Relative Salinity Tolerance of Intermountain Western United States Native Herbaceous Perennials

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Abstract. The authors investigated salinity tolerance of four intermountain western United States native (Penstemon palmeri, Mirabilis multiflora, Geranium viscosissimum, and Erigeron jamesii) and four common (Echinacea purpurea, Lavandula angustifolia, Leucanthemum ×superbum ‘Alaska’, and ×Penstemon mexicali ‘Red Rocks’) ornamental herbaceous perennials. Each was irrigated with a solution containing 2 CaCl₂ : 1 NaCl (M ratio) at salinity levels of 0 (control), 1000, 3000, and 5000 mg L⁻¹ during two 8-week experiments. They measured weekly visual quality and gas exchange and final shoot and root dry weights. Mirabilis multiflora, L. ×superbum, and L. angustifolia maintained high visual quality and 100% survival across salinity levels. However, dry weights for L. ×superbum decreased at salt levels ≥ 3000 mg mL⁻¹ in both experiments and for L. angustifolia in one experiment. Mortality rates of 12% to 100% were observed for the remaining five species irrigated with 3000 and 5000-mg mL⁻¹ solutions. Visual quality of P. palmeri, G. viscosissimum, and E. purpurea varied with time of year the experiment was conducted, with low visual quality associated with high temperatures and light intensities, whereas dry matter and gas exchange responses to salinity were similar between the two experiments. Penstemon ×mexicali and E. jamesii exhibited high mortality, low visual quality, and low gas exchange in the case of E. jamesii at high salinity treatments regardless of when experiments were conducted. Based on visual quality responses, M. multiflora, L. ×superbum, and L. angustifolia are relatively more salt tolerant, and P. ×mexicali and E. jamesii are relatively more intolerant, than the three other species. Penstemon palmeri, G. viscosissimum, and E. purpurea exhibited intermediate tolerance to salinity with acceptable quality during periods of cool temperatures and lower light intensities.

As the demand for and cost of potable water has increased, recycled and secondary water have become attractive alternatives for landscape irrigation (Kjelgren et al., 2000). However, the use of recycled and secondary water in landscape applications is limited because salinity levels are often higher than in primary or culinary sources. Salinity levels for some recycled water may be as low as 2 dS m⁻¹ (Lindsey et al., 1998), whereas salinity levels for secondary water can exceed 5 dS m⁻¹ (James and Jurinak, 1986). Relatively little research has been conducted to assess the soil salinity tolerance of ornamental plants. However, for some crop plants, damage can occur with irrigation salinity levels more than 1.0 to 2.0 dS m⁻¹ (Maas and Grattan, 1999). Salinity stress in soil-based systems is a result of both ion toxicities and the combined osmotic effects of salts accumulating in the soil and matric effects of soil drying (Bernstein, 1975; Glenn and Brown, 1998), and thus can produce different symptoms than those seen in hydroponic culture. Typical plant responses to soil salinity include reduced shoot and root growth rates (Munn, 2002), reduced leaf or shoot number (Munn, 2002), declines in stomatal conductance (gs) and photosynthesis rates (Kerstiens et al., 2002; Rivelli et al., 2002; Wang and Nii, 2000), and damage or death of leaves (Munn, 2002). Because many of the common responses to salinity decrease the visual quality of the plant, salinity may limit the use of specific plants in greenhouse or landscape settings where saline irrigation water is used. Plant responses to salinity, particularly visual responses, are typically more severe when leaves are exposed directly to salinity (Simini and Leone, 1986; Wu et al., 2001). Thus, although salt spray studies (Deeter, 2001; Wu et al., 2001) may be valid for a general comparison of species tolerance to salinity, the results may not be readily extrapolated to soil-based systems in which irrigation water does not come in contact with leaves. A limited number of commonly grown herbaceous perennials have native distributions in saline environments and are thought to have some tolerance to salinity. For example, Leucanthemum ×superbum grows along seashores (Phillips and Burrell, 1993), and Lavandula species are frequently found in harsh Mediterranean climates where they are exposed to sea spray (Upson and Andrews, 2004). These plants are well suited for use in landscapes where saline irrigation water is used. However, to maintain high visual appeal and ecological diversity within these landscapes, more salt-tolerant selections need to be identified. Because a large proportion of the soils in the intermountain western United States (IMW; the biogeographical region between the Sierra Nevada and Rocky Mountain ranges) are saline, this region may be a source of potentially salt-tolerant herbaceous perennials (Mee et al., 2003).

