Morphological and Physiological Responses of Ten Ornamental Taxa to Saline Water Irrigation

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Abstract. Because of limited supply of high-quality water, alternative water sources have been used for irrigation in water-scarce regions. However, alternative waters usually contain high salt levels, which can cause salt damage on salt-sensitive plants. A greenhouse study was conducted to evaluate the relative salt tolerance of 10 ornamental taxa by quantifying relative salt tolerance of the previously described 10 ornamental taxa by quantifying morphological and physiological responses to salinity. The results indicated that the 10 ornamental taxa had different morphological and physiological responses to salinity. The C. speciosa and D. rivularis plants in EC 5 had severe salt foliar damage, whereas those in EC 10 were dead. Hibiscus syriacus and H. macrophylla plants adapted to elevated salinity by tolerating high Na and Cl concentrations in leaf tissue. Forsythia × intermedia ‘Mindor’ and P. quinquefolia ‘Troki’ had relatively low leaf Na and Cl concentration, indicating that both taxa are capable of excluding Na and Cl. C. speciosa and D. rivularis were sensitive to salinity with great growth reduction, severe foliar salt damage, and high Na and Cl accumulation in leaf tissue.

Use of alternative water sources such as municipal reclaimed water for landscape and nursery irrigation is of increasing importance (Yeager et al., 2010). Increased population results in increased demand for freshwater. On the other hand, population growth inevitably increases the production of municipal wastewater. Treated municipal wastewater has already been used for irrigation of landscapes and nursery crops in water-scarce regions for decades (Dobrowolski et al., 2008; Morgan et al., 2008; Tanji et al., 2008; Yeager et al., 2010). However, reclaimed water contains higher salt concentrations than potable water, and the elevated salinity can cause salt damage on salt-sensitive plants (Niu and Cabrera, 2010).

Salinity decreases soil water potential and thereby makes water less available to plants (Munns, 2002). Typical plant responses to salinity include stunted plant growth and foliar injury such as leaf edge burn, scorch, necrosis, and premature defoliation (LeCompte et al., 2017; Munns, 2002; Niu and Cabrera, 2010). Salinity may also induce a series of metabolic dysfunctions in plants, including absorption of excessive Na and Cl, resulting in nutrient imbalance, and inhibition of plant photosynthesis and stomatal conductance (g s) (Munns and Tester, 2008). Information on salt tolerance of commonly used landscape plants is still limited.

The 10 ornamental taxa selected for this study are commonly used for commercial and residential landscapes. C. speciosa (‘Orange Storm’ and ‘Pink Storm’) is a thorny deciduous or semi-evergreen shrub native to eastern Asia. D. rivularis (‘G2X885411’, ‘G2X88544’, and ‘Smndrsf’) is a flowering shrub in the honeysuckle family and native to the eastern United States. F. × intermedia ‘Mindor’ is an ornamental deciduous shrub well adapted to temperature changes and is widely planted in gardens and parks. H. syriacus is a species of flowering plant in the Malvaceae family native to Asia. H. macrophylla (‘Smhmtau’ and ‘Smnhmsigma’) is a species of flowering plant in the family of Hymenaea native to Japan. P. quinquefolia (‘Orange Storm’ and ‘Pink Storm’) is a flowering plant in the family of Hydrangeaceae native to North America, and Forsythia × intermedia (‘Mindor’) is a flowering plant in the family of Vitaceae. The salt tolerance of these taxa is unknown.

To increase the plant selection option for areas where alternative waters may be used for irrigation, evaluation of salt tolerance for popular landscape plants is necessary. The purposes of this study were to compare the relative salt tolerance of the previously described 10 ornamental taxa by quantifying the growth, morphological, and physiological responses to a range of salinity in a greenhouse study.

Materials and Methods

Plant materials and growing conditions. Rooted cuttings (in 5.7 cm pots) of 10 ornamental taxa (Table 1) were received from Spring Meadow Nursery Inc. (Grand Haven, MI) on 3 Mar. 2016. On 4 Mar., the cuttings were transplanted into #1 (2.7 L) Poly-Tainer containers (No. 1P, 16.5 x 16.5 cm) filled with Metro-Mix 360 RSI (canadian
Table 1. Height and shoot dry weight (DW) of 10 ornamental taxa irrigated with nutrient solution [electrical conductivity (EC) = 1.2 dS·m⁻¹; Control] or saline solution [EC = 5.0 dS·m⁻¹ (EC 5) or 10.0 dS·m⁻¹ (EC 10)] in a greenhouse. Plants were harvested after the fourth (first harvest, 5 weeks after initiation of treatment) and eighth treatment (second harvest, 9 weeks after initiation of treatment).

| Taxa                           | First harvest | Second harvest |
|--------------------------------|---------------|----------------|
|                                | Control EC 5  | EC 10          | Control EC 5  | EC 10          |
| Chamaeleo speciosa ‘Orange Storm’ | 18.3 a        | 11.5 b         | 4.4 c         | 23.8 a         |
| Chamaeleo speciosa ‘Pink Storm’  | 18.6 a        | 17.2 a         | 3.4 a         | 32.1 a         |
| Diervilla riviculare ‘G2X88541’  | 12.3 a        | 4.9 b          | 4.3 b         | 16.5 a         |
| Diervilla riviculare ‘G2X88544’  | 23.9 a        | 21.3 a         | 3.5 a         | 33.6 b         |
| Forsythia intermedia ‘Mindor’    | 29.5 a        | 27.1 a         | 16.1 b        | 40.1 a         |
| Hibiscus syriacus ‘ILVOPS’       | 17.6 a        | 17.9 a         | 14.7 a        | 13.2 a         |
| Hydrangea macrophylla ‘Smhnumt’  | 6.1 a         | 2.1 b          | 1.9 a         | 2.7 b          |
| Hydrangea macrophylla ‘Smhrmsigma’ | 6.9 a        | 3.3 ab         | 2 b           | 2.2 a          |
| Parthenocissus quinquefolia ‘Troki’ | 139.2 a      | 114.5 a        | 68.4 b        | 223.7 a        |

