A Test Method to Evaluate Salt Tolerance of Ornamentals

Kimberly Moore^{1,4}, Charles Wajsbrot², Cristina Burgart², and Luci Fisher³

ADDITIONAL INDEX WORDS. electrical conductivity, Na, NaCl, sodium

SUMMARY. Because salts in irrigation water decrease plant growth, we wanted to develop a quick and easy method for evaluating salt tolerance that could be used in the greenhouse. Using plastic containers with lids, sea salt, and rooted cuttings, we monitored changes in plant quality, growth, and leaf water potential as electrical conductivity (EC) and sodium (Na) levels increased. In the first of two experiments, we compared sea hibiscus (*Hibiscus tilliaceous*) leaf water potential and plant quality in solutions with an EC of 0, 2.1, 4.2, 6.1, or 8.2 dS·m⁻¹ (0, 240, 420, 610, or 1010 mg·L⁻¹ Na). After 14 days, sea hibiscus quality in solutions with an EC of 6.1 or 8.2 dS·m⁻¹ was less than plants in solutions of 0, 2.1, or 4.2 dS·m⁻¹. There was no difference in quality among plants in 0, 2.1, or 4.2 dS·m⁻¹ solutions. To test this method, in Expt. 2, we compared coleus (*Coleus ×hybridus*), copperleaf (*Acalypha wilkesiana*), ficus (*Ficus benjamina*), jasmine (*Jasminum multiflorum*), and plumbago (*Plumbago auriculata*) plant quality and growth in solutions with an EC of 0, 1.3, 2.1, 4.2, 5.6, or 6.1 dS·m⁻¹ (0, 170, 240, 420, 520, or 610 mg·L⁻¹ Na). Coleus quality declined at an EC greater than 1.3 dS·m⁻¹, whereas jasmine and plumbago quality declined at an EC greater than 2.1 dS·m⁻¹. Copperleaf and ficus declined at an EC greater than 4.2 dS·m⁻¹. Plant response did vary with low to medium salt-tolerant plants tolerating at an EC up to 1.3 and 170 mg·L⁻¹ Na, whereas plants with a greater salt tolerance tolerated at EC and Na values up to 4.2 dS·m⁻¹ and 420 mg·m⁻¹ Na, respectively. The use of this method benefits growers by determining upper EC and Na limits when faced with poor-quality water resulting from saltwater intrusion or when using reclaimed wastewater with greater EC and Na levels.

Most recommendations about salt tolerance state that plants have low, medium, or high salt tolerance. Salt tolerance can be assessed in terms of plant growth rate, which is appropriate for many plant species (Munns, 2002). We expect to observe a decrease in growth and yield when roots are exposed to high salt levels, because the water potential is reduced in the soil, leading to a reduction in water uptake

by the roots (Boursiac et al., 2005). Under normal growing conditions, the water potential in root cells is less than in the outer environment, and water moves into the roots (Luu and Maurel 2005; Tournaire-Roux et al., 2003). However, when the salt concentration is greater outside the plant root than some arbitrary value, salt stress occurs.

Most salt stress in nature is a result of the presence of Na salts (Levitt, 1980). Some water sources may have high Na levels resulting from saltwater intrusion, the use of reclaimed wastewater, or seasonal variation from snowmelt products. Well water in Massachusetts' greenhouses had

Na levels ranging from 1 to 544 mg·L⁻¹ whereas Na levels in wastewater range from 124 to 384 mg·L⁻¹ (Karleskint et al., 2011). Wastewater effects on field, forage, wetland, forest, and ornamental crops have been the subject of many investigations, with varied plant response resulting from differences in the salt tolerance of the plants investigated (Brister and Schultz, 1981; Day et al., 1981; Fitzpatrick, 1985; Fitzpatrick et al., 1986; Yeager et al., 2009).

Because plant response mechanisms involved in salt tolerance are complicated, there is no standard method for evaluating salt tolerance. One method for measuring salt tolerance is to correlate changes in yield associated with soil EC levels. Other methods monitor changes in osmotic potential in the leaves or the uptake and translocation of Na in the plants (Levitt, 1980; Niu and Cabrera, 2010). However, these methods may be challenging to implement in a greenhouse setting because of the lack of resources or the need for specialized equipment.