Quantitative knowledge of the salinity tolerance of specific herbaceous perennials is important if these plants are to have a place in landscapes irrigated with saline water. Visual quality is an important factor in screening for salt tolerance of herbaceous perennials for ornamental landscapes. Because plants respond differently to salinity, visual quality may or may not be related to biomass production and photosynthetic response. The primary objective of this study was to evaluate the relative salinity tolerance of four commonly grown and four IMW native ornamental herbaceous perennials based primarily on visual quality, survival, and plant biomass. A secondary objective was to assess the effect of saline irrigation on gas exchange properties of these species.

Materials and Methods

Experimental design. The study was conducted at the Utah State University Research Greenhouses (North Logan, Utah; lat., 41°45′N; long., 111°48′W). For each of the eight species used in the study, experiments were performed at two of the four time periods.
periods: Spring 2003 (9 May–3 July), Spring 2004 (10 Apr.–2 June), Summer 2004 (18 June–12 Aug.), or Fall 2004 (22 Oct.–17 Dec.). The experimental design was a randomized complete block with two blocks and four replicates within each block. Individual species were treated as blocking units to minimize the effects of shading from plants of different sizes. Treatments consisted of four irrigations [tap water control, 0 mg L\(^{-1}\) (0.3 dS m\(^{-1}\) measured salinity) or a 3000–, and 5000-mg L\(^{-1}\) increasing levels of salinity. The 1000–, 3000–, and 5000-mg L\(^{-1}\) salinity treatments had average measured electrical conductivities (ECs) of 1.9, 5.0, and 8.1 dS m\(^{-1}\) respectively. Treatments were applied to each of the following eight plant species: Penstemon palmeri (Palmer penstemon), Mirabilis multiflora (desert four o’clock), Geranium viscosissimum (sticky geranium), Eriogonum jamesii (James buckwheat), Echinacea purpurea (purple coneflower), Lavandula angustifolia (English lavender), L. ×superbum ‘Alaska’ (Alaska Shasta daisy), and Penstemon ×mexicali ‘Red Rocks’ (red rocks penstemon). Penstemon palmeri, M. multiflora, G. viscosissimum, and E. jamesii are native to the IMW, whereas the other four species are commercially available in the nursery industry.

Environmental conditions. Greenhouse temperatures were set at 16 °C night/27 °C day for all experiments, and minimum and maximum air temperatures were recorded daily and averaged for the study (Table 1). Supplemental lighting (high-pressure sodium, 16-h photoperiod) was used during the Fall 2004 experiment when ambient light levels were low. Otherwise, ambient light levels were used. The daily integral of photosynthetically active radiation was measured during 2004 and 2005 (Table 1) using a light bar and hand-held datalogger (Apogee, Logan, Utah).

