Bigtooth Maples from Three Geographically Different Origins Endure Root Zone Salinity[1]

Emad Bsoul[2], Rachel Gioannini[3] and Rolston St. Hilaire[3,4]

Abstract

The contiguous geographic range of bigtooth maple (*Acer grandidentatum* Nutt.) covers Utah, Idaho, Wyoming, Arizona, New Mexico, and Texas and suggests that this deciduous tree is a potential landscape plant for many regions. Using bigtooth maples selected from provenances in New Mexico (NM), Utah (UT) and Texas (TX), we evaluated physiological and growth traits of plants subjected to root zone salinity treatments at concentrations 0 (control), 2.5, 5.0 or 10.0 $dS \cdot m^{-1}$ (0, 1,600, 3,200, or 6,400 ppm). At harvest, foliar Kjeldahl nitrogen, potassium, magnesium, phosphorus, and calcium concentrations of salinity-treated plants were not different from control plants. Plants from the TX provenance had the highest leaf dry weight (DW) (15.7 g [0.55 oz]), larger stem diameter (11.4 mm [0.45 in]), less foliar injury, and less negative midday stem water potentials while accumulating three and two times more foliar sodium than plants from the UT and NM provenance plants, respectively. Total DW (95.9 g [3.4 oz]) of TX plants was triple that of the other two provenances. While bigtooth maples from the three provenances tolerated salinity, those from the TX provenance show enhanced resiliency to root zone salinity.

Index words: *Acer grandidentatum,* woody ornamentals, foliar injury, nursery plants, water relations.

Species used in this study: bigtooth maple (*Acer grandidentatum* Nutt.).

Significance to the Horticulture Industry

Salinity is one the major limitations to the successful establishment of plants in managed landscapes in arid and semiarid regions. Bigtooth maple has been recommended for arid and semiarid region managed landscapes, partly because of its small stature, fall foliage color, and its natural occurrence in arid and semiarid regions of the western United States. Information on the salinity tolerance of bigtooth maples is virtually nonexistent. This research shows that bigtooth maple plants from a Texas provenance accumulated the most dry matter, had the least foliar injury and more favorable water relations in response to salinity treatment than plants that originated from either a New Mexico or Utah location. Nursery personnel wishing to choose bigtooth maple plants for managed landscapes that are challenged with salinity might look to the Guadalupe Mountains, Texas, location for their selections.

Introduction

While being a serious challenge worldwide, the problem of plant stress due to salinization is particularly acute in arid and semiarid regions (Rao et al. 2004). Salt accumulation around the root zone inhibits nutrient uptake and with repeated irrigation applications, as is often practiced in managed landscapes in arid and semiarid regions, salts in the soil gradually become more concentrated.

Salt tolerance of plants varies with plant species, the source of the salinity, and environmental factors (Kozlowski and Palardy 1997, Romero-Aranda and Syvertsen 1996, Stevens et al. 1996, West and Taylor 1984). Salinity induces injury, inhibits seed germination, limits vegetative and reproductive growth, alters plant morphology and anatomy, and can even kill glycophytes (Kozlowski and Palardy 1997; Shannon et al. 1994, Volkmar et al. 1998). Glycophytes are plants that are affected by low salt concentrations (<5 $dS \cdot m^{-1}$ [3,200 ppm] sodium chloride [NaCl]).

In addition, salinity promotes senescence of plant tissues by increasing the production of abscisic acid and ethylene (Ke-Fu et al. 1991, Ke-Fu et al. 1992). Senescence causes a decrease in stomatal conductance and cell expansion, and consequently, decreases photosynthesis. That salt buildup in older leaves causes leaf senescence has also been proposed (Munns 1993). Leaf senescence inhibits growth because the supply of hormones in the growing regions is impeded (Munns 1993).

Most woody plants are tolerant to salinity during seed germination and the reproductive stage (Shannon et al. 1994), but are more sensitive to salinity during emergence and as young seedlings. Total plant biomass of navelina orange seedlings (*Citrus sinensis* L. Osbeck) was reduced by 27 to 38% when subjected to saline irrigation treatment (Iglesias et al. 2004). The seedlings in this study were irrigated three times per week with water containing 25 mM NaCl:$CaCl_2$ (calcium chloride) (15:1) or approximately 2.5 $dS \cdot m^{-1}$ (1,600 ppm). Leaf size, plant height, total plant mass, root mass and shoot mass of Rio Grande cottonwood (*Populus deltoides* var. *wislizenii* [S. Wats.] Eckenw.) seedlings were all reduced when seedlings were irrigated with a saline solution at 1.3 $dS \cdot m^{-1}$ (832 ppm) (Rowland et al. 2004).

In 1993, Simpson and Hipp (1993) recommended seven maple species for arid and semiarid regions and among those taxa, bigtooth maple was recommended for further study (Barker 1974). Limited research shows that bigtooth maple and caddo sugar maple (*A. saccharum.* Marsh. Subsp. *saccharum)* that originated from the Texas/Oklahoma region grew better in high-salt irrigation water than drummond red maple (*A. rubrum* var. *drummondii* [Hook. & Arn. Ex Nutt.] Sarg.) (Hatter and Morgan 1992).

More recent research on bigtooth maples showed that seedlings from provenances in Texas adapted to drought stress better than those from provenances in New Mexico and Utah (Bsoul et al. 2007). This current experiment was built on this more recent research, and used seedlings from

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[2]Biological Science and Biotechnology Department, Faculty of Sciences, The Hashemite University, Al-Zarqa, Zip code 13115, Jordan.