Ht (cm)

| Shoot DW (g)                        | First harvest | Second harvest |
|-------------------------------------|---------------|----------------|
| Control EC 5                         | 10.4 a        | 8.2 b          |
| EC 10                                | 19.0 a        | 8.0 b          |
| Control EC 5                         | 12.9 a        | 10.7 b         |
| EC 10                                | 20.9 a        | 7.4 b          |
| Control EC 5                         | 12.7 a        | 8.5 b          |
| EC 10                                | 24.0 a        | 7.9 b          |
| Control EC 5                         | 16.2 a        | 11.3 b         |
| EC 10                                | 32.4 a        | 14.7 b         |
| Control EC 5                         | 11.3 a        | 8.8 a          |
| EC 10                                | 13.2 a        | 9.8 ab         |
| Control EC 5                         | 16.9 a        | 11.3 b         |
| EC 10                                | 32.4 a        | 14.7 b         |
| Control EC 5                         | 15.5 a        | 12.5 b         |
| EC 10                                | 35.7 a        | 13.2 b         |
| Control EC 5                         | 18.5 a        | 13.1 b         |
| EC 10                                | 43.1 a        | 21.7 b         |

Means with same letters within a row and harvest date are not significantly different among treatments by Tukey’s honestly significant difference or (when all plants in one of the three treatments died) with a Student’s t test at P < 0.05.

All plants were dead.

Sphagnum peatmoss 45% to 55%, vermiculite, composted bark, dolomite limestone, and 0.0001% silicon dioxide (SiO₂); SunGro Hort., Bellevue, WA). All plants were grown in a greenhouse in El Paso, TX (lat. 31°41'45"N, long. 106°16'54"W, elev. 1139 m) and well irrigated with reverse osmosis (RO) water-based nutrient solution to avoid salt accumulation in the root zone until treatments started. Two weeks after transplanting (17 Mar.), uniform plants were chosen and treatments were started. The average air temperature in the greenhouse was 25.6 ± 4.2 °C during the day and 17.2 ± 4.2 °C at night. The average daily light integral was 9.5 ± 1.9 mol·m⁻²·d⁻¹ and the average relative humidity was 34.7% ± 13.0% during the experiment.

Treatments. A nutrient solution at an EC of 1.2 dS·m⁻¹ was used as the control. The nutrient solution was prepared by adding 1 g·L⁻¹ 15N–2.2P–12.5K (Peters 15-5-15 Calcium Nitrate) to 15L·day⁻¹ of water. Saline solutions at an EC of 5.0 dS·m⁻¹ (EC 5) was prepared by adding 1.20 g·L⁻¹ sodium chloride (NaCl) and 1.16 g·L⁻¹ calcium chloride (CaCl₂) to the nutrient solution and saline solutions at 10.0 dS·m⁻¹ (EC 10) was prepared by adding 2.84 g·L⁻¹ NaCl and 2.70 g·L⁻¹ CaCl₂ to the nutrient solution. The pH of all solutions was adjusted to 6.6. Both nutrient and saline solutions were prepared in 100-L tanks with confirmed EC using an EC meter (Model B173; Horiba, Ltd., Kyoto, Japan) before irrigation.

From 17 Mar. to 20 May, treatment solutions were applied once a week, eight times in total. At each irrigation, plants were irrigated with 1 L treatment solution per plant. All plants were well watered the day before to avoid water stress.

Leaf greenness and chlorophyll fluorescence. Leaf greenness (or relative chlorophyll content, SPAD reading) was measured using a handheld chlorophyll meter (measured as the optical density; Minolta Camera Co., Osaka, Japan) 1 week before the first and second harvest. Healthy and fully expanded leaves in the middle of the shoot of five plants were chosen for measurements. Meanwhile, to examine the effect of elevated salinity on leaf photosynthetic apparatus, minimal fluorescence (F₀), maximum fluorescence (Fₘ), and the maximal photochemical efficiency of photosystem II (PSII) [variable fluorescence (Fₐ)Fₚₐₚ = Fₘ – F₀] were measured using a Pocket PEA chlorophyll fluorescence system (Hansatech, Norfolk, UK).

