Salinity Tolerance of *Lupinus havardii* and *Lupinus texensis*

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Abstract. Use of recycled water to irrigate urban landscapes and nursery plants may be inevitable as fresh water supplies diminish and populations continue to grow in the arid and semiarid southwestern United States. *Lupinus havardii* Wats. (Big Bend bluebonnet) has potential as a cut flower and *Lupinus texensis* Hook. (Texas bluebonnet) as a bedding plant, but little information is available on salt tolerance of these species. A greenhouse study was conducted to characterize the growth in response to various salinity levels. Plants were grown in 10-L containers and drip-irrigated with synthesized saline solutions at electrical conductivity levels of 1.6, 3.7, 5.7, 7.6, or 9.4 dS·m⁻¹. Although shoot growth of *L. texensis* was reduced as salinity levels increased, it was visually acceptable (without any visual injury) when irrigated with salinity levels of less than 7.6 dS·m⁻¹. All plants survived at 7.6 dS·m⁻¹, whereas only 15% did at 9.4 dS·m⁻¹. In contrast, *L. havardii* had leaf injury at 5.7 dS·m⁻¹. No plants survived at 9.4 dS·m⁻¹, and only 7% plants survived at 7.6 dS·m⁻¹. In addition, growth of *L. havardii* was significantly reduced and plants were shorter at elevated salinity levels. Cut raceme yield of *L. havardii* decreased at salinity levels greater than 3.7 dS·m⁻¹. However, no difference in cut raceme yield was observed between the control and 3.7 dS·m⁻¹, although shoot growth was reduced. Overall, *L. texensis* was more salt-tolerant than *L. havardii*.

Because fresh water supplies are limited in many parts of the world, using alternative water sources for irrigating horticultural crops may become necessary. Alternative water sources (hereafter called nonpotable water) include recycled water, treated municipal effluent (reclaimed water) and brackish groundwater, which generally contain higher levels of salts compared with potable water. Previous research has demonstrated the possibility of using nonpotable water for irrigating high-value horticultural crops (Grieve et al., 2005, 2006; Shannon et al., 2000; Shillo et al., 2002) and for landscape irrigation (Devitt et al., 2005; Marosz, 2004; Niu and Rodriguez, 2006a, 2006b; Wu et al., 2001), although a wide range of salt tolerance among these ornamental plants was observed.

Depending on salt tolerance, some plants became more compact with little visual damage when irrigated with low to moderate salinity compared with nonsaline control (Niu and Rodriguez, 2006a, 2006b; Wu et al., 2001). For landscape plants, maximizing growth is not essential and indeed, excessive shoot vigor is often undesirable. To maintain a compact growth habit, ornamental plants traditionally have either been pruned or treated with growth regulators (Cameron et al., 2004). Therefore, nonpotable water may play an important role for landscape irrigation where potable water supply is limited. Salinity stress in some instances has positive effects on crop yield and quality in some floricultural crops (Grieve et al., 2006). For example, number of flowers, stem weight, and stem diameter of lisianthus were increased when salinity stress was imposed during the final stage of vegetative growth compared with the control (Shillo et al., 2002). Salinity stress during early reproductive stage resulted in shorter, more robust peduncles with larger inflorescences in carnation (Baas et al., 1995).

Lupinus havardii is an annual native to a narrow geographic range along the Rio Grande River in southwest Texas and has

shown potential to be grown as a specialty cut flower (Davis et al., 1994; Picchioni et al., 2001). It has fragrant and attractive blue racemes with a length of 40 to 55 cm supporting 25 to 30 fully opened flowers (Mackay and Davis, 1998). In Texas, *L. texensis* is a hardy winter annual and is the best-known, most widely distributed member of the *Lupinus* genus (Davis et al., 1994). Transplants of *L. texensis* are produced for spring and fall sales, but those grown during late summer and early fall are the best for garden performance in warmer regions in the United States (Davis et al., 1994). There is no information available on the impact of saline irrigation on the growth and development of these two species. The objectives of this study were to determine the salinity threshold for marketable production of *L. havardii* and *L. texensis* and assess the effects of increasing levels of salinity on growth of these species.