[3]Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003.

[4]Corresponding author: rsthilai@nmsu.edu.

the same provenances. The objective of this research was to determine salinity responses of bigtooth maples selected from provenances in the western U.S. states of New Mexico, Utah and Texas.

Materials and Methods

Plant material. Plants were selected from two-year-old seedlings of bigtooth maples that were maintained in a greenhouse collection at the Fabian Garcia Science Center (lat. 34°48'18"N; long. 106°43'42"W) at New Mexico State University (NMSU). Samaras, the seeds of the *Acer* genus, were selected from different trees within the same location of each of the following three sources: Logan Canyon of Utah, designated UT (lat. 41°46'00"N; long. 111°49'00"W), Dripping Springs State Park, New Mexico, designated NM (lat. 32°23'20"N; long. 106°48'47"W), and Guadalupe Mountains, Texas, designated TX (lat. 31°54'00"N; long. 104°52'01"W). Seeds were sown in rows in greenhouse bench-top trays filled with a mixture of peatmoss (Canadian sphagnum peatmoss; VPG, Bohman, TX) and medium perlite (Therm-o-Rock, Therm-o-Rock West, Chandler, AZ) (1:1, v/v). Between March 3 and May 15, 2002, all seedlings that had the first pair of true leaves visible were transplanted individually in #1 plastic pots (height = 17.1 cm [6.7 in]; top diameter = 14.8 cm [5.8 in]; bottom diameter = 10.8 cm [4.3 in]) filled with the same growing media used for germination. For the next two years, plants were maintained in the greenhouse and irrigated weekly with a fertilizer solution (pH 7.3 and EC [Electrical Conductivity] 2.7 $dS \cdot m^{-1}$ [1728 ppm]) containing N (nitrogen) at 150 $mg \cdot L^{-1}$ (ppm) from a mixture of Peter's Excel [15N-2.2P (phosphorus)-12.5K (potassium)], and Peter's Professional (20N-4.4P-16.6K) (1:1, w/w) fertilizer (Scotts, Marysville, OH). In April 2004, the dormant seedlings were transplanted to the same medium in which they had been grown into #10 containers (height = 36.0 cm [14.2 in], top diameter = 117 cm [47.1 in], bottom diameter = 107 cm [42.1 in]). On April 13, 2004, before breaking bud, plants were moved to an outdoor, pot in pot production area at the same location. At the outdoor location, the seedlings were then drip irrigated with 7.6 L (2.0 gal) of tap water every other day. In addition, the seedlings received weekly irrigation with 3.0 L (0.8 gal) fertilizer solution (pH 7.3 and EC 2.7 $dS \cdot m^{-1}$ [1728 ppm]) containing N at 150 $mg \cdot L^{-1}$ (ppm) from Peter's Excel (15N-2.2P-12.5K), and Peter's Professional (20N-4.4P-16.6K) (1:1, w/w) fertilizer (Scotts).

Environmental conditions and experimental design. The experiment was conducted in an outdoor plot at NMSU's Fabian Garcia Science Center using an in-ground nursery production (pot in pot) system. The field plot was plowed and leveled, and then #10 socket pots were placed in holes dug in the soil. A 10 cm (4 in) layer of gravel was placed in the bottom of the socket pot to facilitate good drainage from the holder pots. Sockets were spaced 130 cm (51.2 in) between and within rows. A 150 cm (59 in) walkway was used to separate the blocks used in this study. The experimental design was a randomized complete block with six blocks, three seed sources and four salinity treatments.

During the experimental period, mean midday photosynthetic photon flux density was recorded with a quantum sensor (LI-185; LICOR, Lincoln, NE) was 1310 ± 41 $\mu mol \cdot s^{-1} \cdot m^{-2}$. Daily temperature and relative humidity were determined with a temperature and humidity sensor (CS500, Campbell Scientific, Logan, UT) and monitored hourly. All environmental data were collected by a weather station adjacent to the plot and averaged every day. Sensors were connected to a data logger (CR10X, Campbell Scientific).

Salinity treatment. On September 29, 2004, the six most uniform plants from each of the three seed sources were randomly assigned to one of four treatments, with one being a nontreated control irrigated with tap water (EC = 0.57). The other three treatments were irrigated with amended tap to achieve an EC of 2.5, 5.0, or 10.0 $dS \cdot m^{-1}$ (0, 1,600, 3,200, 6,400 ppm) using a solution of $CaCl_2$ (Sigma-Aldrich, St. Louis, MO) and NaCl (Sigma-Aldrich) (3:1 w/w). Treatments started on the same day and each tree received 3.0 L (0.8 gal) of the treatment solution daily, applied manually. Salinity treatments were increased stepwise to final salinity levels to gradually acclimate the plants. On the first day, all of the plants (except the control) received 1.5 $dS \cdot m^{-1}$ (960 ppm) and then the EC was increased 1 $dS \cdot m^{-1}$ (640 ppm) every day until the intended treatment level was achieved. Plants needed 10 d to reach the final level of 10 $dS \cdot m^{-1}$ (6,400 ppm) treatment. Thereafter, treatments were applied daily for 42 d and the EC was monitored daily. Additionally, plants were irrigated every 10 d with the Peter's fertilizer solution containing N at 150 $mg \cdot L^{-1}$ (ppm) with EC 2.7 $dS \cdot m^{-1}$ (1,728 ppm). The fertilizer solution treatments also began on September 29, 2004. The EC of the fertilizer solution was recorded and the fertilizer solution was supplemented with a solution of $CaCl_2$ and NaCl (3:1, v/v) to attain the three salinity levels. The EC of the fertilizer solution (2.7 $dS \cdot m^{-1}$ [1,728 ppm]) was slightly higher than that of the lowest salinity treatment (2.5 $dS \cdot m^{-1}$ [1,600 ppm]), but was only applied once every 10 d.