Mineral analysis. To analyze leaf Na, chloride (Cl⁻), potassium (K), and calcium (Ca) concentrations, four samples per treatment per taxon were randomly selected from the first harvest. Dried tissue was ground to pass a 40-mesh screen with a stainless Wiley Mill (Thomas Scientific, Swedesboro, NJ). Dried tissue samples were extracted with 2% acetic acid (EM Science, Gibbstown, NJ) to determine Cl⁻ using the method described in Gavlak et al. (1994). The concentration of Cl⁻ was determined with a M926 Chloride

Gas exchange. Leaf net photosynthesis (Pₐ), transpiration (E), and gₛ of four plants per taxon per treatment were measured at the end of the experiment (on 20 Apr. and 20 May) using a CIRAS-2 portable photosynthesis system (PP Systems, Amersbury, MA) with an automatic universal PLC6 broad leaf cuvette. The fully expanded leaf at the top of the plant was chosen for the measurements. The environmental conditions within the cuvette were maintained at a leaf temperature of 25 °C, photosynthetic photon flux of 1000 μmol·m⁻²·s⁻¹, and CO₂ concentration of 375 μmol·mol⁻¹. Data were recorded when the environmental conditions and gas exchange rates in the cuvette became stable. These measurements were taken on sunny days between 1000 and 1400 h and plants were well watered the day before to avoid water stress.

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Fig. 1. Time course of the weekly leachate electrical conductivity (EC) during an experimental period. Control (CNT) represents nutrient solution at an EC of 1.2 dS m⁻¹; EC 5 represents saline solution at an EC of 5.0 dS m⁻¹; and EC 10 represents saline solution at an EC of 10.0 dS m⁻¹. All plants were watered with the nutrient solution on 12 May. Vertical bars represent standard errors of 10 measurements, one per taxon. 

**Experimental design and statistical analysis.**

The experiment used a split-plot design with the salinity treatment as the main plot and 10 taxa as the subplot with five replications for each harvest per treatment per taxon. For growth, gas exchange, and relative chlorophyll content (SPAD readings), there were five replications. For mineral analysis, there were four replications; for measurement of chlorophyll fluorescence and weekly leachate, there were three replications. A two-way analysis of variance was used to test the effects of salinity and taxon on plant growth. Means separation among treatments was conducted using Tukey's honestly significant difference multiple comparison, when all plants in one of the three treatments died, a Student's t-test was used at \( P < 0.05 \).

Hierarchical cluster analysis was conducted based on Ward linkage method and squared Euclidian distance on the means of the main salt tolerance indices (Zeng et al., 2002), including relative values of height, DW, and visual score data (Wu et al., 2016a). All statistical analyses were performed using JMP (Version 12; SAS Institute Inc., Cary, NC).

**Results and Discussion**

**Leachate EC.** The average leachate EC of control solution treatment ranged from 2.6 to 4.9 dS m⁻¹ during the experiment (Fig. 1). For EC 5 and EC 10, the leachate EC increased from 4.9 to 10.3 dS m⁻¹, and from 7.0 to 17.3 dS m⁻¹, respectively. The results revealed that the salinity of medium leachate was much higher than that of irrigation solution. The leachate EC increased as the salinity level and irrigation frequency increased. Similar results were reported in other comparable studies (Niu and Rodriguez, 2006; Wu et al., 2016a, 2016b). Peatmoss is a common component in potting mix for nursery crop and has higher cation exchange capacity than pine bark (Altland et al., 2014), and thus salt accumulates. Therefore, when reporting salinity, the root zone EC should be provided (Niu and Cabrera, 2010). Some studies used inert substrate such as perlite or growing plants hydroponically may minimize the fluctuation of root zone salinity (Bernstein et al., 2006). For long-term crop production in containers, a substrate with lower percent-

**H. syriacus ‘ILVOPS’** throughout the experiment, except those plants in EC 10 at the second harvest (Table 2). Treatment EC 5 did not significantly reduce the leaf area of *C. speciosa ‘Orange Storm’, D. rivularis ‘G2X88544’, F. xintermedia ‘Minder’, and H. macrophylla ‘Smnhmsigma’* at the first harvest, however, all the leaf areas were reduced at the second harvest. In addition, leaf area of all tested taxa was reduced at EC 10.

Severe foliar salt damage such as leaf burn and necrosis was observed on *C. speciosa ‘Orange Storm’* and *D. rivularis ‘G2X88544’, ‘G2X88544’, and ‘Smnrdsf’ in EC 5, and all died in EC 10 (Table 2). Four taxa including *F. xintermedia ‘Minder’, H. syriacus ‘ILVOPS’, and H. macrophylla ‘Smnhmsigma’* were still of good quality in EC 5 with an average visual score greater than 4 at both harvests. Plants of *F. xintermedia ‘Minder’* and *H. macrophylla ‘Smnhmsigma’* experienced slight foliar salt damage with mean visual scores of 3 in EC 10 at both harvests. Although *H. syriacus ‘ILVOPS’* had slight foliar salt damage in EC 10 at the first harvest, severe foliar salt damage such as leaf burn, necrosis, and discoloration exhibited in EC 10 at the second harvest and only one of five plants survived. All *P. quinquefolia ‘Troki’* plants in EC 5 and EC 10 had minimal foliar salt damage at both harvests.