Table 1. Species, average greenhouse daily light integral (DLI), and average minimum and maximum air temperature for the four experiment periods.

| Season                  | Species used               | DLI (mol m\(^{-2}\) d\(^{-1}\)) | Average air temperature (min./max., °C) |
|-------------------------|-----------------------------|----------------------------------|----------------------------------------|
| Spring 2003 (9 May–3 July) | Echinacea purpurea, Eriogonum jamesii, Lavandula angustifolia, Penstemon palmeri, E. jamesii, L. angustifolia, Leucanthemum ×superbum, E. purpurea | Not recorded | 15/28 |
| Spring 2004 (10 Apr.–2 June) | Geranium viscosissimum, Mirabilis multiflora, P. ×mexicali, P. palmeri, G. viscosissimum, L. ×superbum, E. purpurea | 13.88 | 16/28 |
| Summer 2004 (18 June–12 Aug.) | Geranium viscosissimum, Mirabilis multiflora, P. ×mexicali, P. palmeri, G. viscosissimum, L. ×superbum, M. multiflora, P. ×mexicali | 17.98 | 15/33 |
| Fall 2004 (22 Oct.–17 Dec.) | Geranium viscosissimum, E. jamesii, L. ×superbum, E. purpurea | 15.54 | 12/29 |

DLI, daily light integral.

Visual quality and dry weight. Visual quality of each plant was assessed weekly and ranked on a scale of 1 to 5 based on the amount of burn, discoloration, and wilt plants exhibited. Gradations in the rating scale were as follows: 1, no leaf burn; 2, 25% to 50% of the leaf area burned; 3, 5% to 24% of the leaf area burned; 4, less than 5% of the leaf area burned, with burn primarily restricted to leaf tips; 5, no leaf burn. For discoloration, 1, more than 50% of the leaf area discolored (yellowed); 2, 25% to 50% of the leaf area discolored; 3, 5% to 24% of the leaf area discolored; 4, less than 5% of the leaf area discolored; 5, no discoloration. For wilt, 1, more than 65% of the plant wilted; 2, 35% to 65% of the plant wilted; 3, 5% to 34% of the plant wilted; 4, less than 5% of the plant wilted; 5, plant fully turgid. Dead plants were given a quality rating of 0. Individual ratings for burn, discoloration, and wilt were averaged weekly to give an overall visual quality rating. Other visual symptoms were also noted if observed. At the end of each experiment, plants were harvested, medium was washed from the roots, and shoots and roots were separated. Plant tissue was dried at 70 °C for 48 h, and dry weights were recorded.

Gas exchange. Photosynthesis (P\(_{\text{g}}\)) and G, was monitored weekly using an open gas exchange system equipped with a leaf chamber fluorometer (Li-6400; LI-COR). Measurements were made on one recently fully expanded leaf on each plant. Ambient light level was sampled at the beginning of each measurement period and set to that level for the duration of the period. There was little variation in light levels between weeks within a specific experiment. Measurements were not taken on cloudy days, and all measurements were taken between 1000 and 1400 hr. Ambient air temperatures were used and chamber CO\(_2\) level was set at 400 µmol mol\(^{-1}\) for all measurements. Gas exchange was measured for all species except P. ×mexicali and L. angustifolia because leaves of these species were too small to fill the measuring chamber.

Plant tissue analyses. Leaf Ca and Na concentrations were determined for plants grown in the Spring and Summer 2004 experiments. Leaves were removed from dry shoots, and for each species the leaves from all replications of a given salinity treatment were combined and ground. One composite tissue sample for each species and salinity treatment was digested in a solution of nitric acid and peroxide (Jones and Case, 1990), and analyzed using inductively coupled plasma emission spectroscopy at the Utah State University Analytical Laboratory (Logan, Utah). The single replicate of tissue data precluded statistical analysis of these data. Results are provided only to suggest trends and possible explanations for salinity effects.

