Responses of Growth and Mineral Nutrition of Garden Roses to Saline Water Irrigation

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Abstract. The responses of garden roses to irrigation water with elevated salts are unknown. Two experiments were conducted to evaluate the relative salt tolerance of 13 self-rooted rose cultivars by irrigating the plants with nutrient solutions at an electrical conductivity (EC) of 1.4 dS m⁻¹ (control) or nutrient saline solutions at EC of 3.1, 4.4, or 6.4 dS m⁻¹. In Expt. 1, 'Belinda’s Dream', 'Caldwell Pink', 'Carefree Beauty', 'Folksinger', 'Quietness', and ‘Winter Sunset’ plants were grown in a greenhouse from 13 Aug. to 21 Oct. (10 weeks). Shoot dry weight of all cultivars decreased as EC of irrigation water increased. ‘Winter Sunset’ was most sensitive among these cultivars to salt stress followed by ‘Carefree Beauty’ and ‘Folksinger’ with severe leaf injury at EC of 3.1 dS m⁻¹ or higher or death at EC of 6.4 dS m⁻¹. No visual damage was observed in ‘Belinda’s Dream’ or ‘Caldwell Pink’, regardless of the salinity level. In Expt. 2, ‘Basye’s Blueberry’, ‘Iceberg’, ‘Little Buckaroo’, ‘The Fairy’, ‘Marie Pavie’, ‘Rise N’Shine’, and ‘Sea Foam’ plants were grown in the greenhouse from 29 Sept. to 16 Nov. (7 weeks) and irrigated with the same nutrient or nutrient saline solutions. Salinity treatment did not affect shoot dry weight of ‘Basye’s Blueberry’, ‘Little Buckaroo’, ‘Sea Foam’, and ‘Rise N’Shine’. Shoot dry weight of ‘Iceberg’, ‘The Fairy’, and ‘Marie Pavie’ decreased as EC of irrigation water increased. No or little visual damage was observed in ‘Little Buckaroo’, ‘Sea Foam’, and ‘Rise N’Shine’. Leaf tip burns were seen in ‘Iceberg’, ‘Marie Pavie’, ‘Basye’s Blueberry’, and The Fairy’ at EC 6.4 of dS m⁻¹. Generally, these symptoms were less severe than those observed in Expt. 1, probably attributable partially to the shorter treatment period. Whereas shoot Na⁺ and Cl⁻ varied greatly among the rose cultivars, the shoot concentrations of Ca²⁺, K⁺, and Mg²⁺ did not. Generally, salinity-tolerance cultivars had higher shoot Na⁺ and Cl⁻ concentrations. In summary, in Expt. 1, ‘Belinda’s Dream’ was the most tolerant cultivar, whereas ‘Winter Sunset’ was the least tolerant followed by ‘Carefree Beauty’. In Expt. 2, ‘Iceberg’, ‘Marie Pavie’, and ‘The Fairy’ were less tolerant to salinity as compared with other cultivars, although the differences were small.

In arid and semiarid regions, high-quality water supply is often limited and soil salinity is often high as a result of low rainfall and heavy evapotranspiration. With a rapid increase in urban populations, the intense competition for high-quality water among agriculture, industry, and recreational users has promoted the use of alternative water sources for irrigating landscapes in arid and semiarid regions. Alternative water, primarily municipal-treated effluents (also called reclaimed water), has higher salinity compared with that of potable water. In coastal regions, seawater intrusion results in high soil salinity, whereas deicing salts also increase soil salinity in northern areas. Thus, tolerant plants are needed for these regions.

The relative salt tolerance among multiple cultivars or species is often assessed based on survival rate, growth, and yield. Mineral analysis and other physiological responses to salinity help to understand the mechanisms of salt tolerance (Carter and Grieve, 2006; Niu and Cabrera, 2010). Salinity reduces the ability of plants to take up water, and this quickly causes reductions in growth rate along with a suite of metabolic changes identical to those caused by water stress (Marschner, 1995; Munns, 2002). Increasing salinity stress as a result of higher salinity and/or extended time exposure to salinity generally leads to foliar salt injury. For ornamental plants, being compact and free of foliar damage is more important compared with maximum growth. Many researchers have used visual ratings as one of the parameters to assess salinity tolerance (Cameron et al., 2004; Fox et al., 2005; Niu et al., 2008, 2012; Zollinger et al., 2007).