We questioned whether we could design a quick and easy test to screen plants based on EC and Na levels in solution that would confirm observational data classifying plants as low, medium, or high salt-tolerant. We monitored changes in leaf water potential and plant quality of sea hibiscus, a high salt-tolerant plant, exposed to increasing EC and Na levels. Because measuring water potential is impractical for a grower, for additional testing we compared plant quality and growth of low to medium salt-tolerant plants—specifically, coleus, copperleaf, ficus, jasmine, and plumbago—in solutions exposed to increasing EC and Na levels.

Material and methods

EXPT. 1. Rooted cuttings of sea hibiscus were placed randomly into individual 42-fl oz containers

Received for publication 28 Mar. 2019. Accepted for publication 20 May 2019.

Published online 24 June 2019.

Department of Environmental Horticulture, University of Florida, IFAS, Fort Lauderdale Research and Education Center, 3205 College Avenue, Davie, FL 33314

We thank the Horticulture Research Institute and Florida Nursery Grower and Landscape Association for funding to support this work (FLA-FTL-005315).

¹Professor.

²Former graduate student.

³Biological scientist.

⁴Corresponding author. E-mail: klock@ufl.edu.

This is an open access article distributed under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

<https://doi.org/10.21273/HORTTECH04365-19>

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
100	bar	kPa	0.01
29.5735	fl oz	mL	0.0338
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Fig. 1. Change in leaf water potential of sea hibiscus over 72 h for plants grown in deionized water with salt added to create an electrical conductivity (EC) of 0, 2.1, 4.2, 6.1, or 8.2 $\text{dS}\cdot\text{m}^{-1}$ (0, 240, 420, 510, or 1010 $\text{mg}\cdot\text{L}^{-1}$ sodium). Values are the average of five replicates. Vertical bars represent the SE of five measurements. 1 $\text{dS}\cdot\text{m}^{-1}$ = 1 mmho/cm, 1 $\text{mg}\cdot\text{L}^{-1}$ = 1 ppm, 1 bar = 100 kPa.

Fig. 2. Final plant quality rating of sea hibiscus after 14 d grown in deionized water with salt added to create an electrical conductivity (EC) of 0, 2.1, 4.2, 6.1 or 8.2 $\text{dS}\cdot\text{m}^{-1}$ (0, 240, 420, 510, or 1010 $\text{mg}\cdot\text{L}^{-1}$ sodium). Quality was rated on a scale of 5 to 1, with 5 = plants not wilted and no visible necrosis; 4 = plants with slight wilting, no necrosis; 3 = plants wilted with necrosis; 2 = wilted plants with significant necrosis; and 1 = plants dead. Values are the average of five replicates. Vertical bars represent the SE of five measurements. 1 $\text{dS}\cdot\text{m}^{-1}$ = 1 mmho/cm, 1 $\text{mg}\cdot\text{L}^{-1}$ = 1 ppm.

(Gladware® Tall Entrée; Glad Products Co., Oakland, CA). One cutting was supported through a hole cut in the center of each lid placed on the container. Each container was filled with 1 L deionized water with 0, 1, 2, 3, or 4 g sea salt (All-Purpose Sea Salt; Morton Salt, Chicago, IL) to create an EC of 0, 2.1, 4.2, 6.1, or 8.2 $\text{dS}\cdot\text{m}^{-1}$ (Na concentration of 0, 240, 420, 610, or 1010 $\text{mg}\cdot\text{L}^{-1}$). No additional nutrients were added. EC was measured using a combination pH/EC

probe (Accumet AP8P portable pH/conductivity meter; Fisher Scientific, Waltham, MA). Na was measured using a specific ion probe (Accumet XL250; Fisher Scientific). Each treatment was replicated five times. Cool white fluorescent lights [Twister Mini 23 W (100-W) bulbs; Phillips Lighting North American Corp., Somerset, NJ] were placed on the counter to provide $96\ \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of supplemental light (Quantum Meter; Apogee Instruments, Logan, UT)

for 12 h/d for 14 d. Temperature was maintained at 21 °C in the laboratory and around plants. After 14 d, plant quality was rated on a scale of 1 to 5 with 5 = plants not wilted and no visible necrosis; 4 = plants with slight wilting, no necrosis; 3 = plants wilted with necrosis; 2 = wilted plants with significant necrosis; and 1 = plants dead.

