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Response of 18 Earth-Kind® Rose Cultivars to Salt Stress

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***Abstract*. Earth-Kind® is a special designation given to select rose cultivars with superior stress tolerance (heat, drought, and pest tolerance) and outstanding landscape performance. The responses of Earth-Kind® roses to high salinity stress are unknown. A greenhouse study was conducted to evaluate 18 Earth-Kind® rose cultivars (Belinda's Dream, Cecile Brunner, Climbing Pinkie, Ducher, Duchesse de Brabant, Else Poulsen, Georgetown Tea, La Marne, Madame Antoine Mari, Marie Daly, Monsieur Tillier, Mrs. Dudley Cross, Mutabilis, Perle d'Or, Reve d'Or, Sea Foam, Souvenir de St. Anne's, and Spice) in College Station and 10 of the same 18 cultivars in El Paso in response to two salinity levels at electrical conductivity (EC) of 1.2 (control, nutrient solution) and 10.0 dS·m^{-1} (EC 10). In both locations, 'Belinda's Dream' and 'Climbing Pinkie' in EC 10 had no or little reduction in shoot growth, flower number, and leaf SPAD readings. The net photosynthetic rate (P_n), stomatal conductance (g_S), and transpiration (E) did not decrease in these two cultivars at EC 10 in El Paso. In College Station, 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' in EC 10 also had no or little reduction in shoot growth, flower number, and leaf SPAD readings. In both locations, 'Cecile Brunner' and 'Else Poulsen' in EC 10 had severe visual foliar salt damage, and they had the greatest reductions in shoot growth and flower number. In addition to these two cultivars, the lowest relative shoot dry weight (DW) and flower number was observed in 'Madame Antoine Mari', 'Perle d'Or', 'Spice', and 'Souvenir de St. Anne's' in College Station. In summary, 'Belinda's Dream', 'Climbing Pinkie', ' Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' were the most salt-tolerant cultivars, whereas 'Cecile Brunner', 'Else Poulsen', 'Madame Antoine Mari', 'Perle d'Or', 'Spice', and 'Souvenir de St. Anne's' were the least salt-tolerant among the cultivars investigated.**

With rapid increases in urban populations and industrial development, the availability of fresh water for landscape irrigation will be limited in the future. Therefore, alternative water sources such as reclaimed water are becoming commonly used to irrigate urban landscapes and agricultural crops (Niu and Rodriguez, 2008). Reclaimed water contains high levels of soluble salts, inducing salt stress to plants. High soil salinity is the result of low rainfall and high evapotranspiration in arid and semiarid regions, whereas it is the result of deicing salts in northern areas (Niu et al., 2013). Increasing soil salinity negatively affects plant physiological and biochemical mechanisms that are associated with plant growth and development. Thus, screening and identifying salt-tolerant plant species and cultivars is becoming increasingly important, which could permit the use of lower quality water and conserve higher quality water for other purposes.

Sodium (Na^+) and chloride (Cl^-) are usually the most prevalent ions in saline water, which may cause deleterious effects in plants such as necrosis and leaf edge burn (Wahome et al., 2001). Excessive Na^+ and Cl^- uptake competes with uptake of other nutrient ions such as potassium (K^+), calcium (Ca^{2+}), or nitrogen (N), resulting in nutritional disorders and reduced yield and plant quality (Grattan and Grieve, 1999). High soil salinity also causes reduction in soil water potential, inhibiting plants' ability to extract water from the soil and maintain turgor. In addition, high ionic concentration can disturb membrane integrity and function, internal solute balance, and nutrient uptake, and it affects plant growth, water relations, and photosynthesis (Grattan and Grieve, 1999). Increased sodium chloride (NaCl) levels resulted in a reduction in shoot, root, and leaf biomass and an increase in root/shoot ratio, which were reported in cotton (*Gossypium hirsutum* L.), soybean [*Glycine max* (L.) Merr.], and alfalfa (*Medicago sativa* L.) (Berstein and Ogata, 1966; Kant et al., 1994; Meloni et al., 2001).