Materials and Methods

Plant materials and cultural conditions. Seeds of *L. havardii* and *L. texensis* were obtained from a nursery (Plants of the Southwest, Albuquerque, N.M.), scarified with concentrated sulfuric acid for 90 min for *L. havardii* and 45 min for *L. texensis*, and sowed in a greenhouse on 10 Jan. in plug trays (85 cm³ per cell) filled with a mix consisting of equal parts of vermiculite, peat, and perlite on a volume basis. Seedlings were transplanted on 1 Mar. to 10-L containers filled with Metromix 200 (Scotts Co., Marysville, Ohio). Plants were drip-irrigated as needed, based on container weight, with a nutrient solution containing 0.5 g·L⁻¹ of 20N–8.6P–16.7K (Peters 20–20–20; Scotts, Allentown, PA). The air temperature in the greenhouse was 18 to 24 °C during the day and 12 to 14 °C at night during the experimental period. The daily light integral (photosynthetically active radiation) was 10 to 20 mol·m⁻²·d⁻¹ measured by a quantum sensor (Model QSO-SUN; Apogee Instruments, Logan, Utah). A 21X datalogger (Campbell Scientific, Logan, Utah) was used to measure temperature and light at 10-s intervals and the hourly averages were recorded.

Treatments. Saline solutions were prepared by adding sodium chloride (NaCl), magnesium sulfate (MgSO₄·7H₂O), and calcium chloride (CaCl₂) at 87%, 8%, and 5% (by weight), respectively, to the nutrient solution mentioned previously to simulate the salt composition in reclaimed municipal effluent discharged by the local water utility. Five salinity levels of 1.6 (nutrient solution, control), 3.7, 5.7, 7.6, or 9.4 dS·m⁻¹ electrical conductivity (EC) were created, and saline irrigation was initiated on 9 Mar. and ended on 24 May (11 weeks). There were 15 plants per treatment for each species, which were randomly placed on greenhouse benches. Five magnetic drive pumps (Model 3-MD-MT-HC; Little Giant Co., Oklahoma City, Okla.) were used to pump the nutrient or saline solutions to each container through a

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drip irrigation system. The amount of irrigation volume was determined by measuring the flow rates of the drip irrigation system and the water-holding capacity of the medium to obtain at least 30% leaching fraction to prevent rapid salt accumulation. Plants were irrigated when $\approx 50\%$ of the water was depleted from the substrate by weighing five indicator containers to prevent drought stress and overwatering for all treatments.

Measurements. On termination of the experiment, plant height, two perpendicular canopy widths (after racemes were removed), visual quality, and dry weight of shoots were measured. Growth index was calculated as: $\text{growth index} = [\text{height} + (\text{canopy width } 1 + \text{canopy width } 2)/2]$. Visual quality of plants was assessed on a scale of 1 to 5, in which 1 = severely stunted growth with over 50% foliage salt damage (leaf necrosis, browning) or dead; 2 = somewhat stunted growth with moderate (25% to 50%) foliage salt damage; 3 = average quality with slight (less than 25%) foliage salt damage; 4 = good quality with acceptable growth reduction and little foliage damage; and 5 = excellent with vigorous growth and no foliage damage. Dry weight of shoots was determined by oven-drying the tissue at 70°C for 4 d. The racemes of *L. havardii* were harvested weekly on shoots that were 40 cm or longer. Total number of racemes per plant was determined for *L. texensis* at harvest.

Leaf osmotic potentials (ψ_s) were determined by sampling a few leaves from the middle section of the shoots in the early morning (0800 to 0900 HR) at the end of the experiment. Leaves were sealed in a plastic bag and immediately stored in a -80°C freezer until analysis. Frozen leaves were thawed in a plastic bag at room temperature before sap was pressed with a Markhart leaf press (LP-27; Wescor, Logan, Utah) and analyzed using a vapor pressure osmometer (Vapro Model 5520; Wescor) to determine the leaf ψ_s . Osmometer readings ($\text{mmol}\cdot\text{kg}^{-1}$) were converted to MPa using the van't Hoff equation at 25°C (Nobel, 1991).