Sodium chloride is usually the primary salt in salinized soils and low-quality irrigation water. Ions of Na⁺ and Cl⁻ are often excessively absorbed by plants under salinity conditions, which reduce the uptake of other nutrients such as Ca²⁺ and K⁺. Most salt-tolerant plants have better ability to exclude Na⁺ and/or Cl⁻ to prevent their accumulation or limit the transport of these ions to shoots (Munns and Tester, 2008; Niu and Cabrera, 2010). Therefore, the shoot or leaf Na⁺ and/or Cl⁻ concentrations are often used to examine the salt tolerance of a plant and the mechanism of salt tolerance along with other parameters. For example, R. × fortuniana had higher Na⁺ exclusion ability than R. multiflora and R. odorata, as evidenced by lower Na⁺ concentrations in stems and leaves (Niu et al., 2008).

Garden rose (Rosa spp.) is one of the most economically important and popular ornamental plants in the world. Rose has been traditionally categorized as a salt-sensitive species with salt injury reported within a range of 0.5 to 3 dS m⁻¹ EC, depending on species and cultivar, cultural medium, leaching fraction, and environmental conditions (Urban, 2003). However, our previous research indicated that rose rootstocks R. fortuniana, R. multiflora, R. odorata, and Dr. Huey could tolerate moderate salinity (EC up to 4.0 dS m⁻¹) with acceptable growth reduction and aesthetic appearance (Niu et al., 2008; Niu and Rodriguez, 2008). Other researchers also reported that yield and quality of roses did not decrease when irrigated with drainage recycled water at EC of 3.5 dS m⁻¹ provided that an appropriate rootstock and aerated medium were used (Cabrera, 2003; Raviv et al., 1998). More information on salt tolerance for greenhouse cut roses is available (Bernstein et al., 2006; Cabrera, 2003; de Vries, 2003; Fernández-Falcón et al., 1986; Hughes and Hanan, 1978; Wahome et al., 2001) as compared with garden roses, especially self-rooted roses. The objectives of this study were to compare the relative salt tolerance of selected garden roses, which are economically important and popular ornamentals, and to determine the mineral nutrition of these roses when irrigated with nutrient solution with increasing salinity.

Materials and Methods

Plant materials and cultural conditions. For Expt. 1, cuttings of ‘Belinda’s Dream’, ‘Caldwell Pink’, ‘Carefree Beauty’, ‘Folksinger’, ‘Quietness’, and ‘Winter Sunset’ were taken on 7 Apr. 2010, dipped in 1000 ppm rooting hormone (Dip N Grow, EastWestHydro, Denver, CO) for 2 s, stuck into 240-ml pots filled with rooting medium Sunshine Mix No. 1 (SunGro, Hort., Bellevue, WA), and placed on a mist bench. On 22 July, 2010, rooted plants were transplanted to 2.6-L plastic containers filled with Sunshine Mix No. 4 (SunGro). Plants were grown in the greenhouse and irrigated with nutrient solution

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before the initiation of treatment. Nutrient solution was prepared by adding 0.72 g L\(^{-1}\) of 15N-2.2P-12.5K (Peters 15-5-15; Scotts, Marysville, OH) to tap water and the EC of the solution was 1.4 dS m\(^{-1}\). The major ions in the tap water were Na\(^{+}\), Ca\(^{2+}\), Mg\(^{2+}\), Cl\(^{-}\), and SO\(_4^{2-}\) at 184, 52.0, 7.5, 223.6, and 105.6 mg L\(^{-1}\), respectively. Before treatments, uniform plants with the same number (two or three) of shoots, which varied with cultivar, were selected. All plants were pruned to the same height (two nodes per shoot).

For Expt. 2, cuttings of ‘Basye’s Blueberry’, ‘Iceberg’, ‘Little Buckaroo’, ‘The Fairy’, ‘Marie Pavie’, ‘Rise N’Shine’ and ‘Sea Foam’ plants were taken on 23 July 2010 using the same methodology as in Expt. 1. Rooted plants were transplanted on 9 Sept. to 2.6-L containers filled with the same substrate as described in Expt. 1 and irrigated with nutrient solution before initiating the treatment (29 Sept.). These cultivars were selected because they are commonly used in landscapes in southern regions of the United States.

Salinity treatment. For both experiments, four treatments were created: nutrient solution (control, no addition of salts, EC of 1.4 dS m\(^{-1}\)) and saline nutrient solutions at EC of 3.1, 4.4, or 6.4 dS m\(^{-1}\). Saline nutrient solutions at various salinity levels were prepared by adding calculated amounts of sodium chloride and calcium chloride at 2:1 (molar ratio) to the nutrient solution. Solutions were prepared in 100-L tanks with confirmed EC and pH (\(\pm 0.5\)) each time. Plants were then irrigated (overwatering with a leaching fraction of \(\approx 30\%\)) with nutrient or saline nutrient solutions whenever the substrate surface started to dry to prevent water stress. Irrigation intervals varied with plant size (biomass), treatment, and environmental conditions. To quantify the salt accumulation, leachate was collected every week and the EC of leachate was determined using an EC meter (Model B-173; Horiba, Ltd., Japan).