Plants have various salt tolerance mechanisms, including ion exclusion, maximizing Na^+ efflux from roots and its recirculation out of shoots and intercellular compartments, maintaining high cytosolic K^+/Na^+ ratio, or accumulation of optimal amount of compatible solute (Tester and Davenport, 2003). Salt-tolerant plants usually have less adverse effects on foliar salt injury and growth and yield reduction at elevated salinity (Grieve et al., 2008). The relative salt tolerance among multiple cultivars based on their growth and physiological responses at elevated salinity levels has been studied in greenhouse and garden roses and rose rootstocks (Cabrera et al., 2009; Niu et al., 2008, 2013; Niu and Rodriguez, 2008). As irrigation salinity increased from 1.4 to 6.4 dS·m^{-1}, there was no or little visual damage in salt-tolerant rose cultivars, Little Buckaroo, Sea Foam, and Rise N Shine, and shoot DW of these cultivars was unaffected by salt stress (Niu et al., 2013). In a study by Niu et al. (2008), *R.* ×*fortuniana* was relatively more salt-tolerant than the other two rootstocks, *R. odorata* and *R. multiflora*, with smaller growth reductions and higher visual quality at elevated salinities.

Garden roses (*Rosa hybrida* L.) are some of the most economically important flowering shrubs in the world. Generally, roses are salt-sensitive species with reduction in yield and quality at salinity levels that exceed EC of 3.0 dS·m^{-1} (Urban, 2003). Earth-Kind® is a special designation given to select rose cultivars by the Texas AgriLife Extension Service through the Earth-Kind® landscaping program (Aggie Horticulture, 2014). These roses are trialed in large outdoor field plots in a location with typical conditions (MacKay et al., 2008). During years of testing, no pesticides and chemical or organic were applied to the research and trial roses. Based on actual recorded field data, best rose cultivars are selected by conformational trials throughout the region in various soil types, ranging from acid sands to highly alkaline clays (MacKay et al., 2008). The Earth-Kind® Rose Trials help to serve the horticulture community by identifying the most adaptable landscape roses (Harp et al., 2009). These roses exhibit consistent and superior pest tolerance combined with outstanding landscape performance with minimum fertilizer, water, and pesticides (Aggie Horticulture, 2014). However, salt stress was not a factor considered during the evaluation process. There is little science-based knowledge about

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the responses of the Earth-Kind® roses to high salinity levels.

Using salt-tolerant garden roses is important in urban landscapes in areas where soil salinity is high or irrigation water quality is poor. Our objectives were to compare the relative salt tolerance in 18 Earth-Kind® rose cultivars (Belinda's Dream, Cecile Brunner, Climbing Pinkie, Ducher, Duchesse de Brabant, Else Poulsen, Georgetown Tea, La Marne, Madame Antoine Mari, Marie Daly, Monsieur Tillier, Mrs. Dudley Cross, Mutabilis, Perle d'Or, Reve d'Or, Sea Foam, Souvenir de St. Anne's, and Spice) in College Station, TX, and 10 of the same 18 Earth-Kind® rose cultivars replicated in El Paso, TX, and to determine the visual quality, shoot growth, flower number and DW, chlorophyll content, and gas exchange of these rose cultivars to elevated salinity.

Materials and Methods

Plant materials and culture. The study was conducted in two locations, College Station and El Paso, TX. In College Station, 18 cultivars of rose plants grown from own rooted-cuttings, Belinda's Dream, Cecile Brunner, Climbing Pinkie, Ducher, Duchesse de Brabant, Else Poulsen, Georgetown Tea, La Marne, Madame Antoine Mari, Marie Daly, Monsieur Tillier, Mrs. Dudley Cross, Mutabilis, Perle d'Or, Reve d'Or, Sea Foam, Souvenir de St. Anne's, and Spice, were shipped as potted plants from Chamblee's Rose Nursery (Chamblee Rose Nursery, Inc., Tyler, TX) on 29 Jan. 2013. Larger growth habits of 'Mrs. Dudley Cross', 'Mutabilis', and 'Reve d'Or' required 7.57-L plastic pots and the other 15 cultivars were in 3.79-L plastic pots. As a result of greenhouse space limitation in El Paso, 10 of the same 18 cultivars, Belinda's Dream, Cecile Brunner, Climbing Pinkie, Ducher, Duchesse de Brabant, Else Poulsen, Georgetown Tea, La Marne, Marie Daly, and Monsieur Tillier, in 3.79-L pots from the same nursery were used for the salinity tolerance study. The root substrate was a mix of sand, composted bark, and ground bark (1:1:1 by volume). Before initiating treatments, plants were grown in the greenhouse and well irrigated with a nutrient solution, which was made by adding 1 $g \cdot L^{-1}$ of 15N–7.1P–14.1K (Peters 15-16-17; Scotts, Marysville, OH) or 1 $g \cdot L^{-1}$ 15N–2.2P–12.5K (Peters 15-5-15 Ca-Mg Special®; Scotts) to reverse osmosis water in College Station and El Paso, respectively. In addition, the plants in College Station were periodically watered with 5.15 $g \cdot L^{-1}$ Sequestrene® 138 (6% iron chelate) (Becker Underwood, Inc., Ames, IA) to prevent iron deficiency.