The leaching fraction averaged 30%, and at the end of the experiment, leachate EC averaged 0.9 for the control (EC = 0.57), 3.2 $dS \cdot m^{-1}$ (2,048 ppm) for the 2.5 $dS \cdot m^{-1}$ (1,600 ppm) solution, 5.5 $dS \cdot m^{-1}$ (3,520 ppm) for 5.0 $dS \cdot m^{-1}$ (3,200 ppm), and 11.4 $dS \cdot m^{-1}$ (7,296 ppm) for the 10.0 $dS \cdot m^{-1}$ (6,400 ppm). During the experimental period, there were four precipitation events that averaged 6.1 mm (0.24 in) and did not affect the EC values.

Growth analysis. Plant height was recorded as the length of the plant from the growing substrate to the uppermost bud while plants were in pots. Stem length was measured at 2.5 cm (1.0 in) above the stem base to the uppermost bud both at the beginning of the experiment and at harvest. We measured stem length at 2.5 cm (1.0 in) since this point was judged to be above the root collar while allowing for consistent measurement of xylem diameter. Xylem diameter was measured at 1 cm (0.4 in) above the stem base after the bark was peeled back at the beginning of the experiment and at harvest. After 42 d of salinity treatment, the plants were destructively harvested on November 9, 2004. Roots were washed in water to remove growing substrate 2 d after severance of stems. Weights of leaves, stems and washed roots were determined after drying for 5 d at 65 C (149 F). Specific stem length was calculated by dividing stem length by stem dry weight. Stem dry weight included all material, exclusive of leaves, severed above 2.5 cm.

Mineral nutrient analysis. Dried foliar tissue was ground to pass a 2.0 mm screen (Wiley Mill, Arthur H. Thomas, Philadelphia, PA). Tissue was analyzed for magnesium (Mg),

Table 1. **Growth and development traits of bigtooth maple plants harvested after 42 d of salinity treatments, averaged over salinity treatment, for three seed sources. Values are LSMeans. Means within columns with the same letter are not statistically different at $P \leq 0.05$.**

Seed provenances, state	Tree code used	Plant height (cm)	Xylem diameter (mm)	Specific stem length ($cm \cdot g^{-1}$)	Leaf DW[z] (g)	Shoot DW (g)	Root/shoot DW	Plant DW (g)
Dripping Springs State Park, NM	NM	64.6a	11.2ab	5.1a	4.5b	14.7b	2.6a	42.7b
Guadalupe Mountains, TX	TX	68.7a	11.4a	2.6b	15.7a	45.6a	1.6c	95.9a
Logan Canyon, UT	UT	57.3a	9.8b	4.9a	5.8b	17.2b	2.1b	43.8b
Significance					P value			
Salinity treatment		0.629	0.090	0.633	0.356	0.677	0.921	0.639
Provenance		0.548	0.046	0.001	0.003	0.000	0.002	0.000
Provenance × salinity treatment		0.484	0.060	0.764	0.824	0.815	0.418	0.363

[z]Abbreviations: DW = dry weight.

calcium (Ca), K, P and Na following mineralization. Total N content was determined by micro-Kjeldahl digestion (KN) (Helrich 1990). Samples were analyzed by the Soil, Water, and Agricultural Testing Laboratory at New Mexico State University, Plant and Environmental Sciences Department, Las Cruces, NM.

Visual assessment of foliar injury. Visual assessment of the aesthetic condition of the plants was conducted by scoring the plants for foliar injury every 10 d during the experimental period. The scoring was on a scale of 1 to 5. A score of 1 indicated the plants had foliar growth and green leaves with little leaf senescence. A score of 2 denoted plants that had healthy new growth with some marginal leaf tip burn in the older leaves and senescence of some old leaves with no signs of necrosis or chlorosis. A score of 3 indicated leaves had started to show signs of necrosis and chlorosis, and old leaves had senesced but new growth was healthy. A score of 4 meant about 90% of leaves showed signs of necrosis and chlorosis, the old leaves had senesced and new growth appeared wilted and a score of 5 indicated trees with complete defoliation and no new growth.

Plant water relations. Three blocks of the six blocks were randomly chosen to determine plant water status. Transpiration, stomatal conductance (g_s), and leaf water potential were determined on each plant of three blocks every 10 d. Predawn water potential (Ψ_{pd}) was recorded between 03:30 HR and 04:30 HR using a pressure chamber (PMS Instruments, Corvallis, OR). Between 11:30 HR and 12:30 HR of the same day, transpiration, g_s, and leaf water potential were taken on the leaf opposite the leaf used for the Ψ_{pd}. Transpiration and g_s were recorded with a steady state porometer (LI-1600, LI-COR, Lincoln, NE).