Expt. 1 started on 13 Aug. and ended on 21 Oct. 2010 (10 weeks), whereas Expt. 2 was from 29 Sept. to 16 Nov. 2010 (7 weeks). Plants in Expt. 1 were pruned on 2 Sept. (in the middle of the treatment duration) and the dry weight of pruned shoots was determined by oven-drying at 65 \(^\circ\)C to a constant weight. The average air temperature in the greenhouse for Expt. 1 was 27.4 ± 1.4 \(^\circ\)C and average daily integrated photosynthetically active radiation [daily light integral (DLI)] was 16.7 ± 3.5 mol m\(^{-2}\) d\(^{-1}\). In Expt. 2, average air temperature was 24.3 ± 2.4 \(^\circ\)C and DLI was 15.8 ± 3.8 mol m\(^{-2}\) d\(^{-1}\). A layer of shadecloth with 25% light exclusion was placed on top of the greenhouse roof from early April to early October, which reduced the differences in DLIs between the two experiments.

Measurement. At the end of each experiment, foliar salt damage was rated by giving a visual score based on a criterion reference scale from 0 to 5, where 0 = dead; 1 = over 90% foliar damage (salt damage: burning, necrosis, and discoloration); 2 = moderate (50% to 90%) foliar damage; 3 = slight (less than 50%) foliar damage; 4 = good quality with minimal foliar damage; and 5 = excellent with no foliar damage. The foliar salt damage rating did not consider the plant size. For example, a score of 5 was given to a plant, if no salt damage was visible, although the plant was more compact as compared with the control.

Flowering characteristics were quantified by counting the number of flower buds, open flowers, and faded flowers. On termination, shoots were harvested and dry weight (DW) was determined after oven-drying at 65 \(^\circ\)C until a constant weight was reached. For Expt. 1, final shoot DW included the DW of pruned shoots, which was done during the treatment period.

Mineral analysis. To analyze shoot Na\(^{+}\), Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\), and Cl\(^{-}\) concentrations, four shoot samples were randomly collected. To minimize the number of samples, only the control and the highest salinity level (EC 6.4 dS m\(^{-1}\)) were sampled. Dried tissue samples were ground to pass a 40-mesh screen with a stainless Wiley mill (Thomas Scientific, Swedesboro, NJ) and the samples were submitted to the Soil, Water, and Air Testing Laboratory of New Mexico State University (Las Cruces, NM) for cation and anion analyses. Cation concentrations were determined by U.S. Environmental Protection Agency (EPA) method 200.7 (U.S. EPA, 1983) and analyzed using an Inductively Coupled Plasma/Aтомic Emission Spectrophotometer Trace Analyzer (Thermo Jarrell Ash, Franklin, MA). Cl\(^{-}\) was determined by EPA method 300.0 (U.S. EPA, 1983) and analyzed using an Ion Chromatograph (Dionex, Sunnyvale, CA).

Experimental design and statistical analysis. Both experiments followed a split-plot design with salinity of irrigation water as the main plot and cultivar subplots with 10 replications. All data were analyzed by a two-way analysis of variance using PROC GLM. When the main effect was significant, Student-Newman-Keuls multiple comparisons were performed to determine the differences among cultivars. Linear regression between salinity and shoot DW was conducted using PROC REG. All statistical analyses were performed using SAS software (Version 9.1.3; SAS Institute Inc., Cary, NC).

Results

Salinity effect on total number of flowers and buds varied with cultivar in both experiments (Table 1). In Expt. 1, the number of flowers and buds in ‘Belinda’s Dream’ was unaffected by treatments. In all other cultivars, salt treatment significantly reduced the number of flowers and buds with highest reduction of 57% in ‘Caldwell Pink’, 76% in ‘Carefree Beauty’, 52% in ‘Folksinger’, 62% in ‘Quietness’, and 80% in ‘Winter Sunset’. In Expt. 2, there were no salinity treatment differences in total number of flowers and buds in ‘Rise-N’Shine’ and ‘Sea Foam’. In all other cultivars, the number of flowers and buds was reduced by salt treatment with the highest reduction of 77% in ‘Basye’s Blueberry’, 48% in ‘Iceberg’, 68% in ‘Little Buckaroo’, 74% in ‘Marie Pavie’, and 53% in ‘The Fairy’.