Five shoot samples per treatment were collected for mineral analysis of Na and Cl at the end of the experiment. Dried shoots were ground with a stainless Wiley mill and ground samples were sent to an analytic laboratory for mineral analysis (SWAT laboratory at New Mexico State University, Las Cruces, N.M.). The Na concentrations were determined by EPA method 200.7 (U.S. Environmental Protection Agency, 1983) and analyzed on an ICAP Trace Analyzer (Thermo Jarrell Ash, Franklin, Mass.). Chloride was determined by EPA method 300.0 (U.S. Environmental Protection Agency, 1983) and analyzed using an Ion Chromatograph (Dionex, Sunnyvale, Calif.).

Statistical analysis. The significance of salinity treatments was analyzed by analysis of variance using SAS software (SAS Institute, Cary, N.C.). When differences were found among salinity treatments, means were separated by Student-Newman-Keuls multiple comparison at $P = 0.05$. Whenever the two species were compared, t test was used.

Results

After 11 weeks of treatment, *L. havardii* had leaf injuries at salinity levels $5.7\text{ dS}\cdot\text{m}^{-1}$ or greater. The $7.6\text{ dS}\cdot\text{m}^{-1}$ and $9.4\text{ dS}\cdot\text{m}^{-1}$ salinity treatments had 7% and 0% survival rates, respectively. Plants had similar visual appearance and no differences were found in cut raceme yield between the control ($1.6\text{ dS}\cdot\text{m}^{-1}$) and $3.7\text{ dS}\cdot\text{m}^{-1}$ (Fig. 1). In contrast, *L. texensis* were visually acceptable (without any injuries) when irrigated at salinity up to $7.6\text{ dS}\cdot\text{m}^{-1}$ with a 100% survival rate at $7.6\text{ dS}\cdot\text{m}^{-1}$ and 15% at $9.4\text{ dS}\cdot\text{m}^{-1}$. Shoot growth of both species decreased as salinity levels increased, but the reduction at $5.7\text{ dS}\cdot\text{m}^{-1}$ and $7.6\text{ dS}\cdot\text{m}^{-1}$ was more severe in *L. havardii* than *L. texensis*. Similar observations were noted as growth index decreased with increasing salinity levels for both species. Number of flowers and visual quality in *L. texensis* were similar at salinity up to $5.7\text{ dS}\cdot\text{m}^{-1}$.

Shoot Na concentrations in *L. havardii* were significantly higher in salinity treatments $3.7\text{ dS}\cdot\text{m}^{-1}$ or greater compared with the control (Fig. 2). Shoot Cl concentrations in *L. havardii* was similar among 3.7 , 5.7 , and $7.6\text{ dS}\cdot\text{m}^{-1}$ and was ≈ 5 times higher than in the control. In *L. texensis*, shoot Na

concentration was higher at $7.6\text{ dS}\cdot\text{m}^{-1}$ than the control, but there were no differences among 1.6 , 3.7 , and $5.7\text{ dS}\cdot\text{m}^{-1}$ or among 3.7 , 5.7 , and $7.6\text{ dS}\cdot\text{m}^{-1}$. Shoot Cl concentrations in *L. texensis* at $3.7\text{ dS}\cdot\text{m}^{-1}$ and $5.7\text{ dS}\cdot\text{m}^{-1}$ were different from the control or $7.6\text{ dS}\cdot\text{m}^{-1}$. Shoot Na and Cl increased to their maximum level at $3.7\text{ dS}\cdot\text{m}^{-1}$ for *L. havardii* but increased incrementally for *L. texensis* with increasing salinity. Decrease in ψ_s followed the same trend. Species main effect was not significant for shoot Na or Cl concentrations or ψ_s .