Medium salinity. Medium salinity was assessed at the end of each experiment. For
Results and Discussion

Of the eight species tested, *L. ×superbum* and *M. multiflora* maintained the highest overall visual quality across salinity treatments (Fig. 1). This response was similar for both experiments, with light intensity and greenhouse temperature having little effect on plant response to salt treatments. Similarly, there were no statistical differences in visual quality of *L. angustifolia* at salinity levels ≤3000 mg L⁻¹, with similar quality responses between experiments. About 25% of the *M. multiflora* plants treated with saline water showed some pink discoloration on leaf margins and flower bracts, and leaves from plants in all salinity treatments were visibly thicker than those in the control group. *Mirabilis multiflora* plants developed some succulence when exposed to salinity, similar to what has been observed for several other dicotyledonous glycophytes exposed to NaCl (Jennings, 1976). Succulence may be linked with the ability of plants to dilute salts within their cells and thus tolerate high levels of salinity (Munns, 2002). *Leucanthemum ×superbum* showed occasional minor tip burn at the highest salinity treatments, whereas *L. angustifolia* exhibited no visual symptoms in response to salinity treatments. No mortality was observed for *L. ×superbum*, *M. multiflora*, or *L. angustifolia* in any salinity treatment.

*Geranium viscosissimum*, *P. palmeri*, and *E. purpurea* showed intermediate visual quality responses to salt treatments, and responses varied with the time of the year the experiment was performed. *Geranium viscosissimum* had similar visual quality ratings among salinity treatments ≥1000 mg L⁻¹ in both experiments. However, in Expt. 1 (Summer 2004), responses were more severe; severe leaf burn and chlorosis were present, and the plants experienced 25% and 38% mortality at salinity levels of 3000 mg L⁻¹ and 5000 mg L⁻¹ respectively. *Penstemon palmeri* showed severe leaf burn and wilting in Expt. 1 (Spring 2003) when exposed to ≥3000 mg L⁻¹ salinity, with 75% mortality as salinity increased to 5000 mg L⁻¹. Plants were less affected in Expt. 2 (Summer 2004), with similar visual ratings among the control, 1000-mg L⁻¹, and 3000-mg L⁻¹ treatments. Visual quality of *E. purpurea* declined and mortality increased at lower salinity levels in Expt. 1 (Spring 2003) than in Expt. 2 (Spring 2004). Plants treated with 5000 mg L⁻¹ salt showed 62% and 100% mortality in Expt. 1 (Spring 2003) and Expt. 2 (Spring 2004). Niu and Rodriguez (2006) also found that *E. purpurea* was relatively sensitive to a solution composed of NaCl, MgSO₄, and CaCl₂, with a salinity level as low as 2 dS m⁻¹.

The daily light integral (DLI) and temperature ranges for the experimental periods were 13.88 to 17.98 mol m⁻² d⁻¹ and 12 to...
and root shoot biomass responses to salinity (Fig. 2). For example, as salt levels increased there was a decrease in visual quality and biomass production of G. viscosissimum and P. superbum. Leucanthemum ×superbum, however, maintained high visual quality ratings but experienced a significant reduction in biomass with increasing salinity treatments in both experiments. In contrast, E. jamesii experienced relatively small (Expt. 1, Spring 2003) or no (Expt. 2, Spring 2004) declines in shoot biomass with increasing salinity, but visual quality ratings declined significantly, and mortality increased in both experiments as salinity increased to ≥ 3000 mg L⁻¹. Niu and Rodriguez (2006) found similar results with Agastache cana, for which relatively few differences were found in biomass production among salinity treatments, but low visual quality ratings made the species unacceptable for the landscape. Results from our study suggest species vary in visual quality and biomass responses to salinity, with some able to maintain quality with declining biomass and others experiencing decreases in quality while maintaining biomass in response to increasing salinity. This is not surprising because visual quality, as defined here, is not directly related to plant size or other characteristics that may influence biomass at harvest.

Many of the species showed more similar trends between visual quality ratings and Pₙ and gₙ (Figs. 1 and 3) than between biomass and Pₙ and gₙ (Figs. 2 and 3). One exception was M. multiflora, which maintained high visual quality ratings throughout all treatments but showed a reduction in Pₙ and gₙ at ≥ 3000 mg L⁻¹. For L. ×superbum and M. multiflora, reductions in Pₙ for salt-treated plants were generally less severe than reductions in gₙ. This has been observed for the halophytes Salicornia europaea ssp. rubra and Puccinellia muttilliana grown under saline conditions (Guy and Reid, 1986; Guy et al., 1980). However, for sunflower, a less
salt-tolerant species, the opposite was observed (Rivelli et al., 2002). The mechanisms by which these species are able to maintain high $P_c$ while decreasing $g_s$ have not been determined.