For ornamental plants, maintaining aesthetic appearance is important when irrigated with low-quality water. Therefore, foliar salt damage such as tip burn, leaf margin burn, necrosis, and discoloration has been taken into consideration when assessing salt tolerance of ornamental plants (Cai et al., 2014; Niu et al., 2012; Zollinger et al., 2007). Based on this criterion, *F. xintermedia ‘Minder’, P. quinquefolia ‘Troki’,* and the two *H. macrophylla* cultivars were more tolerant to salinity, followed by *H. syriacus*...
Table 2. Leaf area and visual score of 10 ornamental taxa irrigated with nutrient solution [electrical conductivity (EC) = 1.2 dS m⁻¹; Control] or saline solution [EC = 5.0 dS m⁻¹ (EC 5) or 10.0 dS m⁻¹ (EC 10)] in a greenhouse. Plants were harvested after the first (harvest, 5 weeks after initiation of treatment) and eighth treatment (second harvest, 9 weeks after initiation of treatment).

| Taxa                  | First harvest | Control | EC 5 | EC 10 | Second harvest | Control | EC 5 | EC 10 |
|-----------------------|--------------|---------|------|-------|----------------|---------|------|-------|
| Chaenomeles speciosa  | 'Orange Storm'| 564 a   | 413 b| 150 c | 1,442 a        | 434 b   | —    | —     |
|                       |              | 873 a   | 778 a| —     | 1,536 a        | 423 b   | —    | —     |
| Diervii rivularis      | 'Pink Storm' | 1,257 a | 583 b| —     | 3,791 a        | 165 b   | —    | —     |
| Diervii rivularis      | 'G2X88544'   | 2,364 a | 1,555 a| —     | 57,778 a       | 318 b   | —    | —     |
| Forsythia xintermedia | 'Minder'     | 1,550 a | 796 a | 390 b | 2,793 a        | 1,159 b | 289 b| —     |
| Hibiscus syriacus      | 'ILVOPS'     | 719 a   | 632 a | 404 a | 584 a          | 538 a   | 172 b| —     |
| Hydrangea macrophylla  | 'Smnhmsigma' | 2,193 a | 1,019 a| 567 b | 3,945 a        | 1,668 b | 566 c| —     |
| Hydrangea macrophylla  | 'Troki'      | 1,659 a | 1,179 a| 805 b | 4,431 a        | 1,370 b | 518 c| —     |
| Parthenocissus quinquefolia | 'Pink Storm'  | 2,272 a | 1,488 b| 850 c | 4,743 a        | 2,601 b | 600 c| —     |

'a' Means with same letters within a row and harvest date are not significantly different among treatments by Tukey's honestly significant difference or (when all plants in one of the three treatments died) with a Student's t-test at P < 0.05.

'ILVOPS', whereas both C. speciosa and D. rivularis cultivars were sensitive to salinity.

Chlorophyll fluorescence. For the first harvest, no significant difference in F/F₃₅₀ was observed between control and EC 5 in all taxa except for D. rivularis 'Smnndrsf' (Table 3). Treatment EC 10 decreased F/F₃₅₀ in H. syriacus 'ILVOPS' and H. macrophylla 'Smnhmsigma'. For the second harvest, EC 5 reduced F/F₃₅₀ in the remaining surviving plants of D. rivularis and H. macrophylla 'Smnhmsigma'. The effects of EC 10 on F/F₃₅₀ were similar to those at the first harvest.

Chlorophyll fluorescence has been offered as a potentially quick, reliable, and inexpensive procedure to detect the differences of ornamental plants in response to salinity (Percival, 2005). The maximal photochemical efficiency of PSII, the ratio of F₉/F₇₅₀, is commonly measured to examine damage in the photosynthetic apparatus caused by salinity stress (Percival, 2005; Sixto et al., 2006). Many studies revealed that the response of chlorophyll fluorescence to salinity varied with plant species and salinity level. For example, salinity of irrigation water did not influence F/F₃₅₀ of the six Lamiaceae ornamental species (Wu et al., 2016b) and Suaeda salsa (Lu et al., 2003). In this experiment, among the survived plants, there were either no or small difference in F/F₃₅₀ such as the salt-sensitive C. speciosa 'Orange Storm' and 'Pink Storm' and the salt-tolerant P. quinquefolia 'Troki', where no differences were found between the control and EC 5. Therefore, it would be difficult to assess the salt tolerance relying solely on F/F₃₅₀ in these taxa.

Relative chlorophyll content (SPAD). Relative chlorophyll contents of all C. speciosa and D. rivularis plants in EC 5 and EC 10 were lower than that of control (Table 4). At the first harvest, F. xintermedia 'Minder' and P. quinquefolia 'Troki' plants had similar relative chlorophyll content among treatments. Treatment EC 5 did not affect the relative chlorophyll content of H. syriacus 'ILVOPS' but EC 10 did. In addition, both EC 5 and EC 10 decreased the relative chlorophyll content of H. macrophylla 'Smnhmsigma' and 'Smnhmtau'. At the second harvest, the relative chlorophyll content of H. syriacus 'ILVOPS', H. macrophylla 'Smnhmtau' and 'Smnhmsigma', and P. quinquefolia 'Troki' plants in EC 5 were not significantly different from that of the control. Treatment EC 10 reduced the relative chlorophyll content of all survived plants except H. macrophylla 'Smnhmsigma'.

Foliar SPAD readings have been used as a reference index for evaluating salt tolerance of plants (Niu and Cabrera, 2010). In a number of herbaceous and woody landscape plants, the relative chlorophyll content of less salt-tolerant species were found significantly reduced with increasing salinity stress (Cabrera, 2009; Niu et al., 2007). In the present study, the sensitive species C. speciosa and D. rivularis had greater reduction in relative chlorophyll content.

Leaf gas exchange. At the first harvest, no significant reductions were found between control and EC 5 in E, gₛ, and Pₗ for C. speciosa 'Orange Storm', D. rivularis 'G2X88544', and S. m rdrsf', F. xintermedia 'Minder', H. macrophylla 'Smnhmsigma', and P. quinquefolia 'Troki' (Tables 4 and 5). Treatment EC 5 significantly reduced the E, gₛ, and Pₗ of all taxa.

