texas Pink' phlox died in EC 10. 'Katie Blue' ruellia plants in EC 5 or EC 10 had lower visual score numbers than those in the control, but their foliage salt damage were minimal. Although 'Henry Duelberg' salvia and 'Blue Princess' verbena plants in EC 10 had significantly lower visual score numbers than those in the control, their foliar salt damage were minimal, and all plants were in good quality. Mexican bush sage in EC 10 exhibited severe foliar salt damage with a visual score of 1.8; however, all plants in EC 5 were excellent without any foliar salt damage.

EC 5 significantly reduced the height of Turk's cap and 'Henry Duelberg' salvia plants by 20% and 16%, respectively, in comparison with control (Table 1). The average width of 'Katie Blue' ruellia plants in EC 5 was also 50% smaller than that in control. Compared with their respective control, significant reductions were found in height for mexican bush sage, Turk's cap, 'Texas Pink' phlox, 'Henry Duelberg' salvia, and 'Blue Princess' verbena plants in EC 10 (in the order of high to low, from 62% to 26%). EC 10 reduced the average width of 'Katie Blue' ruellia plants by 41% in comparison with the control. Shoot DWs of Turk's cap and 'John Fanick' phlox were not different between EC 5 and control, but 'Texas Pink' phlox, mexican bush sage, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and 'Blue Princess' verbena plants in EC 5 was reduced by 45% to 11% (from high to low) compared with the control (Table 1). However, shoot DW of 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and mexican bush sage plants was reduced by 32%, 29%, and 56%, respectively, compared with the control.

The numbers of shoots in control and EC 5 were all tested perennial species (Table 2). EC 10 significantly decreased the number of shoots of Turk's cap, mexican bush sage, and 'Blue Princess' verbena plants by 56%, 50%, and 27%, respectively, in comparison with the control.

However, EC 10 did not reduce the number of shoots of 'Henry Duelberg' salvia. Turk's cap plants had a few flowers over the period of experiment, and 'Katie Blue'

ruellia did not flower at all, possibly due to the different timing for flowering for these two species. Compared with the control, EC 5 slightly decreased the number of inflorescences of 'Henry Duelberg' salvia by 19%, but significantly reduced the number of inflorescences of mexican bush sage by 43%. EC 10 further decreased the number of inflorescences of 'Henry Duelberg' salvia and mexican bush sage by 29% and 86%, respectively. However, EC 5 and EC 10 did not affect the number of inflorescences of 'Blue Princess' verbena.

SPAD reading and gas exchange. All Turk's cap, 'Katie Blue' ruellia, and 'Blue Princess' verbena plants had similar SPAD readings among treatments, indicating that salt treatment did not impact their relative chlorophyll content (Table 2). EC 5 did not affect the SPAD readings of 'Henry Duelberg' salvia and mexican bush sage plants, but EC 10 significantly decreased their SPAD readings.

All Turk's cap, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, mexican bush sage, and 'Blue Princess' verbena plants had similar leaf transpiration (Table 3). Leaf transpiration of 'John Fanick' phlox plant in EC 10 was 66% lower than that in EC 5 and in the control. Leaf transpiration of 'Texas Pink' phlox plant in EC 5 and EC 10 was 30% and 75% lower than that in the control, respectively.

Turk's cap and 'John Fanick' phlox plants in EC 5 had similar leaf g_s to those in the control (Table 3). EC 10 reduced the leaf g_s of Turk's cap and 'John Fanick' phlox plants by 46% and 73%. Leaf g_s of 'Texas Pink' phlox plants in EC 5 and EC 10 was 35% and 82% lower than that in the control, respectively. Leaf g_s of 'Katie Blue' ruellia, 'Henry Duelberg' salvia, mexican bush sage, and 'Blue Princess' verbena plants was not significantly different among treatments.

EC 5 did not affect the leaf P_n of Turk's cap, 'John Fanick' phlox, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and 'Blue Princess' verbena, but reduced the leaf P_n of 'Texas Pink' phlox and mexican bush sage by 29% and 26% (Table 3). Leaf P_n of 'John Fanick' phlox, 'Texas Pink' phlox, mexican bush sage, Turk's cap, and 'Katie Blue' ruellia in EC 10 decreased by 92% to 20% (from high to low) compared with the control. EC 10 did not affect the leaf P_n of 'Blue Princess' verbena and 'Henry Duelberg' salvia.