Although the cultivars used for the study are relatively pest-free in the landscape, in this greenhouse study, plant foliage was washed with soapy water and M-pede® (49% potassium salts of fatty acids; Dow AgroSciences LLC, Indianapolis, IN) periodically to control spider mites in College Station. In addition, AVID® 0.15 EC (2% Abamectin; Syngenta Crop Protection Inc., Greensboro, NC) and Talstar® (0.2% Bifenthrin; FMC Corporation Agricultural Products Group, Philadelphia, PA) were applied periodically to control spider mites in El Paso. Marathon® 1% G (1% imidacloprid; OHP, Inc., Mainland, PA) was also applied to control aphids in both locations. Greenhouse temperatures were controlled by a pad-and-fan cooling system and gas heating system. During the experimental period in College Station, the average air temperature in the greenhouse was 24.9 °C during the day and 19.3 °C at night, the average daily light integral (DLI) was 21.6 $mol \cdot m^{-2} \cdot d^{-1}$, and the average relative humidity (RH) was 54.9%. In El Paso, the average air temperature in the greenhouse was 25.5 °C during the day and 21.7 °C at night. The average DLI was18.5 $mol \cdot m^{-2} \cdot d^{-1}$, and the average RH was 23.8% during the experiment period. Before initiation of the treatment, all plants were pruned to a uniform height of 12.5 cm and rotated around the bench weekly to reduce variability.

Salt treatment. There were 18 Earth-Kind® rose cultivars in College Station, TX, and 10 of the same 18 rose cultivars in El Paso, TX. In both locations, uniform plants of each cultivar were selected and divided into two irrigation treatment groups: 1) control solution: EC = 1.2 $dS \cdot m^{-1}$;and 2) saline solution: EC = 10.0 $dS \cdot m^{-1}$ (EC 10). By choosing this high salinity level, plants could have quick response to salt stress in a short-term study. There were 10 plants per treatment per cultivar, a total of 360 and 200 plants in College Station and El Paso, respectively. The 10.0-$dS \cdot m^{-1}$ saline solution was prepared by adding sodium chloride (NaCl) and calcium chloride ($CaCl_2$) at 2:1 M ratio to the 1.2 $dS \cdot m^{-1}$ nutrient solution, confirmed by EC using a salinity meter (Model B-173; Horiba, Ltd., Kyoto, Japan) . Irrigation treatment was initiated on 25 Feb. and ended on 8 Apr. 2013. Irrigation or saline solution was applied manually with 500 mL treatment solution for plants in 3.79-L pots and 1000 mL for plants in 7.57-L pots in the same treatment, which resulted in a leaching fraction of 30% to 50%. By irrigating consistent salinity solution, excessive salts were accumulated around the root zone, which could cause severe root damage and leaf necrosis in a short term. To prevent excessive salt accumulation and make proper measurement, saline solution was applied only once a week with control solution at all other times.

Measurements. In both locations, the EC of leachate was determined on two or three plants per treatment per cultivar every week. At the end of the experiment, visual quality of the plants was assessed based on visual foliar salt damage (leaf edge burn, leaf necrosis, and leaf discoloration) on seven or 10 plants per treatment per cultivar. Each plant was given a score of 1 to 5, where 1 = over 50% foliar damage (salt damage: burning and discoloring) or dead; 2 = moderate (25% to 50%) foliar damage; 3 = slight (less than 25%) foliage damage; 4 = good quality with little foliar damage (acceptable as landscape performance); 5 = excellent without foliar damage.