Data analysis. Data were analyzed using the SAS software for Windows, Version 9 (SAS Institute, Cary, NC). Analysis of variance procedures for Ψ_{pd} and final harvest destructive harvest data were done using Proc Mixed procedures. Fixed effects included treatment, source and time. A block represented random factors, and a tree served as an experimental unit. Differences in least squares means were assessed at $P \leq 0.05$ using the PDIFF option. Analyses included repeated time measures utilizing compound symmetric covariance structure for the observations taken from the same tree. Kenward-Rogers adjusted degrees of freedom were used.

Results and Discussion

At the end of the experiment, there was no significant interaction between plant source and salinity treatment for growth and development traits. Growth and development traits data were therefore averaged over salinity treatments. Averaged over all salinity treatment, plants from TX had larger xylem diameter, specific stem length and leaf dry weight (DW) than those from NM and UT (Table 1). The total plant DW of TX plants was more than double that of NM or UT plants. Plants from TX also had a shoot DW at harvest roughly triple that of NM and UT plants. Plants from NM and UT had higher root/shoot DW than those from TX.

There were no significant differences among tree sources for leaf KN, K, and Mg content (Table 2). However, leaf content of Ca and P was different among sources. The salinity treatments did not affect leaf nutrient concentrations of KN, K, Ca, Mg, and P. In contrast, leaf Na content was affected by both sources as well as salinity treatments. Plants from TX had the highest concentration of Na in their leaves, with about three times more than the plants from NM, and two times more than plants from UT. This suggests that plants from TX are translocating Na^+ to the leaves. However, we speculate that plants from TX have the capacity to osmotically adjust their leaf cell contents and that limits the injurious osmotic effects of salt accumulation.

Plants, averaged over source, that received the salinity treatment of 10.0 $dS \cdot m^{-1}$ (6,400 ppm) had the highest concentration of Na (0.55%), over twice that of the control plants (Table 3). Plants in the 2.5 $dS \cdot m^{-1}$ (1,600 ppm) and 5.0 $dS \cdot m^{-1}$ (3,200 ppm), salinity treatments had Na concentrations similar to those irrigated with tap water (control).

Foliar injury scores for trees from all three sources increased during the salinity treatments when averaged over salinity treatment (Fig. 1). The salinity treatments had less of an effect on trees from TX compared to those from NM and UT. The final foliar injury assessment for TX trees of 2.0 was half that of UT trees.

TX's trees' lowest Ψ_{pd} (0.55 MPa) was higher than any measurement UT trees had over the duration of salinity treatments (Fig. 2). Plants from TX also maintained a better (less negative) Ψ_{pd} over the course of the treatments than seedlings from the other two provenances.

Transpiration and g_s were both similar among sources and treatments. Over time, both g_s (Fig. 3A) and transpiration (Fig. 3B) tended to decrease.

Table 2. **Leaf mineral content of Kjeldahl nitrogen (KN), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), and phosphorus (P) of three bigtooth maple sources harvested after 42 d of salinity treatments, averaged over salinity treatment, for three seed sources. LSMeans within columns were assessed at $P \leq 0.05$ using the Proc Mixed, PDIFF option.**

Seed provenances, state	Tree code	KN (%)	K (%)	Na (%)	Ca (%)	Mg (%)	P (%)
Dripping Springs State Park, NM	NM	1.81a	0.509a	0.173b	2.98a	0.423a	0.181b
Guadalupe Mountains, TX	TX	1.86a	0.590a	0.551a	2.23b	3.348a	0.295a
Logan Canyon, UT	UT	1.68a	0.400a	0.269b	3.22a	0.403a	0.288a
Means		1.79	0.499	0.331	2.81	0.391	0.255
Significance				P value			
Salinity treatment		0.0954	0.3063	0.0049	0.3017	0.4731	0.5142
Tree		0.2810	0.1113	0.0002	0.0001	0.2584	0.0226
Tree × salinity treatment		0.3637	0.1197	0.2553	0.1020	0.5316	0.8717

Table 3. **Leaf sodium (Na) content of bigtooth maple seedlings harvested after 42 d of salinity treatments for three seed sources. LSMeans within rows were assessed at $P \leq 0.05$ using the Proc Mixed, PDIFF option. There were significant differences among treatments ($P = 0.0049$) for leaf Na.**

Seed provenances, state	Tree code	Leaf sodium content (%) Salinity treatments EC ($dS \cdot m^{-1}$)				
		Control (0)	2.5	5.0	10.0	Means
Dripping Springs State Park, NM	NM	0.120a	0.170a	0.100a	0.303a	0.173
Guadalupe Mountains, TX	TX	0.140b	0.330b	0.493b	0.970a	0.550
Logan Canyon, UT	UT	0.197a	0.303a	0.193a	0.383a	0.269