Leaf water potential was measured at 0, 6, 24, 48, or 72 h after being placed into saline solutions. One leaf from the top of each plant was sampled at 8:00 AM and was placed in a pressure chamber (model 3000 pressure extractor PV200/300158; Soilmoisture Equipment Corp., Santa Barbara, CA) that used compressed nitrogen (N_2) gas with a maximum pressure of 40 bars.

EXPT. 2. Rooted cuttings of coleus, copper leaf, ficus, jasmine, and plumbago were placed into 42-fl oz containers as described in Expt. 1. Sea salt—0, 0.5, 1, 2, 2.5, or 3 g—was added to 1 L deionized water to create solutions with an EC of 0.0, 1.3, 2.1, 4.2, 5.6, or 6.1 $\text{dS}\cdot\text{m}^{-1}$ (Na concentration of 0, 170, 240, 420, 520, or 610 $\text{mg}\cdot\text{L}^{-1}$). There were 10 replicates per treatment of each plant. After 14 d, we rated plant quality on a scale of 1 to 5. Shoots and roots were harvested and placed in a forced-air oven set at 90 °C until a constant weight was achieved to determine dry weight.

Data from Expts. 1 and 2 were analyzed separately. In Expt. 1, leaf water potential was analyzed using analysis of variance (ANOVA) [PROC GLM (SAS version 9.2; SAS Institute, Cary, NC)] with factors for replication, time, and treatment (salt level). Plant quality for both experiments and shoot dry weight, root dry weight, and shoot:root ratio in Expt. 2 were analyzed using ANOVA with comparisons between salt treatments performed using Tukey-Kramer's test. Both experiments were repeated to verify results. Because the results were not different between the repeats of each experiment, the data were pooled.

Results and discussion

EXPT. 1. Placing sea hibiscus cuttings into solutions with an EC greater than 4.2 $\text{dS}\cdot\text{m}^{-1}$ (>420 $\text{mg}\cdot\text{L}^{-1}$ Na) resulted in decreased leaf water potential and plant quality (Figs. 1

Table 1. Final visual plant quality of coleus, copperleaf, ficus, jasmine, and plumbago plants after 14 d in deionized water with salt added to create solutions with increasing electrical conductivity (EC) and sodium (Na) concentrations.

Solution EC (dS·m ⁻¹) ^z	Solution Na (mg·L ⁻¹) ^z	Plant quality rating (1–5 scale) ^y				
		Coleus	Copperleaf	Ficus	Jasmine	Plumbago
0.0	0	3.5 a ^x	3.5 a	4.0 a	3.3 a	4.2 a
1.3	170	3.7 a	3.3 a	3.8 a	3.1 ab	3.3 b
2.1	240	2.6 b	3.7 a	3.6 a	3.0 ab	3.0 b
4.2	420	2.2 b	3.7 a	3.7 a	2.7 bc	2.7 c
5.6	520	1.7 c	1.7 b	1.7 b	2.0 c	2.1 c
6.1	610	1.2 c	1.1 b	1.3 b	2.0 c	2.1 c

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

^y5 = plants not wilted and no visible necrosis; 4 = plants with slight wilting, no necrosis; 3 = plants wilted with necrosis; 2 = wilted plants with significant necrosis; 1 = plants dead. Values are averaged for 10 replicates.

^xMeans followed by the same lowercase letter within a column are not significantly different by Tukey's method at $\alpha = 0.05$.

Table 2. Final shoot dry weight, root dry weight, and shoot:root ratio of coleus, copperleaf, ficus, jasmine, and plumbago after 14 d in deionized water with salt added to create solutions with increasing electrical conductivity (EC) and sodium (Na) concentrations.