The highest leachate EC in Expt. 1 for the control, EC 3.1, EC 4.4, and EC 6.4 were 5.0, 6.8, 8.3, and 12.0 dS m\(^{-1}\), respectively. In Expt. 2, the highest leachate EC for the control, EC 3.1, EC 4.4, and EC 6.4 were 5.1, 7.6, 9.3, and 13.2 dS m\(^{-1}\), respectively. Salt accumulated in substrates in both experiments, which increased the salinity of the root zone (substrate). The higher the salinity of irrigation water, the more salt accumulated in the root zone, which is common in substrates containing peat (Niu and Rodriguez, 2006).

Visual rating. All plants in the control had a visual rating of 5.0, except for ‘Folksinger’ (Table 2). In Expt. 1, most plants survived the highest salinity treatment, except for ‘Carefree Beauty’ and ‘Winter Sunset’. Thirty percent of the plants of these two cultivars did not survive the highest salinity (EC 6.4). ‘Belinda’s Dream’ and Caldwell Pink’ had similar best visual ratings, whereas Winter Sunset’ had the lowest ratings among the six cultivars. At EC 6.4, ‘Carefree Beauty’ and ‘Folksinger’ also had very low ratings. ‘Folksinger’ plants were infected with powdery mildew in all treatments. ‘Quietness’ in EC 6.4 treatments had more severe salt damage, as compared with ‘Belinda’s Dream’ and Caldwell Pink’, with a rating of 4.4.

In Expt. 2, all plants survived with minor foliar damage in some cultivars. As a result of the shorter treatment period and relatively cool weather compared with those in Expt. 1, plants in Expt. 2 received milder salt stress. Among the seven, ‘Iceberg’, ‘Marie Pavie’, and ‘The Fairy’ had more obvious foliar salt damage in EC 4.4 and EC 6.4 treatments.
which may indicate that these cultivars were less tolerant to salt stress. There were no differences in visual ratings between ‘Basye’s Blueberry’ and ‘Rise N Shine’. No or little visual damage was observed in ‘Little Buckaroo’ and ‘Sea Foam’.

**Shoot dry weight.** Salinity and cultivar had significant interaction on shoot DW in both experiments. In Expt. 1, shoot DW decreased linearly as the salinity of irrigation water increased in all cultivars (Table 3). For ‘Belinda’s Dream’, there were no differences in shoot DW among the control, EC 3.1, and EC 4.4 treatments. Shoot DW at EC 6.4 was reduced by 30% compared with that of the control, whereas shoot DW at EC 4.4 was 70% that of the control. For ‘Caldwell Pink’, shoot DW at EC 4.4 was lower than that in the control and shoot DW at EC 6.4 decreased by 50% compared with the control. Shoot DW of ‘Carefree Beauty’ at EC 3.1 was significantly lower than that in the control. At EC 6.4, shoot DW of ‘Carefree Beauty’ decreased by 62% compared with control. For ‘Folksinger’, no differences were found in shoot DW among treatment. EC 3.1, and EC 4.4; however, shoot DW at EC 6.4 decreased by 35%. For both ‘Quietness’ and ‘Winter Sunset’, shoot DW at EC 3.1 was lower than that of controls and decreased by 45% and 75% at EC 6.4, respectively, compared with their respective controls.

In Expt. 2, salinity of irrigation water did not affect the shoot DW of ‘Basye’s Blueberry’, ‘Little Buckaroo’, ‘Rise N Shine’, and ‘Sea Foam’ (Table 3). Shoot DW of ‘Iceberg’, ‘Marie Pavie’, and ‘The Fairy’ decreased linearly as salinity of irrigation water increased. The reduction percentages in these cultivars at EC 6.4 were 34%, 42%, and 32% for ‘Iceberg’, ‘Marie Pavie’, and ‘The Fairy’, respectively, compared with their respective controls. The three cultivars with significant shoot DW reduction at EC 6.4 showed leaf margin burn, which resulted in lower visual ratings. The magnitude of shoot DW reduction was in agreement with severity of foliar salt damage (visual rating) in both experiments.

**Mineral analysis (Expt. 1).** Cultivar and treatment had an interactive effect on elements of Na+, Cl−, Ca2+, and K+. Indicating that these mineral concentrations responded to salinity differently among cultivars (Fig. 1). For Mg2+, no significant differences were found among cultivars and there were no interactive differences between cultivar and treatment.

In the control, ‘Carefree Beauty’ and ‘Folksinger’ had the highest Na+ concentrations in shoots followed by ‘Winter Sunset’, whereas ‘Belinda’s Dream’, ‘Caldwell Pink’, and ‘Quietness’ had the lowest (Fig. 1). At EC 6.4, ‘Folksinger’ and ‘Carefree Beauty’ had the highest Na+ concentrations, whereas the rest of the cultivars had statistically similar Na+ concentrations.