Mineral content. Salt treatment significantly affected the concentrations of Na and Cl in leaf tissue of all species, and the interactive effects between salt treatment and species were significant (Table 4), indicating that salt treatment on leaf mineral concentrations varied with species. Compared with the control, EC 5 significantly increased the leaf Na concentration of Turk's cap, 'Katie Blue' ruellia, and 'Henry Duelberg' salvia plants by 10.5, 4.6, and 11.5 times, respectively. EC 5 also numerically increased leaf Na concentration of 'John Fanick' phlox, 'Texas Pink' phlox, mexican bush sage, and 'Blue Princess' verbena plants, but no statistical difference

Fig. 1. Leachate electrical conductivity (EC) measured after treatment solutions applied. Control, EC 5, and EC 10 represent nutrient solution at EC of 1.2 $\text{dS}\cdot\text{m}^{-1}$, salt solutions at EC of 5.0 and 10.0 $\text{dS}\cdot\text{m}^{-1}$, respectively. Error bars represent SE of means. During the experimental period, nutrient and salt solutions were applied weekly from 7 Mar. to 11 Apr., while only nutrient solution was applied to all plants on 22 Apr.

Table 2. Number of shoots, number of inflorescences/flowers, and relative chlorophyll content (SPAD) of Texas Superstar® perennials irrigated with nutrient solution [control, electrical conductivity (EC) = 1.2 dS·m⁻¹] or saline solutions (EC = 5.0 or 10.0 dS·m⁻¹, EC 5 or EC 10) in the greenhouse (n = 8).

Common name ^z	No. shoots			No. flowers/inflorescences			SPAD		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Turk's cap	5.6 a ^y	4.4 ab	2.5 b	0.1 a	0.1 a	0.4 a	40.3 a	42.1 a	43.0 a
'Katie Blue' ruellia	— ^x	—	—	—	—	—	64.6 a	67.6 a	67.7 a
'Henry Duelberg' salvia	3.9 a	4.3 a	3.9 a	47.1 a	38.3 ab	33.4 b	45.9 a	46.5 a	40.1 b
Mexican bush sage	11.9 a	9.8 a	6.0 b	24.1 a	13.9 b	3.4 c	51.7 a	55.1 a	39.5 b
'Blue Princess' verbena	5.6 ab	6.8 a	4.1 b	137.1 a	136.1 a	115.6 a	50.4 a	51.6 a	45.2 a

^z'John Fanick' and 'Texas Pink' phlox did not produce any secondary branches and flowers over the period of experiment.

^yFor each species, same letters among treatments are not significantly different by Tukey's honestly significant difference multiple comparison at $P < 0.05$.

^xDue to the growth habits of 'Katie Blue' ruellia, number of shoots was not taken. No flowers were observed for this species during the experiment.

Table 3. Leaf transpiration (E), stomatal conductance (g_s), and net photosynthesis (P_n) of Texas Superstar® perennials irrigated with nutrient solution [control, electrical conductivity (EC) = 1.2 dS·m⁻¹] or saline solutions (EC = 5.0 or 10.0 dS·m⁻¹, EC 5 or EC 10) in the greenhouse (n = 4).

Common name	E (mmol·m ⁻² ·s ⁻¹)			g _s (mmol·m ⁻² ·s ⁻¹)			P _n (μmol·m ⁻² ·s ⁻¹)		
	Control	EC 5	EC 10	Control	EC 5	EC 10	Control	EC 5	EC 10
Turk's cap	4.4 a ^z	4.1 a	2.6 a	266.0 a	235.0 ab	144.3 b	12.9 a	12.1 a	8.9 b
'John Fanick' phlox	2.8 a	2.8 a	1.0 b	163.3 a	176.1 a	44.3 b	10.6 a	11.3 a	0.9 b
'Texas Pink' phlox	3.4 a	2.4 b	0.8 c	186.6 a	121.4 b	33.3 c	11.2 a	8.0 b	2.2 c
'Katie Blue' ruellia	5.0 a	5.9 a	4.2 a	326.3 a	353.0 a	312.3 a	17.5 a	18.0 a	13.9 b
'Henry Duelberg' salvia	4.7 a	4.6 a	4.2 a	253.5 a	302.7 a	280.7 a	16.2 a	17.2 a	16.2 a
Mexican bush sage	4.5 a	4.3 a	3.1 a	331.5 a	233.7 a	191.3 a	17.4 a	12.8 b	8.1 c
'Blue Princess' verbena	3.7 a	3.7 a	3.7 a	193.0 a	211.5 a	203.8 a	13.2 a	12.7 a	10.1 a