For most species, leaf Na and Ca levels increased with increasing salinity (data not presented). Sodium levels in the composite leaf samples of *L. angustifolia* irrigated with saline water were extremely high, especially for plants in the 3000- and 5000-mg L$^{-1}$ salinity treatments, which accumulated close to 4000 and 7700 mg kg$^{-1}$ Na respectively. The amount of Na in *L. angustifolia* leaves from plants in the 3000- and 5000-mg L$^{-1}$ salinity treatments was nearly twice the amount in *M. multiflora* leaves from the same salinity treatments. *Lavandula angustifolia* was apparently able to tolerate extremely high levels of Na in leaf tissue while maintaining relatively high visual quality (Fig. 1) and dry matter (Fig. 2), suggesting that the species likely has mechanisms that protect cellular functions from salts. One possibility is that salts are compartmentalized within vacuoles. Interestingly, the three species deemed relatively salt tolerant based on visual quality response (*L. angustifolia*, *M. multiflora*, and *L. ×superbum*) accumulated the highest levels of Na in the leaves.

Some species are able to exclude salts from being absorbed, tolerating absorption by compartmentalizing salts in vacuoles, regulating movement of salts to shoots or exporting the salts away from the shoot, increasing succulence to dilute salts within the cell, excreting salts via salt glands or salt hairs, or dropping older leaves in which salts have accumulated (Greenway and Munns, 1980; Munns, 2002). Many of these species, including Texas sage (*Leucophyllum frutescens*) and iceplant (*Delosperma*), grow more vigorously in saline soils than in nonsaline soils (Francois and Clark, 1978). There was evidence of succulence with *M. multiflora* leaves. However, there was no indication that salinity enhanced the growth of any of the species used in this study.

Sodium is likely particularly toxic to *E. purpurea* and *P. ×mexicali*, because the plants apparently took up very little before death occurred, and visual symptoms of toxicity (marginal chlorosis and necrosis) were similar to those seen for other plants experiencing Na toxicity (Marschner, 1995). Studies by Bernstein et al. (1975) suggested accumulation of Cl or Na in leaves of selected ornamental shrubs and groundcovers might also interfere with stomatal closure and cause excessive water loss.

In summary, salt-sensitive plant species exhibited visual responses to salinity such as discoloration, wilt, and leaf burn that, for some species, were not consistent with dry matter responses. Aesthetic factors or visual appearance are more important than yield of ornamental plants, so salt sensitivity can limit the use of certain plants that might otherwise produce biomass. Other studies with herbaceous perennials have also emphasized the importance of visual quality for expressing relative salt tolerance and acceptability of species for landscape use (Fox et al., 2005; Niu and Rodriguez, 2006). The knowledge and potential use of herbaceous perennials tolerant of higher salinity situations would be valuable information for the landscaping industry. Based on our study, *L. ×superbum*, *M. multiflora*, and *L. angustifolia* would be considered relatively tolerant of salinity treatments up to 5000 mg L$^{-1}$ as evidenced by survival and visual quality, while *G. viscosissimum*, *P. palmeri*, and *E. purpurea* would be considered intermediate in tolerance, with lower visual quality experienced during periods of high temperature and light levels. *Eriogonum jamesii* and *P. ×mexicali* were relatively intolerant of salinity $\geq$3000 mg L$^{-1}$. Because three of the species in our study with relatively high (M. multiflora) to moderate (G. viscosissimum and P. palmeri) salinity tolerance are IMW native species, the IMW may be a potential source for other salt-tolerant species.
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