For Cl− concentration in the control, ‘Caldwell Pink’ had a lower Cl− concentration compared with those of other cultivars. At EC 6.4, ‘Folksinger’ and ‘Quietness’ had higher Cl− concentrations compared with those of ‘Belinda’s Dream’, ‘Caldwell Pink’, and ‘Winter Sunset’. No differences were found in Cl− concentrations among ‘Carefree Beauty’, ‘Folksinger’, and ‘Quietness’ or among the other three cultivars.

For Ca2+ concentrations, in the control, ‘Belinda’s Dream’ and ‘Quietness’ had the highest Ca2+ shoot concentration, whereas ‘Folksinger’ and ‘Winter Sunset’ had the lowest (Fig. 1). ‘Caldwell Pink’ and ‘Carefree Beauty’ had similar Ca2+ concentrations and were not different from those of ‘Belinda’s Dream’ and ‘Quietness’. At EC 6.4, ‘Belinda’s Dream’ had the highest Ca2+ concentration followed by ‘Quietness’ and ‘Caldwell Pink’.

‘Carefree Beauty’ had the lowest followed by ‘Folksinger’ and ‘Winter Sunset’.

For K+ concentration, in the control, ‘Folksinger’ had the highest followed by ‘Caldwell Pink’ and ‘Winter Sunset’, and by ‘Belinda’s Dream’ and ‘Quietness’, and ‘Carefree Beauty’ had the lowest. At EC 6.4, ‘Belinda’s Dream’ and ‘Quietness’ had the highest K+ concentrations followed by ‘Caldwell Pink’, ‘Folksinger’ and ‘Winter Sunset’, and ‘Carefree Beauty’ had the lowest.

For Mg2+ concentration, because no differences were found among cultivars, data were pooled. The elevated salinity treatment increased shoot Mg2+ concentration by 20%. The differences in Ca2+, K+, and Mg2+ among cultivars were smaller compared with those of Na+ and Cl− regardless of salinity treatment.

**Mineral analysis (Expt. 2).** In Expt. 2, similar to Expt. 1, cultivar and treatment had an interactive effect on most elements of Na+, Cl−, Ca2+, and K+, indicating that Na+, Cl−, and Mg2+ concentrations responded to salinity differently among cultivars (Fig. 2). For Ca2+ and K+, there were differences among cultivars but not among salinity treatments.

Na+ concentrations in the control were highest in ‘Sea Foam’ followed by ‘The Fairy’, ‘Iceberg’, ‘Marie Pavie’, and ‘Rise N Shine’, whereas ‘Basye’s Blueberry’ and ‘Little Buckaroo’ had the lowest. At EC 6.4, ‘The Fairy’ had the highest Na+ concentration followed by ‘Iceberg’, ‘Sea Foam’, ‘Little Buckaroo’, ‘Marie Pavie’, and ‘Basye’s Blueberry’ and ‘Rise N Shine’ had the lowest.

In the control, ‘Marie Pavie’ had the highest Cl− concentration followed by ‘The Fairy’, ‘Iceberg’, ‘Sea Foam’, and ‘Rise N Shine’, whereas ‘Basye’s Blueberry’ and ‘Little Buckaroo’ had the lowest. At EC 6.4, Cl− concentrations of ‘Iceberg’, ‘Marie

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**Tables:**

| Cultivar               | Control EC 3.1 | EC 4.4 | EC 6.4 |
|------------------------|---------------|--------|--------|
| **Belinda’s Dream**    | 5.0 a         | 5.0 a  | 4.9 a  |
| **Caldwell Pink**      | 5.0 a         | 5.0 a  | 4.9 a  |
| **Carefree Beauty**    | 5.0 a         | 4.8 a  | 4.3 b  |
| **Folksinger**         | 4.0 a         | 4.2 a  | 4.8 a  |
| **Quietness**          | 5.0 a         | 5.0 a  | 4.4 b  |
| **Winter Sunset**      | 5.0 a         | 4.4 b  | 2.5 c  |

*Plants irrigated with nutrient solution had a visual score of 5.0, regardless of cultivar, except for ‘Folksinger’ that was infected with powdery mildew at the late part of the experiment and had a score of 4.0.