At the second harvest, EC 5 did not reduce the E of C. speciosa 'Orange Storm', Hibiscus syriacus 'ILVOPS', H. macrophylla 'Smnhmsigma', and P. quinquefolia 'Troki', whereas EC 10 reduced the E of all taxa except H. macrophylla 'Smnhmsigma'. For gₛ, C. speciosa 'Orange Storm' and P. quinquefolia 'Troki' plants in EC 5 were similar to those in control. Both EC 5 and EC 10 treatments did not affect gₛ of H. macrophylla 'Smnhmsigma'. For Pₗ, C. speciosa 'Orange Storm' and P. quinquefolia 'Troki' plants in EC 5 were similar to those in control. Both EC 5 and EC 10 treatments reduced the Pₗ of all taxa except C. speciosa 'Orange Storm', F. xintermedia 'Minder', and P. quinquefolia 'Troki' in EC 5.

The effect of salinity on leaf gas exchange depends on many factors such as taxa, salinity level, and duration of salinity stress exposure (Niu and Cabrera, 2010). Differences in gas exchange rates between the control and salinity treatments became greater over time in Phillyrea latifolia (Tattini et al., 2002). Generally, salt-tolerant taxa have higher gas exchanges under the same salinity levels than less-tolerant taxa. In this study, higher salinity treatment EC 10 had greater impact than that of EC 5 and the negative impact was greater in the second harvest. Because of the nature of instantaneous measurement of a single leaf, gas exchange rates sometime may not accurately reflect the whole plant response and long-term effect of salinity. Eventually, accumulative biomass over the treatment period would be the most reliable parameter to assess the impact of salinity.

Mineral analysis. Elevated salinity increased the concentrations of Na and Cl in leaf tissue of all taxa compared with the control (Table 6). Treatment EC 5 increased the leaf Na concentration of C. speciosa 'Pink Storm', D. rivularis 'G2X88544', H. macrophylla 'Smnhmtau' and 'Smnhmsigma', and P. quinquefolia 'Troki' plants by 32, 23, 22, 14, and 11 times, respectively. No statistical difference between EC 5 and control treatment were found in leaf Na concentration of C. speciosa 'Orange Storm', D. rivularis 'G2X88544' 'Smndrsf', F. xintermedia 'Minder', H. macrophylla 'Smnhmsigma', and P. quinquefolia 'Troki'. Treatment EC 10 increased the leaf Na concentration of all tested plants. The highest Na concentration (15.1 mg g⁻¹ DW) among taxa was found in H. macrophylla 'Smnhmsigma', whereas the lowest Na concentration was found in F. xintermedia 'Minder' (1.91 mg g⁻¹ DW). Compared with their respective control, salt treatment increased leaf Cl concentrations in both EC 5 (from 10 to 45 times) and EC 10 (from 19 to 103 times). The highest Cl concentration (83.8 mg g⁻¹ DW) among taxa was found in H. syriacus 'ILVOPS' in EC 10, whereas the lowest Cl concentration (29.3 mg g⁻¹ DW) was found in P. quinquefolia 'Troki' in EC 10. Salinity did not change the leaf K concentration in C. speciosa 'Orange Storm', two
Table 3. The maximal photochemical efficiency of photosystem II ($F_{v}/F_{m}$) of 10 ornamental taxa irrigated with nutrient solution [electrical conductivity (EC) = 1.2 dS m$^{-1}$; Control] or saline solution [EC = 5.0 dS m$^{-1}$ (EC 5) or 10.0 dS m$^{-1}$ (EC 10)] in a greenhouse. Plants were harvested after the fourth (first harvest, 5 weeks after initiation of treatment) and eighth treatment (second harvest, 9 weeks after initiation of treatment).

| Taxa                                | First harvest | Second harvest |
|--------------------------------------|---------------|----------------|
|                                      | Control       | EC 5           | EC 10           | Control       | EC 5           | EC 10           |
| Chaenomeles speciosa 'Orange Storm'  | 0.81 a        | 0.79 a         | 0.78 a          | 0.81 a        | 0.80 a         | —              |
| Chaenomeles speciosa 'Pink Storm'    | 0.83 a        | 0.78 a         | —               | 0.81 a        | 0.75 a         | —              |
| Diervilla rivularis 'GZ2885411'      | 0.80 a        | 0.79 a         | —               | 0.79 a        | 0.74 b         | —              |
| Diervilla rivularis 'GZ288544'       | 0.81 a        | 0.79 a         | —               | 0.81 a        | 0.73 b         | —              |
| Forsythia intermedia 'Mindor'        | 0.82 a        | 0.82 a         | 0.79 a          | 0.81 a        | 0.76 a         | 0.69 a         |
| Hibiscus syriacus 'ILVOPS'           | 0.83 a        | 0.83 a         | 0.75 b          | 0.84 a        | 0.82 a         | 0.70 b         |
| Hydrangea macrophylla 'Smnmtau'      | 0.78 a        | 0.75 b         | 0.71 b          | 0.78 a        | 0.72 b         | 0.72 b         |
| Hydrangea macrophylla 'Smnhmsigma'   | 0.77 a        | 0.75 a         | 0.68 b          | 0.77 a        | 0.75 ab        | 0.63 b         |
| Parthenocissus quinquefolia 'Troki'  | 0.80 a        | 0.81 a         | 0.80 a          | 0.80 ab       | 0.81 a         | 0.78 a         |