^zFor each species, same letters among treatments are not significantly different by Tukey's honestly significant difference multiple comparison at $P < 0.05$.

was found. In comparison with control, all plants in EC 10 had significantly higher leaf Na concentration. EC 10 significantly increased the leaf Na concentration of Turk's cap, 'John Fanick' phlox, 'Texas Pink' phlox, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, Mexican bush sage, and 'Blue Princess' verbena plants by 25, 30, 35, 12, 26, 82, and 5 times, respectively. The highest Na concentrations (12.7 mg·g⁻¹ DW) were found in Mexican bush sage in EC 10. Salt treatment also increased the leaf Cl concentration (Table 4). Leaf Cl concentration of Turk's cap, 'John Fanick' phlox, 'Texas Pink' phlox, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, Mexican bush sage, and 'Blue Princess' verbena in EC 5 increased 4, 15, 15, 7, 23, 21, and 6 times, respectively. Leaf Cl concentration of Turk's cap, 'John Fanick' phlox, 'Texas Pink' phlox, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, Mexican bush sage, and 'Blue Princess' verbena in EC 10 increased by 9, 21, 26, 9, 52, 47, and 9 times, respectively. The highest Cl concentrations (81.7 mg·g⁻¹ DW) were found in 'John Fanick' phlox in EC 10.

Plants adapt to soil salinity by excluding Na and Cl ion accumulation and/or tolerating the accumulated Na and Cl in shoot tissue (Munns and Tester, 2008). In this study, leaf Na concentration of 'Katie Blue' ruellia and 'Blue Princess' verbena was lower than the other five tested species (Table 4). 'Katie Blue' ruellia and 'Blue Princess' verbena also had lower leaf Na concentrations than *Zinnia marylandica* and *Zinnia maritime* plants (zinnia) (Niu et al., 2012b) and *C. plumbaginoides*, *D. cooperi*, *G. rigens*, and *T. chamaedrys* (Niu and Rodriguez, 2006a). Leaf Na concentration of Turk's cap, 'John Fanick' phlox, 'Texas Pink' phlox, 'Henry Duelberg' salvia, and Mexican bush sage in EC 5 and EC 10 is similar to that in zinnia plants at EC of 3.0 dS·m⁻¹ (Niu et al., 2012b), but lower than that in zinnia plants at EC of 4.2 dS·m⁻¹ (Niu et al., 2012b). This

Table 4. Leaf ion concentrations of Texas Superstar® perennials irrigated with nutrient solution [control, electrical conductivity (EC) = 1.2 dS·m⁻¹] or saline solutions (EC = 5.0 or 10.0 dS·m⁻¹, EC 5 or EC 10) in the greenhouse (n = 4).

Common name	Treatment	Ion concn (mg·g ⁻¹)			
		Na	Ca	Cl	K
Turk's cap	Control	0.4 c ^z	30.2 b	3.3 c	44.5 a
	EC 5	4.6 b	36.5 a	17.3 b	34.3 b
	EC 10	10.5 a	40.3 a	33.7 a	29.4 b
'John Fanick' phlox	Control	0.4 b	12.7 c	3.7 c	30.9 b
	EC 5	7.0 ab	31.0 b	57.5 b	36.1 ab
	EC 10	11.9 a	41.1 a	81.7 a	38.8 a
'Texas Pink' phlox	Control	0.3 b	14.8 c	2.7 c	33.4 a
	EC 5	5.6 ab	27.6 b	43.2 b	47.7 a
	EC 10	10.5 a	34.1 a	72.5 a	42.8 a
'Katie Blue' ruellia	Control	0.2 c	41.0 a	3.1 c	49.8 a
	EC 5	0.9 b	50.9 a	23.7 b	45.8 b
	EC 10	2.0 a	47.9 a	32.3 a	37.9 c
'Henry Duelberg' salvia	Control	0.3 c	11.4 c	0.6 c	35.2 a
	EC 5	3.6 b	14.0 b	14.8 b	30.0 a
	EC 10	7.8 a	16.1 a	33.2 a	30.3 a
Mexican bush sage	Control	0.2 b	16.0 b	1.1 c	34.6 a
	EC 5	0.9 b	23.8 b	22.6 b	28.4 b
	EC 10	12.7 a	35.3 a	50.7 a	32.0 ab
'Blue Princess' verbena	Control	0.2 b	14.4 b	1.7 b	32.9 a
	EC 5	0.5 b	15.9 ab	11.5 a	29.5 b
	EC 10	1.0 a	16.9 a	16.1 a	29.0 b