Leaf greenness index was measured by the non-destructive handheld chlorophyll meters [measured as the optical density, SPAD-502 reading (Minolta Camera Co., Osaka, Japan)] at the end of the experiment on four or six leaves at similar positions for five or 10 plants per treatment per cultivar. The SPAD value ranged from 0 to 100 to estimate leaf chlorophyll content by measuring the light transmission at the wavelengths of 650 and 940 nm (Markwell et al., 1995). All plants had been watered before measurement.

Shoots were severed at the substrate surface at the end of the experiment. Total shoot length was determined by measuring all shoots of seven or 10 plants per treatment per cultivar. Flower number was recorded, including buds, flowers, and dead flowers. Flowers, leaves, and stems were harvested, and DWs of shoots and flowers were determined after oven-drying at 80 °C to a constant weight. Flower DW was determined by collecting flower buds and open and dead flowers just below the hypanthium at the end of the experiment. To compare the effect of salt stress on the reduction of shoot growth and flowers, a relative value to the control treatment was calculated for each plant in the salt treatment. That is, relative total shoot length was calculated as:

$$\textit{Relative total shoot length} = 100\% \times \frac{\textit{Total shoot length in salt treatment}}{\textit{Averaged total shoot length in control}}$$

Similarly, relative flower numbers and shoot and flower DW were calculated.

In El Paso, instantaneous leaf gas exchange parameters including net P_n, g_S, and E were measured on five or seven plants per treatment per cultivar at the end of the experiment. The measurement was taken by clipping a young, fully expanded leaflet into the leaf chamber (cuvette) of a portable gas exchange system (CIRAS-2; PP Systems, Amesbury, MA). The environmental conditions in the cuvette were controlled at 25 °C, 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux, and 375 $\mu mol \cdot mol^{-1}$ CO_2. Data were recorded when the environmental conditions and gas exchange parameters in the cuvette became stable. These measurements were taken between 1000 and 1200 HR.

Experimental design and data analysis. The experiment used a split-plot design with the salinity treatment as the main plot and cultivars as the subplot with 10 replications per treatment at both locations. A two-way analysis of variance procedure was used to test the effects of salinity and cultivar on plant growth. When there was an interaction between treatment and cultivar, means were separated into two treatments of each cultivar by Student-Newman-Keuls multiple comparison at $P = 0.05$. When the interaction was not significant, data were pooled across salinity treatment or cultivar. Visual scores were analyzed by PROC NPARIWAY, which was designed for non-parametric tests. All statistical analyses were performed using SAS (Version 9.1.3; SAS Institute, Cary, NC).

Results and Discussion

Leachate EC. In both locations, cultivar did not affect leachate EC, and data were pooled across cultivars. The leachate EC slightly increased for plants treated with control solution (EC of irrigation solution at 1.2 dS·m^{-1}), and it ranged from 1.6 to 3.2 dS·m^{-1} and 1.6 to 2.9 dS·m^{-1} from beginning to end of the experiment in College Station and El Paso, respectively (Fig. 1). When plants were treated with 10.0 dS·m^{-1}, the leachate EC was 5.8 to 9.3 dS·m^{-1} and 5.9 to 10.0 dS·m^{-1} in College Station and El Paso, respectively, during the first 2 weeks of the treatment (Fig. 1). After 3 weeks of the treatment, the leachate EC for plants treated with10.0 dS·m^{-1} was 10.6 to 13.7 dS·m^{-1} and 10.3 to 13.4 dS·m^{-1} in College Station and El Paso, respectively.

Relative shoot DW and total shoot length. There was a strong positive correlation of relative shoot DW in the 10 same rose cultivars between College Station and El Paso, TX, and the correlation coefficient is 0.90 (P = 0.0004). In College Station, compared with the control solution, the saline solution did not reduce the relative shoot DW of 'Reve d'Or', and it had the highest relative total shoot length of 92% (Table 1). 'Belinda's Dream', 'Climbing Pinkie', 'Mrs. Dudley Cross', and 'Sea Foam' had a slight shoot DW reduction of 18%, 21%, 22%, and 20%, respectively (Table 1). In El Paso, 'Belinda's Dream' and 'Climbing Pinkie' had the lowest shoot DW reduction of 25% and 22% compared with that of control, respectively (Table 2). 'Climbing Pinkie' also had the highest relative total shoot length of 89% (Table 2).

