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-tolerant 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 high 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 salinity 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 salinity 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 commonly used in southern regions, 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⁺, Ca²⁺, Mg²⁺, Cl⁻, and SO₄²⁻ 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 (≈6.5) each time. Plants were then irrigated (overwatering with a leaching fraction of ≈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 °C to a constant weight. The average air temperature in the greenhouse for Expt. 1 was 27.4 ± 1.4 °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 °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 °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⁺, Ca²⁺, Mg²⁺, 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/Atomic 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%

Table 1. Total number of buds, open flowers, and faded flowers for 13 rose cultivars irrigated with nutrient solution (control, without addition of salts) or saline solution at electrical conductivity (EC) of 3.1, 4.4, or 6.4 dS·m⁻¹ (EC 3.1, EC 4.4, and EC 6.4) counted at the end of experiment.

Cultivar	Treatment			
	Control	EC 3.1	EC 4.4	EC 6.4
<i>Expt. 1 (10 weeks)</i>				
Belinda's Dream	3.6 a ^z	3.5 a	3.3 a	2.7 a
Caldwell Pink	32.0 a	24.1 b	19.1 bc	13.7 c
Carefree Beauty	6.3 a	3.5 b	2.8 b	1.5 b
Folksinger	6.1 a	5.6 a	4.9 a	2.9 b
Quietness	5.6 a	4.3 ab	2.3 b	2.1 b
Winter Sunset	6.7 a	4.5 b	3.4 b	1.4 c
<i>Expt. 2 (7 weeks)</i>				
Basye's Blueberry	12.1 a	8.4 b	3.6 c	2.8 c
Iceberg	18.8 a	18.3 a	12.6 b	9.8 b
Little Buckaroo	23.3 a	15.8 b	8.5 c	7.4 c
Marie Pavie	25.3 a	20.7 a	9.3 b	6.7 b
Rise N Shine	17.1 a	16.0 a	15.6 a	13.9 a
Sea Foam	12.5 a	8.7 a	11.0 a	9.2 a
The Fairy	75.1 a	65.8 a	60.4 a	35.3 b

^zMeans 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.

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

Table 2. Visual score of 13 rose cultivars irrigated with nutrient solution (control, without addition of salts) or saline solution at electrical conductivity (EC) of 3.1, 4.4, or 6.4 dS·m⁻¹ (EC 3.1, EC 4.4, and EC 6.4) assessed at the end of the experiments.²

Cultivar	Treatment			
	Control	EC 3.1	EC 4.4	EC 6.4
<i>Expt. 1</i>				
Belinda's Dream	5.0 a ²	5.0 a	5.0 a	4.9 a
Caldwell Pink	5.0 a	5.0 a	5.0 a	4.9 a
Carefree Beauty	5.0 a	4.8 a	4.3 b	1.5 c
Folksinger	4.0 a	4.2 a	4.8 a	2.2 b
Quietness	5.0 a	5.0 a	5.0 a	4.4 b
Winter Sunset	5.0 a	4.4 b	2.5 c	1.2 c
<i>Expt. 2</i>				
Basye's Blueberry	5.0 a	5.0 a	4.9 ab	4.8 b
Iceberg	5.0 a	5.0 a	4.8 b	4.7 c
Little Buckaroo	5.0 a	5.0 a	5.0 a	5.0 a
Marie Pavie	5.0 a	5.0 a	4.9 ab	4.6 c
Rise N Shine	5.0 a	5.0 a	4.9 ab	4.8 b
Sea Foam	5.0 a	5.0 a	5.0 a	4.9 a
The Fairy	5.0 a	5.0 a	4.9 ab	4.6 c

²Plants 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.

³Means 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.

Table 3. Shoot dry weight (DW, g/plant) of 13 rose cultivars irrigated with nutrient solution [control, without addition of salts, electrical conductivity (EC) 1.4] or saline nutrient solution at EC (EC) of 3.1, 4.4, or 6.4 dS·m⁻¹ (EC 3.1, EC 4.4, and EC 6.4).