Table 4. Leaf relative chlorophyll content (SPAD) and transpiration (E) of 10 ornamental taxa irrigated with nutrient solution [electrical conductivity (EC) = 1.2 dS m$^{-1}$; Control] or saline solution [EC = 5.0 dS m$^{-1}$ (EC 5) or 10.0 dS m$^{-1}$ (EC 10)] in a greenhouse. Plants were harvested after the fourth (first harvest, 5 weeks after initiation of treatment) and eighth treatment (second harvest, 9 weeks after initiation of treatment).

| Taxa                                | SPAD | Transpiration |
|--------------------------------------|------|---------------|
|                                      | Control EC 5 | EC 10 | Control EC 5 | EC 10 | Control EC 5 | EC 10 |
| Chaenomeles speciosa 'Orange Storm'  | 56.1 a | 43.2 b | 38.1 b | 66.3 a | 45.0 b | — |
| Chaenomeles speciosa 'Pink Storm'    | 57.3 a | 42.4 b | — | 58.9 a | 39.4 b | — |
| Diervilla rivularis 'GZ2885411'      | 38.2 a | 32.4 b | — | 49.8 a | 26.0 b | — |
| Diervilla rivularis 'GZ288544'       | 42.9 a | 33.3 b | — | 47.7 a | 33.5 b | — |
| Forsythia intermedia 'Mindor'        | 52.3 a | 40.8 b | — | 49.1 a | 35.3 b | — |
| Hibiscus syriacus 'ILVOPS'           | 51.3 a | 48.8 a | 44.4 b | 62.4 a | 53.6 a | 16.7 b |
| Hydrangea macrophylla 'Smnmtau'      | 49.5 a | 42.6 b | 42.5 b | 50.8 a | 44.7 ab | 39.7 b |
| Hydrangea macrophylla 'Smnhmsigma'   | 52.1 a | 45.7 b | 41.8 c | 54.4 a | 48.9 a | 46.7 a |
| Parthenocissus quinquefolia 'Troki'  | 40.9 a | 38.3 a | 40.1 a | 49.4 a | 45.3 ab | 41.5 b |

Table 5. Leaf stomatal conductance ($g_s$, mmol m$^{-2}$ s$^{-1}$) and net photosynthesis ($P_n$, mmol m$^{-2}$ s$^{-1}$) of 10 ornamental taxa irrigated with nutrient solution [electrical conductivity (EC) = 1.2 dS m$^{-1}$; Control] or saline solution [EC = 5.0 dS m$^{-1}$ (EC 5) or 10.0 dS m$^{-1}$ (EC 10)] in a greenhouse. Plants were harvested after the fourth (first harvest, 5 weeks after initiation of treatment) and eighth treatment (second harvest, 9 weeks after initiation of treatment).

| Taxa                                | Stomatal Conductance | Net Photosynthesis |
|--------------------------------------|----------------------|--------------------|
|                                      | Control EC 5 | EC 10 | Control EC 5 | EC 10 | Control EC 5 | EC 10 | Control EC 5 | EC 10 |
| Chaenomeles speciosa 'Orange Storm'  | 381.8 a | 251.0 ab | 153.2 b | 423.3 a | 326.3 a | — | 12.5 a | 7.2 ab | 4.8 b | 8.9 a | 5.6 a |
| Chaenomeles speciosa 'Pink Storm'    | 208.8 a | 104.3 b | — | 247.0 a | 95.0 b | — | 11.2 a | 5.1 b | — | 7.6 a | 2.0 b |
| Diervilla rivularis 'GZ2885411'      | 265.8 a | 67.9 b | — | 180.0 a | 60.8 b | — | 12.7 a | 3.1 b | — | 8.1 a | 1.3 b |
| Diervilla rivularis 'GZ288544'       | 250.8 a | 164.5 a | — | 165.8 a | 69.5 b | — | 9.9 a | 8.2 a | — | 8.6 a | 0.7 b |
| Forsythia intermedia 'Mindor'        | 238.0 a | 112.3 a | — | 147.0 a | 33.3 b | — | 9.5 a | 4.6 a | — | 7.4 a | 1.8 b |
| Hibiscus syriacus 'ILVOPS'           | 331.3 a | 191.5 ab | 96.8 b | 166.3 a | 104.0 b | 78.0 b | 14.6 a | 11.5 a | 5.7 b | 8.9 a | 6.4 ab | 3.7 b |
| Hydrangea macrophylla 'Smnmtau'      | 451.0 a | 302.2 b | 117.5 c | 439.0 a | 203.3 b | 53.0 c | 12.5 a | 7.4 b | 1.9 c | 15.8 a | 8.3 b | 0.4 c |
| Hydrangea macrophylla 'Smnhmsigma'   | 234.0 a | 112.8 b | 43.8 b | 290.3 a | 125.6 b | 66.5 b | 12.2 a | 5.1 b | 0.9 b | 9.7 a | 1.9 b | — |
| Parthenocissus quinquefolia 'Troki'  | 272.5 a | 167.0 ab | 61.8 b | 184.3 a | 109.5 a | 136.3 a | 11.2 a | 7.4 a | 1.0 b | 4.8 a | -1.0 b | -5.3 c |

$^a$Means with same lowercase letters within a row and harvest date are not significantly different among treatments by Tukey’s honestly significant difference or (when all plants in one of the three treatments died) with a Student’s $t$ test at $P < 0.05$.