Means in the same column with same letters are not significantly different among treatments tested by Student-Newman-Keuls multiple comparison at P = 0.05. Analysis was conducted separately for both experiments.

| Cultivar               | Treatment          | EC 1.4 | EC 3.1 | EC 4.4 | EC 6.4 | Linear regression (P) |
|------------------------|--------------------|--------|--------|--------|--------|-----------------------|
| **Belinda’s Dream**    | 21.0 a             | 20.6 a | 19.0 a | 14.7 b | 0.003* |
| **Caldwell Pink**      | 23.0 a             | 20.0 a | 18.3 b | 11.5 c | <0.0001|
| **Carefree Beauty**    | 22.8 a             | 14.3 b | 11.8 b | 8.8 b  | <0.0001|
| **Folksinger**         | 18.0 a             | 17.6 a | 16.6 a | 11.8 b | 0.0058 |
| **Quietness**          | 29.5 a             | 22.7 b | 22.2 b | 16.3 c | <0.0001|
| **Winter Sunset**      | 23.9 a             | 16.4 b | 14.2 b | 6.5 c  | <0.0001|

In Expt. 2 (7 weeks):

| Cultivar               | Treatment          | EC 1.4 | EC 3.1 | EC 4.4 | EC 6.4 | Linear regression (P) |
|------------------------|--------------------|--------|--------|--------|--------|-----------------------|
| **Basye’s Blueberry**  | 11.9 a             | 11.4 a | 10.1 a | 8.8 a  | NS     |
| **Iceberg**            | 25.3 a             | 24.1 a | 23.5 a | 16.9 b | 0.0004 |
| **Little Buckaroo**    | 20.5 a             | 19.5 a | 17.9 a | 16.1 a | NS     |
| **Marie Pavie**        | 31.7 a             | 29.7 a | 27.8 a | 18.5 b | <0.0001|
| **Rise N Shine**       | 23.6 a             | 22.7 ab| 19.3 b | 19.2 b | NS     |
| **Sea Foam**           | 12.5 a             | 10.2 a | 11.2 a | 11.6 a | NS     |
| **The Fairy**          | 26.2 a             | 24.3 a | 24.0 a | 18.1 b | <0.0001|
The Fairy' had the highest Ca$^{2+}$ concentration followed by 'Iceberg', 'Rise N Shine', and 'Sea Foam'. 'Little Buckaroo' and 'Basye's Blueberry' had the lowest K$^+$ concentrations. There were no differences in Mg$^{2+}$ concentrations between 'The Fairy' and 'Marie Pavie'; among 'Iceberg', 'Marie Pavie', and 'Rise N Shine'; and among 'Iceberg', 'Rise N Shine', and 'Sea Foam'. At EC 6.4, 'The Fairy' had the highest Mg$^{2+}$ concentration, followed by 'Marie Pavie', and by 'Iceberg' and 'Rise N Shine'. The rest of the three cultivars had lower Mg$^{2+}$ concentrations.

Pavie', 'Rise N Shine', and 'The Fairy' were higher than those of 'Basye's Blueberry', 'Little Buckaroo', and 'Sea Foam'.

For Ca$^{2+}$ concentration, there were no differences between salinity treatments and no interaction between cultivar and salinity treatment. Data were pooled for statistical analysis. 'The Fairy' had the highest Ca$^{2+}$ concentration followed by 'Iceberg' and then by 'Marie Pavie', 'Rise N Shine', and 'Sea Foam'. 'Little Buckaroo' and 'Basye's Blueberry' had the lowest Ca$^{2+}$ concentrations.

For K$^+$ concentration, there were no differences between salinity treatments and no interaction between cultivar and salinity treatment. Data were pooled for statistical analysis. 'Rise N Shine' had the highest K$^+$ concentration followed by 'Iceberg', 'Little Buckaroo', and 'Marie Pavie' and then by 'Sea Foam', whereas 'Basye's Blueberry' and 'The Fairy' had the lowest K$^+$ concentrations.

For Mg$^{2+}$ concentration, in the control, 'The Fairy' had the highest, and 'Basye’s Blueberry' and 'Little Buckaroo' had the lowest. There were no differences in Mg$^{2+}$ concentrations between 'The Fairy' and 'Marie Pavie'; among 'Iceberg', 'Marie Pavie', and 'Rise N Shine'; and among 'Iceberg', 'Rise N Shine', and 'Sea Foam'. At EC 6.4, 'The Fairy' had the highest Mg$^{2+}$ concentration, followed by 'Marie Pavie', and by 'Iceberg' and 'Rise N Shine'. The rest of the three cultivars had lower Mg$^{2+}$ concentrations.

**Discussion**

Salt tolerance of crops is defined as the inherent ability of plants to withstand the effects of high salt concentrations in the root zone or on the leaves without a significant adverse effect such as foliar salt injury and growth and yield reduction (Grieve et al., 2008; Shannon et al., 1994). As salt stress becomes severe, leaves are generally negatively impacted, resulting in fewer green leaves. For ornamental plants, the typical symptoms of initial salt injury are stunted growth and foliar damage including leaf necrosis and marginal leaf burn (Bernstein et al., 1972; Grieve et al., 2008). Tolerance of salt stress for ornamental plants can be assessed based on survival rate, with or without foliar salt damage or the degree of foliar salt damage, and the degree of growth reduction (Niu and Cabrera, 2010). Aesthetic appearance is more important in ornamental plants than maximum growth and many researchers have used visual ratings to compare relative salt tolerance among tested species (Cameron et al., 2004; Fox et al., 2005; Niu et al., 2008, 2012; Zollinger et al., 2007).