Discussion

For cut flower growers, producing high-quality flowers with an adequate cut length is important. In this study, we found that flower yield and quality (quantified by raceme length) were similar when irrigated with nutrient solution at $1.6\text{ dS}\cdot\text{m}^{-1}$ (control) and $3.7\text{ dS}\cdot\text{m}^{-1}$. The average EC of municipal reclaimed water is $\approx 2.0\text{ dS}\cdot\text{m}^{-1}$ depending on region or water source (Khurram and Miyamoto, 2005; Wu et al., 2001). This may indicate the possibility of using reclaimed water or other saline water to produce *L. havardii* cut flowers with little or no reduction in yield and quality as long as

Fig. 1. Effect of salinity treatments on visual score, dry weight of shoots, growth index, and total number of racemes per plant of *Lupinus havardii* and *Lupinus texensis*. Means within each species followed by the same letters are not significantly different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$. Vertical bars represent standard errors.

Fig. 2. Effect of salinity treatments on shoot sodium and chloride concentration (% dry weight) and leaf osmotic potentials of *Lupinus havardii* and *Lupinus texensis*. Means within each species followed by the same letters are not significantly different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$. Vertical bars represent standard errors.

the salinity of irrigation water is below 3.7 dS·m⁻¹ and well-drained medium is used. Carter et al. (2005) found that saline waters dominated by sulfate and chloride salts at salinity up to 8 dS·m⁻¹ or higher may be used commercially to produce cut flowers of *Celosia argentea* (L.) Kuntze. Beneficial effects of using saline water for irrigation were also reported in lisianthus (Shillo et al., 2002) and carnation (Baas et al., 1995). Salt tolerance and threshold for producing quality cut flowers varied with plant species (Shillo et al., 2002). The slight reduction in shoot growth incited by elevated salinity at 3.7 dS·m⁻¹ did not have a significant impact on yield.

Because *L. texensis* is used as a bedding plant, both growth rate and aesthetic appearance are important for bedding plant growers. Any delay in growth or visual damage may affect profit. Because the reduction in shoot growth is not commercially significant, this species can be produced using saline water at EC of up to 5.7 dS·m⁻¹. After installation in the landscape, visual appearance is more important than growth rate. In fact, for landscape use, a smaller or compact container plant is more preferred than a larger one if attractiveness is similar. In a landscape environment, slower growth is more desirable from a ground maintenance point of view. Therefore, non-

potable water at moderate salinity levels may be used as natural growth regulators to control the excessive growth or elongation.

Some species tolerate salt stress by avoiding taking up certain types of ions or by tolerating high ion concentrations in the tissue. Wu et al. (2001) found that salt-tolerant plants tended to accumulate less salt in leaf tissue than less salt-tolerant plants, and a wide range of salt tolerance was found among the 10 landscape plant species examined. The small differences in salt tolerance between the two species in this study may be attributable to their uptake of Na and Cl ions. For example, shoot Na and Cl concentrations at 3.7 dS·m⁻¹ and 5.7 dS·m⁻¹ were higher in *L. havardii* than *L. texensis*. This may be why the ψ_s were lower in *L. havardii* than *L. texensis* at 3.7 and 5.7 dS·m⁻¹.

In summary, shoot growth in both species were reduced at elevated salinity levels. The threshold of salinity for producing marketable flowers of *L. havardii* is 3.7 dS·m⁻¹ with slight reduction in shoot growth and no visual injury. Although shoot growth in *L. texensis* was also reduced, there was no visible injury at salinity up to 5.7 dS·m⁻¹, and more plants in *L. texensis* survived at higher salinity (7.6 dS·m⁻¹ and 9.4 dS·m⁻¹) than *L. havardii*. Therefore, *L. texensis* was more salt-tolerant than *L. havardii* and the threshold for irriga-

tion may be up to 5.7 dS·m⁻¹ with no visual injury.

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