$^b$All plants were dead.

H. macrophylla cultivars, and P. quinquefolia ‘Troki’ (Table 6), but elevated salinity increased K concentrations in C. speciosa ‘Pink Storm’; D. rivularis ‘GZ2885411’, ‘GZ288544’, and ‘Smnmdsrfs’; F. intermedia ‘Mindor’; and H. syriacus ‘ILVOPS’. Leaf Ca concentration in all taxa increased at elevated salinity (from 1.3 to 1.9 times in EC 5 and 1.4 to 2.3 times in EC 10). The highest Ca concentration (44.6 mg g$^{-1}$ DW) was found in H. syriacus ‘ILVOPS’ in EC 10.

Generally, plants tolerate salt stress by avoiding uptake of Na and Cl ions or by tolerating high concentrations of these ions in the tissue (Munns and Tester, 2008). In this study, H. macrophylla plants had the highest leaf Na and Cl concentrations among all the tested taxa with acceptable visual quality, indicating that H. macrophylla could tolerate high concentration of Na and Cl. This phenomenon was also observed in Texas betony (Stachys coccinea), which survived in EC 10 with the highest leaf Na concentration (56.8 mg g$^{-1}$ DW), and was identified as the most salt-tolerant taxa among the six investigated Lamiaceae ornamental species (Wu et al., 2016b). All C. speciosa and D. rivularis plants also had relatively high leaf Na and Cl.
Table 6. sodium (Na), chloride (Cl), potassium (K), and calcium (Ca) concentrations of 10 ornamental taxa irrigated with nutrient solution [electrical conductivity (EC) = 1.2 dS m⁻¹; Control] or saline solution [EC = 5.0 dS m⁻¹ (EC 5) or 10.0 dS m⁻¹ (EC 10)] in a greenhouse. Plants were harvested after the fourth treatment (5 weeks after initiation of treatment).

| Taxa                      | Treatment | Na   | Cl   | K      | Ca     |
|---------------------------|-----------|------|------|--------|--------|
| Chaenomeles speciosa ‘Orange Storm’ | Control   | 0.15 b | 1.8 c | 23.7 a | 16.4 c |
|                           | EC 5      | 2.79 b | 29.6 b | 26.5 a | 23.6 b |
|                           | EC 10     | 9.69 a | 64.6 a | 27.9 a | 28.7 a |
|                           |           |       |      |        |        |
| Chaenomeles speciosa ‘Pink Storm’ | Control   | 0.13 c | 1.5 c | 23.5 b | 14.5 c |
|                           | EC 5      | 4.20 b | 31.4 b | 28.0 a | 26.4 b |
|                           | EC 10     | 7.57 a | 58.3 a | 28.2 a | 28.7 a |
|                           |           |       |      |        |        |
| Diervilla rivularis ‘G2X885411’ | Control   | 0.14 b | 0.7 c | 24.4 b | 11.5 b |
|                           | EC 5      | 1.08 b | 33.1 b | 30.5 a | 21.3 a |
|                           | EC 10     | 9.33 a | 65.7 a | 34.2 a | 23.1 a |
|                           |           |       |      |        |        |
| Diervilla rivularis ‘G2X88544’ | Control   | 0.14 c | 0.7 c | 27.3 b | 9.7 b  |
|                           | EC 5      | 3.23 b | 30.9 b | 33.8 a | 17.6 a |
|                           | EC 10     | 9.48 a | 64.0 a | 32.6 a | 20.6 a |
|                           |           |       |      |        |        |
| Diervilla rivularis ‘Smndrsf’ | Control   | 0.10 b | 0.7 c | 26.9 b | 9.8 b  |
|                           | EC 5      | 0.55 b | 25.2 b | 32.9 a | 18.4 a |
|                           | EC 10     | 10.04 a | 70.8 a | 34.9 a | 22.7 a |
|                           |           |       |      |        |        |
| Forsythia ×intermedia ‘Mindor’ | Control   | 0.15 b | 2.1 c | 30.7 b | 8.5 c  |
|                           | EC 5      | 0.33 b | 24.4 b | 38.5 a | 13.2 b |
|                           | EC 10     | 1.91 a | 54.1 a | 42.7 a | 19.3 a |
|                           |           |       |      |        |        |
| Hibiscus syriacus ‘ILVOPS’ | Control   | 0.13 b | 1.8 c | 35.7 b | 23.5 c |
|                           | EC 5      | 1.50 b | 36.8 b | 37.6 b | 37.2 b |
|                           | EC 10     | 8.23 a | 83.8 a | 44.6 a | 44.6 a |
|                           |           |       |      |        |        |
| Hydrangea macrophylla ‘Smnhmsigma’ | Control   | 0.18 c | 4.0 c | 45.2 a | 15.8 b |
|                           | EC 5      | 4.20 b | 46.0 b | 42.3 a | 21.6 a |
|                           | EC 10     | 11.66 a | 80.1 a | 43.1 a | 25.0 a |
|                           |           |       |      |        |        |
| Hydrangea macrophylla ‘Smlhmsigman’ | Control   | 0.33 c | 3.6 c | 44.1 a | 14.9 c |
|                           | EC 5      | 4.90 b | 42.2 b | 48.2 a | 20.1 b |
|                           | EC 10     | 15.10 a | 75.8 a | 44.5 a | 24.3 a |
|                           |           |       |      |        |        |
| Partnocissus quinquefolia ‘Troki’ | Control   | 0.12 c | 0.8 c | 22.7 a | 17.3 b |
|                           | EC 5      | 1.48 b | 18.5 b | 23.1 a | 22.6 a |
|                           | EC 10     | 2.57 a | 29.3 a | 22.7 a | 23.5 a |