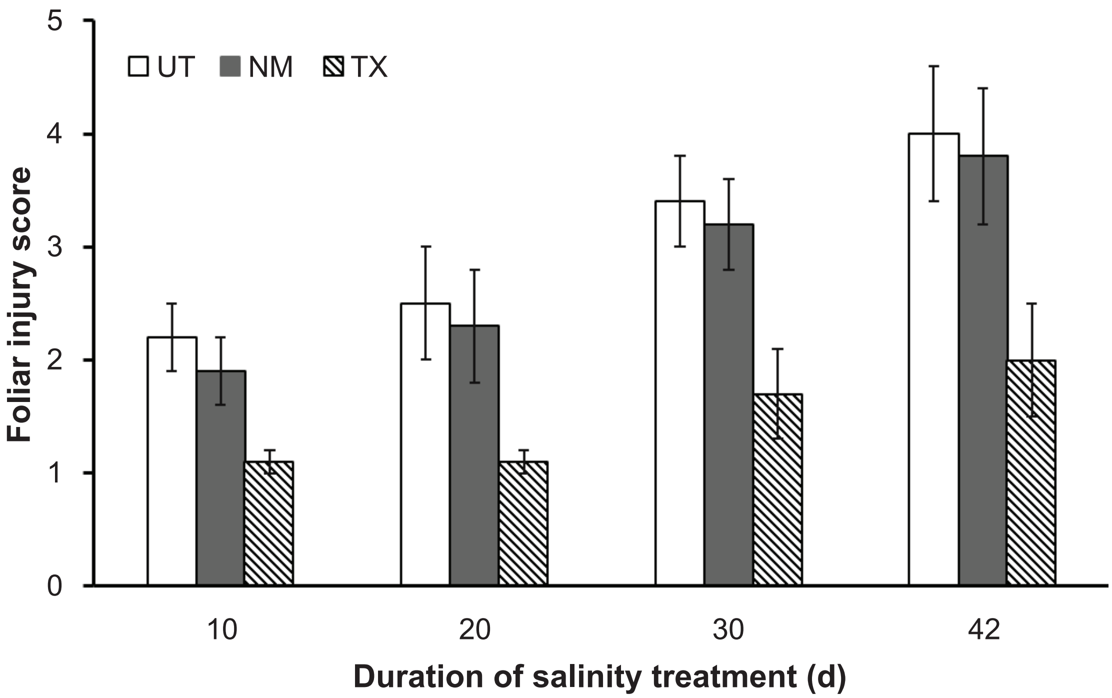


Fig. 1. **Foliar injury score of three seed provenances of bigtooth maples subjected to 42 d of salinity treatments, averaged over salinity level. UT is one seed source from Logan Canyon, Utah. NM is one seed source from Dripping Springs State Park, Las Cruces, NM. TX is one seed source from the Guadalupe Mountains, Salt Flat, TX. Each point represents a mean ± SE ($n = 6$). Plants were scored on a scale of 1 to 5. A score of 1 means plants had foliar growth with green leaves and little leaf senescence. A score of 2 signifies plants had healthy new growth with some marginal leaf tip burn in the older leaves and senescence of some old leaves with no signs of necrosis and chlorosis. A score of 3 means leaves started to show signs of necrosis and chlorosis, old leaves had senesced, and new growth was healthy. A score of 4 denotes about 90% of leaves showed signs of necrosis and chlorosis, old leaves had senesced and new growth appeared wilted, and a score of 5 indicates leaves were completely burned and defoliated and there was no new growth.**

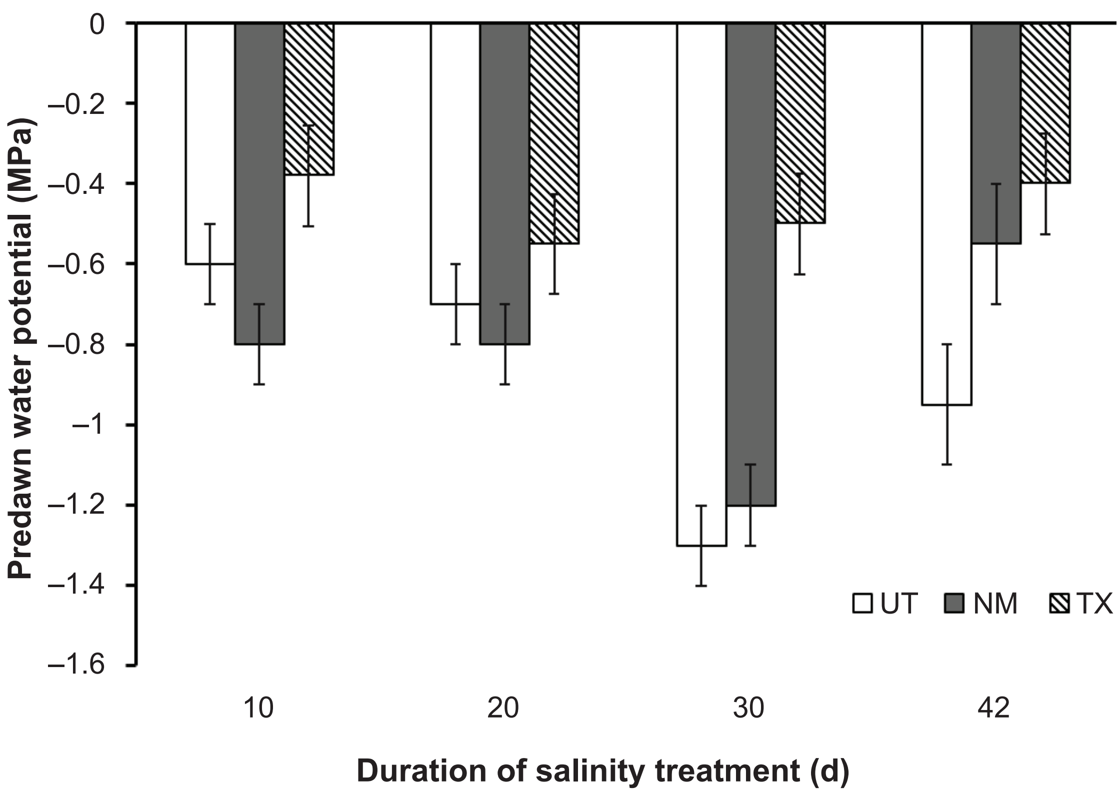


Fig. 2. Predawn water potential of three seed provenances of bigtooth maples subjected to 42 d of salinity treatments, averaged across salinity treatments. NM is one seed source from Dripping Springs State Park, Las Cruces, NM. TX is one seed source from the Guadalupe Mountains, Salt Flat, TX. UT is one seed source from Logan Canyon, Utah. Each point represents a mean ± SE (*n* = 6). The standard error among measurement times was ± 0.08 MPa.