In Expt. 1, ‘Winter Sunset’ and ‘Carefree Beauty’ were less tolerant to salinity as compared with the rest of the cultivars based on shoot growth and visual ratings. ‘Belinda’s Dream’ was the most tolerant because it had the highest visual quality and least shoot growth reduction. ‘Caldwell Pink’ was more tolerant to salinity as compared with ‘Folksinger’ and ‘Quietness’ because of its high visual quality, although shoot growth was reduced significantly. Using both the shoot growth and visual quality, based on the mentioned criterion for ornamental plants, ‘Belinda’s Dream’ was the most tolerant followed by ‘Caldwell Pink’ and ‘Quietness’. ‘Winter Sunset’ was the least tolerant followed by ‘Carefree Beauty’ and ‘Folksinger’. For Expt. 2, ‘Marie Pavie’, ‘The Fairy’, and ‘Iceberg’ were less tolerant to salinity as compared with ‘Basye’s Blueberry’, ‘Sea Foam’, ‘Rise N Shine’, and ‘Little Buckaroo’. However, the differences among these seven cultivars were small.

According to Munns and Tester (2008), there are three distinct mechanisms of action for plants to adapt to salinity: osmotic stress tolerance, Na$^+$ or Cl$^-$ exclusion, and the tolerance of tissue to accumulated Na$^+$ or Cl$^-$ ions. In many cases, salt-tolerant genotypes have lower shoot Na$^+$ and/or Cl$^-$ concentrations because they have the ability to restrict Na$^+$ and/or Cl$^-$ transport to shoots. However, some tolerant genotypes can tolerate high internal Na$^+$ or Cl$^-$ concentrations such as Gazania rigens with Na$^+$ concentration of 39 mg g$^{-1}$ DW in shoots (Niu and Rodriguez, 2006). Ion uptake depends on species or genotype, salinity level, treatment period, and the chemical composition of the salinity (Grattan and Grieve, 1999; Niu and Rodriguez, 2008). In this study, differences in shoot Na$^+$ and Cl$^-$ concentrations were significant among cultivars, even in the control, in both experiments. ‘Carefree Beauty’ and ‘Folksinger’ had higher Na$^+$ concentrations compared with other cultivars. Although Na$^+$ and Cl$^-$ of ‘Winter Sunset’ were not the highest, its tolerance to salt stress was the least, indicating that this cultivar had lower damage...
under salinity stress. Ca\(^{2+}\) uptake is often lower than Cl\(^{-}\) concentrations is essential to survive and thrive those for the rose rootstocks (16 weeks, EC of 760 HORTSCIENCE VOL. 48(6) JUNE 2013).

In this study were rather high compared with the control and EC 6.4, respectively, tested by Student-Newman-Keuls multiple comparison at \(P = 0.05\). For Ca\(^{2+}\) and K\(^{+}\), no differences were found between control and salt treatment. Therefore, data for multiple comparisons were pooled.

Large variations in shoot Na\(^{+}\) and Cl\(^{-}\) concentrations among cultivars in the control and EC 6.4, \(P = 0.05\). For Ca\(^{2+}\) and K\(^{+}\), no differences were found between control and salt treatment. Therefore, data for multiple comparisons were pooled.

These results are supported by other authors, including Drihem and Pilbean (2002), who showed that elevated salinity reduces the effect of Na\(^{+}\) and Cl\(^{-}\) concentrations on the visual quality of greenhouse roses. Acta Hort. 609:51–57.

Bernstein, L., L.E. Francois, and R.A. Clark. 1972. Salt tolerance of ornamental shrubs and ground covers. J. Amer. Soc. Hort. Sci. 97:550–556.

Bernstein, N., B.T. Asher, F. Haya, S. Pini, R. Ilona, C. Amram, and I. Marina. 2006. Application of treated wastewater for cultivation of roses (\(R. h i b r i d a\)) in soil-less culture. Sci. Hortic. 108:185–193.

Cabrera, R.I. 2003. Demarcating salinity tolerance in greenhouse roses. Acta Hort. 609:51–57.

Cameron, R.W.F., S. Wilkinson, W.J. Davies, R.S. Harrison-Murray, D. Dunstan, and C. Burgess. 2004. Regulation of plant growth in container-grown ornamentals through the use of controlled irrigation. Acta Hortic. 630:295–312.