Cultivar	Treatment				Linear regression (<i>P</i>)
	EC 1.4	EC 3.1	EC 4.4	EC 6.4	
<i>Expt. 1 (10 weeks)</i>					
Belinda's Dream	21.0 a ^z	20.6 a	19.0 a	14.7 b	0.003 ^y
Caldwell Pink	23.0 a	20.0 ab	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
<i>Expt. 2 (7 weeks)</i>					
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	20.8 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

²Means in the same row 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.

³Regression between shoot DW vs. salinity.

NS = nonsignificant.

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 control, 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⁻, and Mg²⁺, 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

Fig. 1. Shoot sodium (Na^+), chloride (Cl^-), calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}) concentrations of six rose cultivars irrigated with nutrient solution (control, no addition of salts) or saline solution at electrical conductivity (EC) of $6.4 \text{ dS}\cdot\text{m}^{-1}$ (EC 6.4) in Expt. 1. Mean with the same upper and lower case letters are not significantly different among cultivars in control and EC 6.4, respectively, tested by Student-Newman-Keuls multiple comparison at $P = 0.05$.

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 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^- . 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 $39 \text{ mg}\cdot\text{g}^{-1}$ 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

Fig. 2. Shoot sodium (Na^+), chloride (Cl^-), calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}) concentrations of seven rose cultivars irrigated with nutrient solution (control, no addition of salts) or saline solution at electrical conductivity (EC) of $6.4 \text{ dS}\cdot\text{m}^{-1}$ (EC 6.4) in Expt. 2. Mean with the same upper and lower case letters are not significantly different among cultivars in 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.

threshold for Na^+ and Cl^- concentrations. In Expt. 2, 'The Fairy' had higher Na^+ concentration and relatively obvious foliar damage compared with other cultivars. For all cultivars in both experiments, shoot Na^+ concentrations were lower than Cl^- concentrations, but both Na^+ and Cl^- concentrations varied with cultivar. Na^+ concentrations for most cultivars in this study were rather high compared with rose rootstocks of *R. fortuniana* ($1.1 \text{ mg}\cdot\text{g}^{-1}$), *R. multiflora* ($2.2 \text{ mg}\cdot\text{g}^{-1}$), *R. odorata* ($3.1 \text{ mg}\cdot\text{g}^{-1}$), and 'Dr. Huey' ($1.3 \text{ mg}\cdot\text{g}^{-1}$) (Niu et al., 2008), although the treatment period was shorter and salinity level was lower than those for the rose rootstocks (16 weeks, EC of $8.0 \text{ dS}\cdot\text{m}^{-1}$).

Excessive accumulation of Na^+ often results in a low K^+ concentration (Grattan and Grieve, 1999). Maintaining adequate K^+ concentrations is essential to survive and thrive under salinity stress. Ca^{2+} uptake is often

disturbed under saline conditions (Alam et al., 2001). Even under non-saline conditions, inadequate calcium nutrition occurs in many horticultural crops as a result of physical or chemical stresses (Grattan and Grieve, 1999). In Expt. 1, the salt-sensitive cultivars Carefree Beauty, Winter Sunset, and Folksinger had lower K^+ and Ca^{2+} concentrations under elevated salinity conditions. These results are supported by other authors (Drihem and Pilbean, 2002; Marosz, 2004; Rodriguez-Perez et al., 2000). The reduction in Ca^{2+} , K^+ , and Mg^{2+} by elevated salinity in Expt. 2 was not substantial as compared with those in Expt. 1.

In summary, salt tolerance of the self-rooted garden roses varied with cultivar. In Expt. 1, 'Belinda's Dream' was the most tolerant, 'Caldwell Pink' and 'Quietness' also had good tolerance to salinity, whereas 'Winter Sunset', 'Carefree Beauty', and

'Folksinger' were the least tolerant. In 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'. Because the differences among cultivars in visual quality and shoot growth were small in Expt. 2, further study is needed to confirm the results. Large variations in shoot Na^+ and Cl^- concentrations existed among cultivars under both control and elevated salinity treatments.

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