For a native tree planted in a managed landscape, plant survival after the exposure to short term salinity is critical to plant establishment. Furthermore, the outdoor, pot in pot design used in this experiment better simulates true managed landscape growing conditions than greenhouse conditions. Because woody plants are generally more sensitive to salinity as seedlings than at other stages (Shannon et al. 1994), the use of seedling material presents the worst-case scenario for the use of bigtooth maples in managed landscapes.

Overall, the seedlings in this study were resilient to salinity treatments, and plants from the TX provenance were especially tolerant, which supports the statement by Hatter and Morgan (1992) that bigtooth maple might be well-suited for semiarid landscapes (Hatter and Morgan 1992).

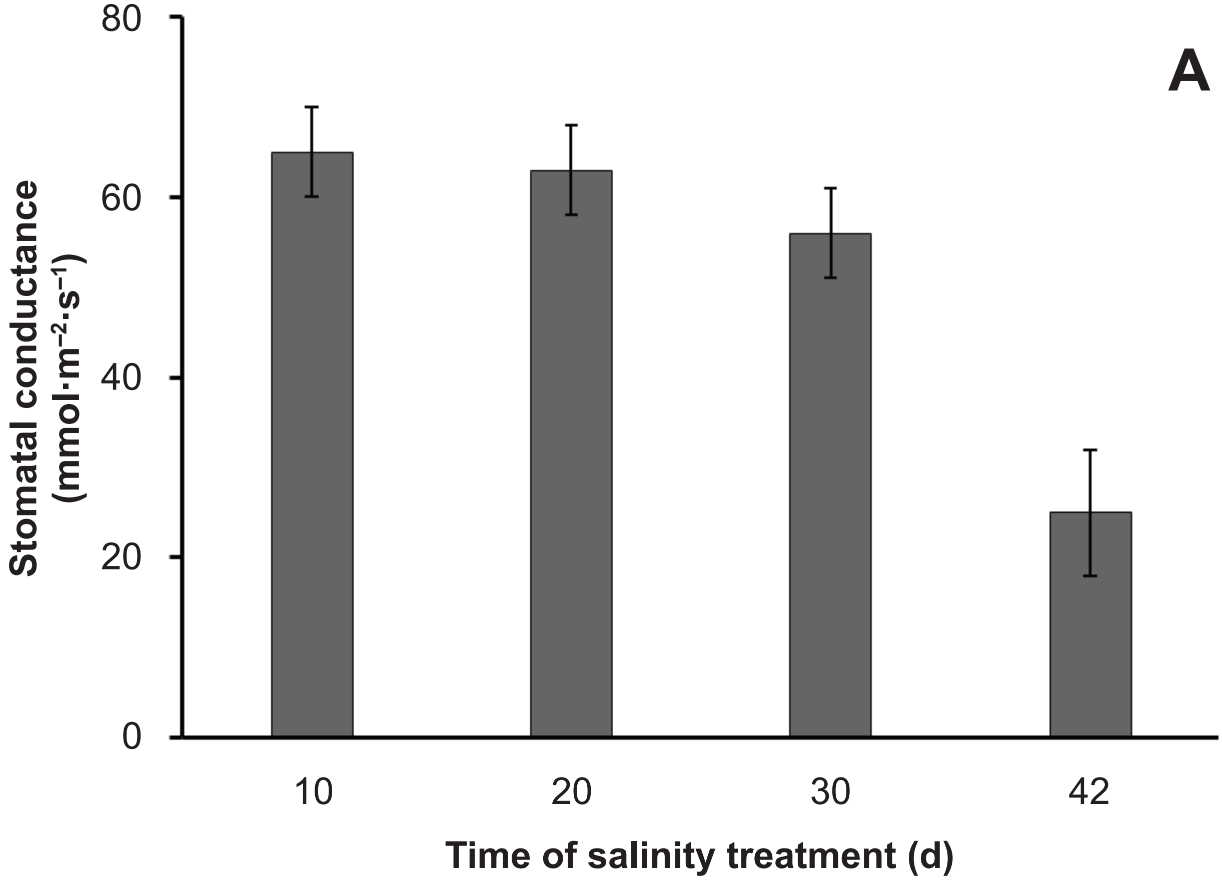
A salinity level of 10 $dS \cdot m^{-1}$ (6,400 ppm) is classified as high salinity (Osman 2013) and many woody plants easily can be injured by salinity at this level, causing limited growth and altered plant morphology. The adverse effect of salinity on trees from UT and NM suggest that bigtooth maple seedlings from these two provenances should be considered less desirable for landscapes challenged with salinity than those from the TX provenance.

While plant heights from all three provenances were similar, plants from TX had nearly three times as much leaf DW as those from UT and NM, averaged across salinity treatments (Table 1). An increase in leaf DW can be partially explained by the tendency in woody plants to increase leaf thickness in response to salinity (Kozlowski and Palardy 1997). We did not measure leaf thickness in this study.