Carter, C.T. and C.M. Grieve. 2006. Salt tolerance of floriculture crops, p. 279–287. In: Khan, M.A. and D.J. Weber (eds.). Ecophysiology of high salinity tolerant plants. Springer, The Netherlands.

de Vries, D.P.P. 2003. Rootstock, p. 633–638. In: Robert, A. V. T. Debener, and S. Gudin (eds.). Encyclopedia of rose science. Elsevier Academic Press, San Diego, CA.

Drihem, K. and D.J. Pilbean. 2002. Effect of salinity on nutrient accumulation in wheat grown with nitrate-nitrogen or mixed ammonium: Nitrate-nitrogen. J. Plant Nutr. 25:2091–2113.

Fernández-Falcón, M., C.E. Álvarez, V. García, and J. Baez. 1986. The effect of chloride and bicarbonate levels in irrigation water on nutrient content, production and quality of cut roses ‘Mercedes’. Sci. Hortic. 29:373–385.

Fox, L.J., J.N. Grose, B.L. Appleton, and S.J. Donohue. 2005. Evaluation of treated effluent as an irrigation source for landscape plants. J. Environ. Hort. 23:174–178.

Grattan, S.R. and C.M. Grieve. 1999. Salinity-mineral nutrient relations in horticultural crops. Sci. Hortic. 78:127–157.

Grieve, C., L. Wu, L. Rollins, and A. Harivandi. 2008. Tolerance by landscape plants of salinity and of specific ions. In: A comprehensive literature review on salt management guide for landscape irrigation with recycled water in coastal southern California. 1 Feb. 2013. <http://www.salinitymanagement.org>.

Hughes, H. and J. Hanan. 1978. Effect of salinity in water supplies on greenhouse rose production. J. Amer. Soc. Hort. Sci. 103:694–699.

Marosz, A. 2004. Effect of soil salinity on nutrient uptake, growth, and decorative value of four ground cover shrubs. J. Plant Nutr. 27:979–989.

Marschner, H. 1995. Mineral nutrition of higher plants. 2nd Ed. Academic Press, San Diego, CA.
Munns, R. 2002. Comparative physiology of salt and water stress. Plant Cell Environ. 25:239–250.
Munns, R. and M. Tester. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59:651–681.
Niu, G. and R. Cabrera. 2010. Growth and physiological responses to landscape plants to saline water irrigation—A review. HortScience 45: 1605–1609.
Niu, G. and D.S. Rodriguez. 2006. Relative salt tolerance of selected herbaceous perennials and groundcovers. Sci. Hort. 110:352–358.
Niu, G. and D.S. Rodriguez. 2008. Responses of growth and ion uptake of four rose rootstocks to chloride- or sulfate-dominated salinity. J. Amer. Soc. Hort. Sci. 133:663–669.
Niu, G., D.S. Rodriguez, and L. Aguiniga. 2008. Effect of saline water irrigation on growth and physiological responses of three rose rootstocks. HortScience 43:1479–1484.
Niu, G., D. Rodriguez, and S. McKenney. 2012. Response of selected wildflower species to saline water irrigation. HortScience 47:1351–1355.
Raviv, M., A. Krasnovsky, S. Medina, and R. Reuveni. 1998. Assessment of various control strategies for recirculation of greenhouse effluents under semi-arid conditions. J. Hort. Sci. Biotechnol. 73:485–491.
Rodriguez-Perez, J.A., M. Fernandez-Falcon, and A.R. Socorro-Monzon. 2000. The effect of salinity on growth and nutrition of Protea obtusifolia. J. Plant Nutr. 1:97–104.
Shannon, M.C., C.M. Grieve, and L.E. Francois. 1994. Whole-plant response to salinity, p. 199–244. In: Wilkinson, R.E. (ed.). Plant environment interaction. Marcel Dekker; New York, NY.
Urban, I. 2003. Influences of abiotic factors in growth and development, p. 369–374. In: Robert, A.V., T. Debener, and S. Gudin (eds.). Encyclopedia of rose science. Elsevier Academic Press, San Diego, CA.
U.S. Environmental Protection Agency. 1983. Methods of chemical analysis of water and wastes (EPA-600/4-79-020). U.S. Gov. Print. Office, Washington, DC.
Wahome, P.K., H.H. Jesch, and I. Grittner. 2001. Mechanisms of salt stress tolerance in two rose rootstocks: Rosa chinensis ‘Major’ and R. rubiginosa. Sci. Hort. 87:207–216.
Zollinger, N., R. Koenig, T. Cerny-Koenig, and R. Kjelgren. 2007. Relative salinity tolerance of intermountain western United States native herbaceous perennials. HortScience 42:529–534.