In College Station, 'Madame Antoine Mari' had the lowest relative shoot DW of 18%, indicating a shoot DW reduction of 82% compared with that of the control (Table 1). The great shoot DW reductions were also observed in 'Cecile Brunner', 'Else Poulsen', 'Perle' d'Or', 'Spice', and 'Souvenir de St. Anne's', and they had the relative shoot DW of 29%, 31%, 30%, 32%, and 36%, respectively (Table 1). 'Cecile Brunner' and 'Souvenir de St. Anne's' had the lowest relative total shoot length of 23% and 31%, respectively (Table 1). In El Paso, 'Cecile Brunner' and 'Else Poulsen' had the lowest relative shoot DW of 35% and 38%, indicating a shoot DW reduction of 65% and 62% compared with that of the control (Table 2). These two cultivars also had the lowest relative total shoot length of 50% and 59% (50% and 41% reduction), respectively (Table 2).

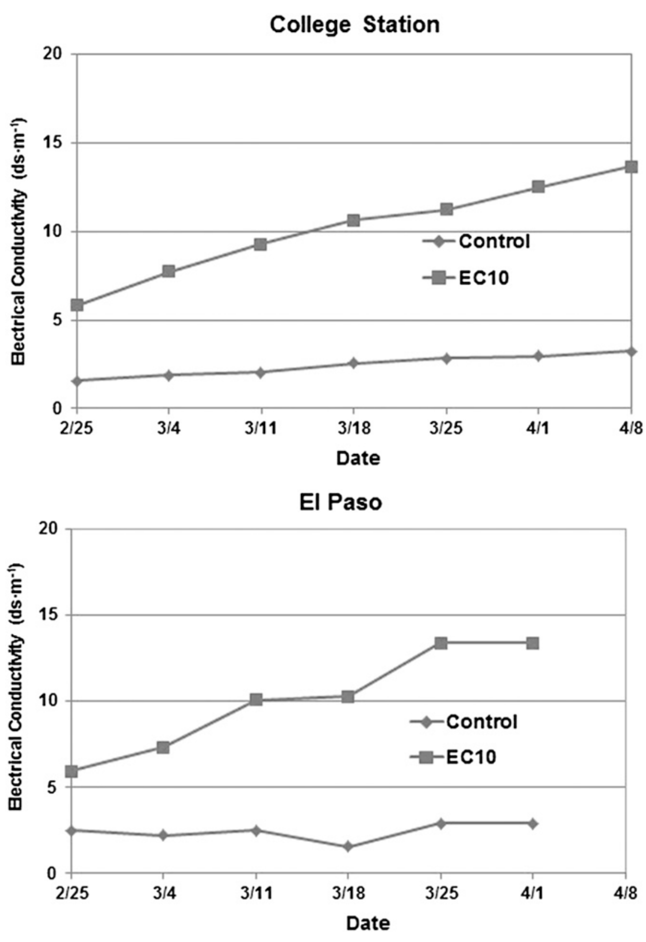

Fig. 1. Variation of weekly leachate electrical conductivity (EC) during the experimental period in College Station and El Paso, TX. Control represents EC at 1.2 dS·m^{-1}; EC10 represents EC at 10.0 dS·m^{-1}.

Many studies have reported that there were less shoot DW reductions in salt-tolerant cultivars compared with salt-sensitive ones at elevated salinity (Cassaniti et al., 2009; Niu et al., 2008; Niu and Rodriguez, 2006, 2008). Niu et al. (2008) found *R.* × *fortuniana* had smaller shoot growth reductions than *R. multiflora* and *R. odorata* as salinity increased from 1.6 to 6.0 dS·m^{-1}. In a study by Marosz (2004), major shoot length and shoot DW of *Cotoneaster horizontalis* and *Potentilla fruticosa* 'Longacre' were unaffected by the highest concentration of NaCl solution (EC = 12 dS·m^{-1}), whereas there was a significant growth reduction in *C.* 'Ursynow' as salinity increased from 1.5 to 12.0 dS·m^{-1}. In the current study in two locations, there was no or little reduction of shoot DW and total shoot length for 'Belinda's Dream' and 'Climbing Pinkie', whereas 'Cecile Brunner' and 'Else Poulsen' had the greatest shoot growth reduction at EC of 10.0 dS·m^{-1} (Tables 1 and 2).