For woody plants, salinity typically reduces root growth more than stem growth causing plants to increase the number of xylem vessels as compensation for the reduction in root growth (Kozlowski and Palardy 1997). However, leaf growth is more sensitive to salinity than root growth (Munns and Termaat 1986). Given that plants from TX had the lowest ratio of root/shoot DW (Table 1), a possible explanation for this result is that lower foliar growth in trees from UT and NM resulted in greater root to shoot ratios.

The higher leaf Na content and lower Ca content (Table 2) of plants from TX suggest that plants from TX are translocating Na^+ to the leaves, which may lead to a displacement of apoplastic Ca^{2+} (free calcium) (Zid and Grignon 1985). The accumulation of Na^+ in leaf tissues inhibits growth and produces necrosis of older leaves (Tester and Davenport 2003). Even though plants from TX accumulated three times more Na than plants from NM and two times more than UT plants (Table 2) and accumulated the most Na at highest salinity level (Table 3), they had the lowest foliar injury score during the experiment (Fig. 1). Even though TX plants accumulated more Na^+ in the leaves, they maintained better growth and appearance than plants from UT and NM, perhaps due to regulation of leaf osmotic cell contents.

During the experiment, plants from TX maintained a more favorable Ψ_{pd} than those from NM or UT (Fig. 2). Salinity induces drought-like effects in plants by decreasing leaf water potential and osmotic potential (Loustau et al. 1995) and this could be reflected in Ψ_{pd}. The maintenance of Ψ_{pd} is an important physiological trait because Ψ_{pd} is an



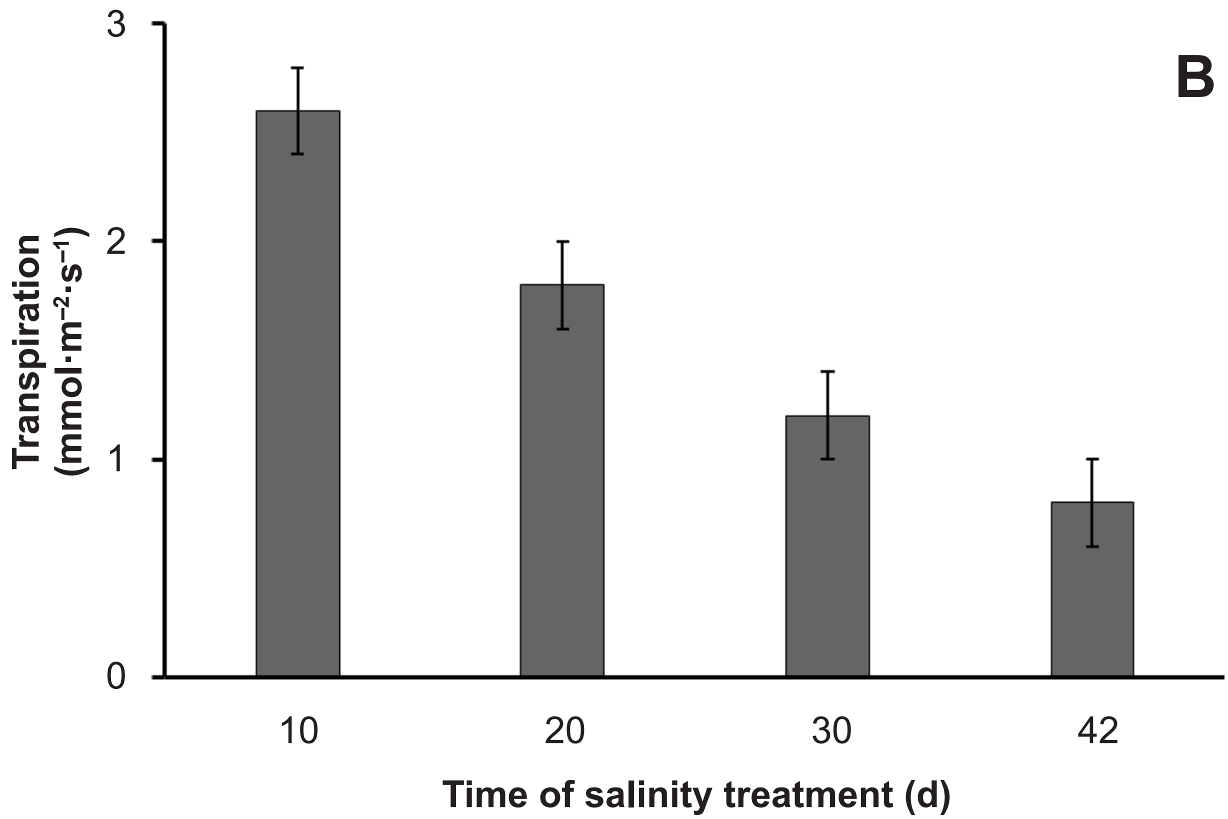


Fig. 3. **(A) Stomatal conductance (g_s); and (B) Transpiration for bigtooth maples subjected to 42 d of salinity treatments, averaged across the three tree sources. Each column represents a mean ± SE (n = 6). UT is one seed source from Logan Canyon, Utah. NM is one seed source from Dripping Springs State Park, Las Cruces, NM. TX is one seed source from the Guadalupe Mountains, Salt Flat, TX.**

indicator of the energy in the leaf before transpiration and photosynthesis have started (Abrams and Knapp 1986, Balok and St. Hilaire 2002).