Solution EC (dS·m ⁻¹) ^z	Solution Na (mg·L ⁻¹) ^z	Coleus	Copperleaf	Ficus	Jasmine	Plumbago
Shoot dry wt (g) ^z						
0.0	0	5.38 a ^y	10.76 a	8.50 a	12.78 a	10.00 a
1.3	170	5.40 a	10.68 a	8.02 a	12.56 a	9.99 a
2.1	240	5.27 b	10.65 a	7.98 a	12.39 a	9.96 a
4.2	420	5.13 bc	10.66 a	7.97 a	10.21 b	9.22 b
5.6	520	5.07 c	8.57 b	6.13 b	10.07 b	9.10 b
6.1	610	4.31 c	8.46 b	6.02 b	9.89 b	9.12 b
Root dry wt (g) ^z						
0.0	0	5.27 a	10.22 a	6.98 a	9.76 a	8.62 a
1.3	170	5.21 a	10.20 a	6.61 a	9.66 a	8.70 a
2.1	240	5.12 b	10.10 a	6.40 a	9.61 a	8.69 a
4.2	420	5.14 b	10.10 a	6.39 a	8.39 b	8.57 b
5.6	520	5.16 b	9.09 b	6.18 b	8.29 b	8.58 b
6.1	610	5.13 b	9.05 b	6.08 b	8.19 b	8.58 b
Shoot:root ratio (by wt) ^z						
0.0	0	1.02 a	1.05 a	1.21 a	1.31 a	1.16 a
1.3	170	1.04 a	1.05 a	1.21 a	1.30 a	1.15 a
2.1	240	1.03 a	1.05 a	1.24 a	1.29 a	1.15 a
4.2	420	0.99 b	1.05 a	1.25 a	1.21 b	1.08 b
5.6	520	0.98 b	0.94 b	0.99 b	1.21 b	1.06 b
6.1	610	0.84 b	0.93 b	0.99 b	1.21 b	1.06 b

^z1 dS·m⁻¹ = 1 mmho/cm, 1 mg·L⁻¹ = 1 ppm, 1 g = 0.0353 oz. Values are averaged for 10 replicates.

^yMeans followed by the same lowercase letter within a column are not significantly different by Tukey's method at $\alpha = 0.05$.

and 2). Sea hibiscus leaf water potential of plants in all solutions decreased during the first 24 h after being placed in solution (Fig. 1). After 48 h, sea hibiscus plants in solutions with an EC of 2.1 and 4.2 dS·m⁻¹ (240 and 420 mg·L⁻¹ Na) started to adjust and were not significantly different from the water potential of plants grown in 0 dS·m⁻¹. The leaf water potential of plants grown in solutions of EC 6.1 and 8.1 dS·m⁻¹ (Na of 610 and 1010

mg·L⁻¹) continued to decrease (Fig. 1). After 72 h, the leaf water potential of plants in 6.1 and 8.2 dS·m⁻¹ was less than plants grown in 0, 2.1, or 4.2 dS·m⁻¹ (Fig. 1). After 14 d, sea hibiscus plants in solutions with an EC of 6.1 or 8.2 dS·m⁻¹ had reduced quality, showing signs of wilting and necrosis (Fig. 2). However, there was no difference in plant quality for plants grown in solutions with an EC of 0, 2.1, or 4.2 dS·m⁻¹.

Because sea hibiscus has been classified as a high salt-tolerant plant (Broschat and Meerow, 1996), we suspect that other salt tolerance mechanisms such as the accumulation of inorganic ions (Na) in the vacuole (Kamel, 2008) or the accumulation of compatible organic solutes, such as amino acids (e.g., proline), soluble sugars (e.g., sucrose), polyols (e.g., mannitol), and betaines (e.g., glycine betaine), in the cytoplasm may be involved in restoring osmotic balance inside the cells of sea hibiscus plants grown in solutions with an EC of 2.1 and 4.2 dS·m⁻¹. For example, halophytes have been reported to absorb large amounts of salt from the external solution, achieving greater osmotic concentration inside the cell than outside the cell to restore osmotic balance (Flowers and Colmer 2008; Levitt, 1980; Parida and Das 2005).