^zFor each species, means with same lowercase letters within column are not significantly different among treatments by Tukey's honestly significant difference multiple comparison at $P < 0.05$.

result indicates 'Katie Blue' ruellia and 'Blue Princess' verbena had a strong ability to exclude Na. 'John Fanick' phlox, 'Texas Pink' phlox, and Mexican bush sage had relatively higher leaf Cl contents than other tested species (Table 4). These three plant species also had lower visual quality. Their leaf Cl content of these three plants in EC 5 is lower than in zinnia plants at EC of 4.2 dS·m⁻¹ (Niu et al., 2012b) and in *C. plumbaginoides*, *D. cooperi*, and *G. rigens* at EC of 6.4 dS·m⁻¹ (Niu and Rodriguez, 2006a). 'Blue Princess' verbena had the least Cl contents among all tested species (Table 4). Its leaf Cl concentration is lower than the zinnia plants (Niu et al., 2012b) and *C. plumbaginoides*, *D. cooperi*, *G. rigens*, and

T. chamaedrys (Niu and Rodriguez, 2006a). These results suggest that 'John Fanick' phlox, 'Texas Pink' phlox, and Mexican bush sage could not tolerate the high Cl concentration and caused Cl toxicity, which is reflected in foliar damage.

Salt treatment increased the leaf Ca concentration, but the magnitude is much smaller than that of Na and Cl (Table 4). Leaf Ca concentration of 'John Fanick' phlox and 'Texas Pink' phlox plants in EC 5 increased by 140% and 90%, respectively, while that of other tested plants only increased 50% or less. 'John Fanick' phlox, 'Texas Pink' phlox, and Mexican bush sage plants in EC 10 had 2.2, 1.3, and 1.2 times more Ca in their leaves, respectively, while other tested plants

had 20% to 40% more Ca in their leaves. The leaf Ca concentration of all species is higher than that in *C. plumbaginoides*, *D. cooperi*, *G. rigens*, *T. chamaedrys* (Niu and Rodriguez, 2006a), and most zinnia cultivars (Niu et al., 2012b).

Potassium plays an important role in the turgor-pressure-driven solute transport in the xylem and the water balance of plants (Marschner, 1995). Plants exposed to NaCl inevitably accumulate a great amount of Na, which subsequently causes a reduction in K contents (Hasegawa et al., 2000). Leaf K concentration decreased significantly with increasing EC in all tested species except 'John Fanick' phlox and 'Texas Pink' phlox (Table 4). Compared with the control, Turk's cap, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, mexican bush sage, and 'Blue Princess' verbena plants in EC 5 accumulated 23% to 8% (from high to low) less K in their leaves. In addition, K may transport against a strong Na concentration gradient (Grattan and Grieve, 1999). In this study, leaf K concentration increased significantly with increasing EC in 'John Fanick' phlox and 'Texas Pink' phlox plants (Table 4). Compared with the control, leaf K concentration in 'John Fanick' phlox and 'Texas Pink' phlox plants in EC 5 increased by 17% and 43%, while that in EC 10 multiplied by 25% and 28%, respectively. Cachorro et al. (1993) also observed that K level in the cell sap of bean leaves increased with increasing NaCl concentration. All these results might suggest that the efficiency of K uptake is species dependent and an adequate K level is preferentially acquired for plant survival in salt conditions.

Conclusions

Texas Superstar® perennials have different growth and physiological responses to salinity. Turk's cap, 'Katie Blue' ruellia, 'Henry Duelberg' salvia, and 'Blue Princess' verbena were the most tolerant perennials to salinity with minor foliage salt damage and 10% to 18% of reductions in shoot DW in EC 5 and 22% to 44% reductions in shoot DW in

EC 10. 'Katie Blue' ruellia and 'Blue Princess' verbena had relatively lower leaf Na concentration suggesting that both species have strong capability to exclude Na. 'John Fanick' phlox, 'Texas Pink' phlox, and mexican bush sage were sensitive perennials to salinity. 'John Fanick' and 'Texas Pink' phlox in EC 5 had severe salt foliage damage with 21% and 45% reductions in shoot DW, respectively, while most phlox plants died in EC 10. Mexican bush sage had severe salt foliage damage with 56% reductions in shoot DW in EC 10. These three perennials had higher leaf Cl concentrations, indicating that they are sensitive to chloride-dominated salinity. It is important to note that the results from this study may be used as a reference for selecting salt-tolerant Texas Superstar® perennials for landscapes, where low quality water may be used.

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