Similar to the maintenance of Ψ_{pd}, the reduction in g_s and transpiration rate are mechanisms that plants use to adapt to salt stress (Tattini et al. 2002). For example, mock privet (*Phillyrea latifolia* L.) plants subjected to salinity demonstrated a decline in leaf transpiration rate and g_s (Tattini et al. 2002). The cumulative effect of salinity appears to reduce g_s and transpiration over time in the mock privet. Under water-stress such as that engendered by salt stress, plants tended to reduce their stomatal aperture for better control of water loss.

The data suggests that plants from all three sources were able to withstand salinity treatments. However, horticulture industry personnel wishing to pick bigtooth maples with superior resilience to saline environments, might look to the Texas provenance for source material.

Literature Cited

Abrams, M.D. and A.K. Knapp. 1986. Seasonal water relations of three gallery forest hardwood species in northeast Kansas. Forest Sci. 32:687–696.

Balok, C.A. and R. St. Hilaire. 2002. Drought responses among seven southwestern landscape tree taxa. J. Amer. Soc. Hort. Sci. 127:211–218.

Barker, P.A. 1974. Spectacular canyon maple. Utah Sci. 35:7–10.

Bsoul, E., R. St. Hilaire, and D.M. VanLeeuwen. 2007. Bigtooth maples from selected provenances effectively endure deficit irrigation. HortScience 42:1167–1173.

Hatter, M.D. and D.L. Morgan. 1992. Growth and visual responses of three southwestern *Acer* taxa to high-salt irrigation water. J. Environ. Hort 10:118–120.

Helrich, K.C. (ed.). 1990. Official methods of analysis of the Association of Official Analytical Chemists. 15th ed. Assn. Off. Anal. Chem., Washington, DC. p. 60.

Iglesias, D.J., Y. Levy, A. Gòmez-Cadenas, F.R. Tadeo, E. Primo-Millo, and M. Talon. 2004. Nitrate improves growth in salt-stressed citrus seedlings through effects on photosynthetic activity and chloride accumulation. Tree Physiol. 24:1027–1034.

Ke-Fu, Z., A. Littlewood, and P. Harris. 1992. Responses of *Gleditsia triacanthos* seedlings to salt stress. Intl. Tree Crops J. 7:149–153.

Ke-Fu, Z., R. Munns, and R. King. 1991. Abscisic acid levels in NaCl-treated barley, cotton and saltbush. Functional Plant Biol. 18:17–24.

Kozlowski, T.T. and S.G. Palardy. 1997. Growth Control in Woody Plants. Academic Press. New York, NY. 641 p.

Loustau, D., S. Crepeau, M. Guye, M. Sartore, and E. Saur. 1995. Growth and water relations of three geographically separate origins of maritime pine (*Pinus pinaster*) under saline conditions. Tree Physiol. 15:569–576.

Munns, R. 1993. Physiological processes limiting plant growth in saline soils: Some dogmas and hypotheses. Plant, Cell and Environ. 16:15–24.

Munns, R. and A. Termaat. 1986. Whole-plant responses to salinity. Austral. J. Plant Physiol. 13:143–160.

Osman, K.T. 2013. Forest soils: Properties and management. Springer Dordrecht, The Netherlands, NL. 271 p.

Rao, S., V. Sreenivasulu, S.M. Bhallamudi, B. Thandaveswara, and K. Sudheer. 2004. Planning groundwater development in coastal aquifers/ Planification du développement de la ressource en eau souterraine des aquifères côtiers. Hydrol. Sci. J. 49:155–170.

Romero-Aranda, R. and J.P. Syvertsen. 1996. The influence of foliar-applied urea nitrogen and saline solutions on net gas exchange of citrus leaves. J. Amer. Soc. Hort. Sci. 121:501–506.

Rowland, D., A. Sher, and D. Marshall. 2004. Inter-and intra-population variation in seedling performance of Rio Grande cottonwood under low and high salinity. Can. J. For. Res. 34:1458–1466.

Shannon, M.C., C.M. Grieve, and L.E. Francois. 1994. Whole-plant response to salinity. R.E. Wilkinson (Ed.). Marckel Dekker Inc. New York. pp. 199–244.

Simpson, B.J. and B.W. Hipp. 1993. Maples of the southwest. Amer. Nurseryman 117:26–35.

Stevens, C., C.L. Wilson, J.Y. Lu, V.A. Khan, E. Chalutz, S. Droby, M.K. Kabwe, Z. Haung, O. Adeyeye, L.P. Pusey, M.E. Wisniewski, and M. West. 1996. Plant hormesis induced by ultraviolet light-C for controlling postharvest disease of tree fruits. Crop Protection 15:129–134.

Tattini, M., G. Montagni, and M.L. Traversi. 2002. Gas exchange, water relations and osmotic adjustment in *Phillyrea latifolia* grown at various salinity concentrations. Tree Physiol. 22:403–412.

Tester, M. and R. Davenport. 2003. Na^+ tolerance and Na^+ transport in higher plants. Ann. Bot. 91:503–527.

Volkmar, K.M., Y. Hu, and H. Steppuhn. 1998. Physiological responses of plants to salinity: A review. Can. J. Plant Sci. 78:19–27.

West, D. and J. Taylor. 1984. Response of six grape cultivars to the combined effects of high salinity and rootzone waterlogging. J. Amer. Soc. Hort. Sci. 109:844–851.

Zid, E. and C. Grignon. 1985. Sodium calcium interactions in leaves of *Citrus aurantium* grown in the presence of NaCl. Physiol. Vegetale (France) 23:895–903.