EXPT. 2. Based on results with sea hibiscus, plant quality was used as an indicator of changes in response to salt stress for low to moderate salt-tolerant plants. Plant quality, shoot dry weight, root dry weight, and shoot:root ratio of coleus, a low salt-tolerant plant, declined at EC levels greater than 1.3 dS·m⁻¹ (170 mg·L⁻¹ Na), whereas growth of jasmine (low salt tolerance) and plumbago (medium salt tolerance) declined at EC levels greater than 2.1 dS·m⁻¹ (240 mg·L⁻¹ Na) (Tables 1 and 2). However, growth of copperleaf (medium salt tolerance) and ficus (medium salt tolerance) declined at EC levels greater than 4.2 dS·m⁻¹ (420 mg·L⁻¹ Na). When substrate EC levels exceeded 2.9 mS·cm⁻¹ and substrate Na levels were greater than 146 ppm, greenhouse plants showed toxicity symptoms (Raudales and Dickson, 2019). Similar results conducted in compost amended with NaCl reported petunia (*Petunia hybrid* 'Blue Flash') growth reductions when Na exceeded 540 mg·L⁻¹ in the substrate, whereas geranium (*Pelargonium zonale* 'Pulsar Red') growth was reduced at a Na level greater than 780 mg·L⁻¹ in the substrate and primula (*Primula obconica* 'Juno Deeprose') at a Na level greater than 140 mg·L⁻¹ in the substrate (Weinhold and Scharpf, 1997). Differences between our results and these studies are likely a result of different plant species and a difference between

growing plants in solutions vs. growing them in substrates. It was beyond the scope of this study to compare uptake of Na from substrates vs. solutions. However, these results reiterate that salt tolerance is highly variable.

The effects of salinity on plant growth may be the result of direct effects of ion toxicity or indirect effects on water potential (Al-Karaki, 2000b). Decreases in tomato (*Solanum lycopersicum*) growth with increasing salt concentrations showed a reduction in water uptake (Al-Karaki, 2000b). One adaptive response to reduced water uptake is a decrease in shoot:root ratio to decrease shoot size when root activity is decreased by external factors (Al-Karaki, 2000a). A similar trend of reduced shoot:root ratio as salt increased was observed in our study.

Salt tolerance is a polygenic trait; plants vary in salt tolerance and in Na tolerance. Plants grow best when Na and salt levels are low, and growers should use water sources low in salts and Na (Raudales and Dickson, 2019). Reported guidelines for water quality show no hazards to plant growth when Na levels are less than 60 to 69 mg·L⁻¹ whereas a moderate hazard to plant growth is expected at Na levels of greater than 120 to 207 mg·L⁻¹ (Peterson, 1996; Rolfe et al., 2000). However, what if growers do not have access to high-quality water? The question becomes: What are the upper EC and Na limits plants will tolerate and still grow? The method described was simple to set up using rooted cuttings and materials purchased from the grocery store, with results achieved in 14 d. Based on our study, plants with a reported low salt tolerance tolerated EC and Na levels in irrigation water up to 1.3 dS·m⁻¹ (170 mg·L⁻¹ Na) whereas plants with moderate to high salt tolerance tolerated EC and Na levels up to 2.1 to 4.2 dS·m⁻¹ and 240 to 420 mg·L⁻¹ Na, respectively. As important as plant response to increasing EC levels, our work highlights the importance of monitoring Na levels. Depending on the source of the salts, plants often tolerate EC levels greater than 2.1

dS·m⁻¹, especially if it is from fertilizer solutions. However, plant tolerance to increasing Na levels appeared to be more detrimental. Our study reinforces the importance of monitoring both EC and Na. The results from our study are based on values for plants grown in solution and might vary in substrates irrigated with water high in salts and Na.