*Means with same lowercase letters within a column and taxa are not significantly different by Tukey’s honestly significant difference multiple comparison at P < 0.05.

concentrations but exhibited severe foliar salt damage or died during the experiment, indicating low tolerance of Na and Cl accumulation and poor ability to exclude these ions from shoots. On the other hand, F. ×intermedia ‘Mindor’ and P. quinquefolia ‘Troki’ plants had relatively low leaf Na concentration at EC 10 and low Cl concentration at both EC 5 and EC 10 with acceptable visual quality. This suggests that the two taxa mentioned are able to restrict Na and Cl uptake and transport to shoots.

Maintenance of adequate K is essential for plant survival in saline environment (Grattan and Grieve, 1998). Although researchers reported a decline of K concentration in plant tissue when plants are exposed to high Na salinity, we did not observe any decrease in K concentration, rather an increase in some taxa, which may be caused by a strong Na concentration gradient (Grattan and Grieve, 1998). Wu et al. (2016a) observed that leaf K concentration increased significantly with increasing EC in Cuphea hyssopifolia. Sun et al. (2015) also observed that K level increased significantly with increasing EC in the leaves of Phlox paniculata ‘John Fanick’ and P. paniculata ‘Texas Pink’ plants.

Maintenance of adequate Ca is essential to prevent any negative impact on plant performance due to Ca deficiency, which occurs often under non-saline conditions. Factors which influence the availability of Ca to plants include the total Ca supply, the nature of counterions, substrate pH, and the ratio of Ca to other cations in the substrate (Grattan and Grieve, 1998). In our study, Ca(NO₃)₂ was supplied as one of the salinizing ions from shoots. On the other hand, factors which influence the availability of Ca to plants include the total Ca supply, the ratio of Ca to other cations in the substrate, the nature of counterions, substrate pH, and the ratio of Ca to other cations in the substrate (Grattan and Grieve, 1998). In our study, Ca(NO₃)₂ supplementation increased the yield and dry matter of cucumber in a soil with NaCl, which contributed to the increase in leaf Ca concentrations in all the taxa. Kaya and Higgs (2002) found that Ca(NO₃)₂ supplementation increased the yield and dry matter of cucumber in a soil with NaCl.

Cluster analysis. Salt-tolerant plants usually have less growth reduction and less foliar salt injury at elevated salinity (Cassaniti et al., 2009). For landscape plants, aesthetic appearance is more important than maximum growth. Therefore, assessment of salt tolerance for landscape plants should include aesthetic visual rating scores. A hierarchical cluster analysis was conducted based on relative values of height, DW, and visual score data. Ten ornamental taxa were separated into two distinguishable clusters in both EC 5 and EC 10 treatments (Fig. 2). All C. speciosa and D. rivularis plants were consistently clustered into group I in both EC 5 and EC 10 treatments and considered as the salt-sensitive plants. Forsythia ×intermedia ‘Mindor’, H. macrophylla ‘Smnhmsigma’, H. ×intermedia ‘Mindor’, P. quinquefolia ‘Troki’ and ‘Smnhmsigma’, and P. quinquefolia ‘Troki’ clustered into group II, representing the salt-tolerant group. Interestingly, H. syriacus ‘ILVOPS’ was classified as salt-tolerant taxa in EC 5 treatment, whereas it fell to salt-sensitive group in EC 10 treatment. This might indicate that H. syriacus ‘ILVOPS’ is moderately salt tolerant. It can grow well in moderate salt levels (EC 5) without growth reduction, but cannot grow well at high salinity (EC 10) where only one of five plants survived after the eighth treatment.

In summary, the 10 ornamental taxa had different growth and physiological responses to salinity. Hydrangea macrophylla ‘Smnhmsigma’, H. ×intermedia ‘Mindor’ and P. quinquefolia ‘Troki’ were the most salt-tolerant taxa with minor foliar salt damage. Hydrangea macrophylla had the highest shoot Na and Cl concentrations with acceptable visual quality indicating that H. macrophylla plants were tolerant to high Na and Cl accumulation. Forsythia ×intermedia ‘Mindor’ and P. quinquefolia ‘Troki’ had relatively low leaf Na and Cl concentration, suggesting that both taxa were able to exclude Na and Cl. Hibiscus syriacus ‘ILVOPS’ was moderately salt tolerant with high leaf Cl concentrations, indicating that it may be sensitive to chloride-dominated salinity. Chaenomeles speciosa and D. rivularis were sensitive to salinity because of their greater growth reduction, foliar salt damage, and high Na and Cl accumulation in leaves. The results from this study may be used as a reference for selecting salt-tolerant plants for landscapes where poor quality water is used for irrigation.
Fig. 2. Cluster analysis on the salt tolerance of 10 ornamental taxa according to the reduction of height, dry weight, and visual score as affected by elevated salinity at electrical conductivity of 5.0 (A) and 10.0 dS·m⁻¹ (B).

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