Literature cited

- Al-Karaki, G.N. 2000a. Growth, sodium, and potassium uptake and translocation in salt stressed tomato. *J. Plant Nutr.* 23:369–379.
- Al-Karaki, G.N. 2000b. Growth, water use efficiency, and sodium and potassium acquisition by tomato cultivars grown under salt stress. *J. Plant Nutr.* 23:1–8.
- Boursiac, Y., S. Chen, D.T. Luu, M. Sorieul, N. van den Dries, and C. Maurel. 2005. Early effects of salinity on water transport in arabidopsis roots: Molecular and cellular features of aquaporin expression. *Plant Physiol.* 139:790–805.
- Brister, G.H. and R.C. Schultz. 1981. The response of a southern Appalachia forest to waste water irrigation. *J. Environ. Qual.* 10:148–153.
- Broschat, T.K. and A.W. Meerow. 1996. *Betrock's reference guide to Florida landscape plants*. Betrock Information Systems, Hollywood, FL.
- Day, A.D., J.A. McFadyen, T.C. Tucker, and C.B. Cluff. 1981. Effects of municipal waste water on yield and quality of cotton. *J. Environ. Qual.* 10:47–49.
- Fitzpatrick, G.E. 1985. Container production of tropical trees using sewage effluent, incinerator ash and sludge compost. *J. Environ. Hort.* 3:123–125.
- Fitzpatrick, G.E., H. Donselmann, and N.S. Carter. 1986. Interactive effects of sewage effluent irrigation and supplemental fertilization on container-grown trees. *HortScience* 21:92–93.
- Flowers, T.J. and T.D. Colmer. 2008. Salinity tolerance in halophytes. *New Phytol.* 179:945–963.
- Kamel, M. 2008. Osmotic adjustment in three succulent species of Zygophyllaceae. *Afr. J. Ecol.* 46:96–104.
- Karleskint, J.L., J.P. Cooke, G. Fitzpatrick, and F. Jiang. 2011. The impacts of salinity on reuse irrigation. *Florida Water Resour. J.* 63:4–9.
- Levitt, J. 1980. Responses of plants to environmental stresses. Vol. II: Water, radiation, salt, and other stresses. Academic Press, New York, NY.
- Luu, D.T. and C. Maurel. 2005. Aquaporins in a challenging environment: Molecular gears for adjusting plant water status. *Plant Cell Environ.* 28:85–96.
- Munns, R. 2002. Comparative physiology of water and salt stress. *Plant Cell Environ.* 25:239–250.
- Niu, G. and R.I. Cabrera. 2010. Growth and physiological responses of landscape plants to saline water irrigation: A review. *HortScience* 45:1605–1609.
- Parida, A.K. and A.B. Das. 2005. Salt tolerance and salinity effects on plant: A review. *Ecotoxicol. Environ. Saf.* 60:324–349.
- Peterson, F.H. 1996. Water testing and interpretation, p. 31–49. In: D.W. Reed (ed.). *Water, media, and nutrition for greenhouse crops*. Ball Publications, Bataavia, IL.
- Raudales, R.E. and R. Dickson. 2019. The roads that lead to salty water. *GrowerTalks* 82(10):54–57.
- Rolfe, C., W. Yiasoumi, and E. Keskula. 2000. *Managing water in plant nurseries*. 2nd ed. NSW Agriculture, Orange, NSW, Australia.
- Tournaire-Roux, C., M. Sutka, H. Javot, E. Gout, P. Gerbeau, D.T. Luu, R. Bligny, and C. Maurel. 2003. Cytosolic pH regulates root water transport during anoxic stress through gating of aquaporins. *Nature* 425:393–397.
- Weinhold, F. and H.C. Scharpf. 1997. Tolerance of ornamental plants to salt, sodium, and chloride in potting substrates containing compost made of separately collected organic residues. *Acta Hort.* 450:221–228.
- Yeager, T., C. Larsen, J. von Merveldt, and T. Irani. 2009. Use of reclaimed water for irrigation in container nurseries. Univ. Florida, Inst. Food Agr. Sci., Florida Coop. Ext. Serv., ENH 1119.