Relative flower number and flower DW. There was a strong positive correlation of relative flower number in the 10 same rose cultivars between College Station and El Paso, TX, and the correlation coefficient is 0.89 (P = 0.0005). In College Station, 'Climbing Pinkie' had the highest relative flower number of 92%, indicating a flower number reduction of 8% compared with that of the control (Table 1). 'Belinda's Dream' and 'Sea Foam' had the second highest relative flower number of 88% and 86%, respectively. These two cultivars also had the highest relative flower DW of 89% and 93%, indicating a flower DW reduction of 11% and 7% compared with that of the control, respectively (Table 1). With saline solution, 'Mrs. Dudley Cross' and 'Reve d'Or' had little reduction in flower number, indicating a flower number reduction of 27% and 23%, respectively (Table 1). In El Paso, compared with the control, saline solution at EC of 10.0 dS·m^{-1} did not reduce the relative flower number and flower DW of 'Climbing Pinkie' (Table 2). 'Belinda's Dream' had the relative flower number and flower DW of 83% and 97%, respectively (Table 2).

In College Station, the lowest relative flower number was observed in 'Cecile Brunner', 'Spice', and 'Souvenir de St. Anne's', indicating a flower number reduction of 57%, 62%, and 61%, respectively (Table 1). 'Cecile Brunner', 'Else Poulsen', and 'Souvenir de St. Anne's' had the lowest relative flower DW of 35%, 30%, and 38%, respectively (Table 1). In El Paso, the lowest relative flower number and flower DW were observed in 'Cecile Brunner' and 'Else Poulsen' (Table 2).

Under high salinity levels, flower buds may fail to open, or growth and branches may die in flowering woody shrubs and trees (Azza Mazher et al., 2007). In a study by Niu et al. (2013), the number of flowers and buds was unaffected by salinity treatment in 'Belinda's Dream', 'Rise N Shine', and 'Sea Foam', whereas there was a significant reduction of flower numbers in 'Basye's Blueberry', 'Bucbi', 'Winter Sunset', and 'Marie

Table 1. Relative shoot dry weight (DW), total shoot length, flower number, and flower DW of 18 Earth-Kind® rose cultivars (classified as salt-tolerant, moderately tolerant, and intolerant) irrigated with saline solution at EC of 10.0 dS·m^{-1} in College Station (n = 7).

Cultivars	Relative shoot DW (%)	Relative total shoot length (%)	Relative flower number (%)	Relative flower DW (%)	Salt-tolerant
Belinda's Dream	82 ab[z]	67 c–f	88 ab	89 a	Tolerant
Climbing Pinkie	79 ab	79 bc	92 a	74 ab	Tolerant
Mrs. Dudley Cross	78 ab	64 c–f	73 abc	71 ab	Tolerant
Reve d'Or	100 a	92 a	77 abc	82 ab	Tolerant
Sea Foam	80 ab	71 b–e	86 ab	93 a	Tolerant
Ducher	41 b–h	51 d–g	65 abc	39 b	Moderate
Duchesse de Brabant	58 b–g	57 c–f	73 abc	61 ab	Moderate
Georgetown Tea	45 b–h	55 d–g	58 abc	49 ab	Moderate
La Marne	54 b–g	52 d–g	53 abc	35 b	Moderate
Mutabilis	55 b–g	54 c–f	72 abc	53 ab	Moderate
Marie Daly	42 b–g	54 d–g	55 abc	52 ab	Moderate
Monsieur Tillier	47 b–h	65 c–f	61 abc	59 ab	Moderate
Cecile Brunner	29 f–h	23 h	43 bc	35 b	Intolerant
Else Poulsen	31 f–h	43 e–h	48 abc	30 b	Intolerant
Madame Antoine Mari	18 h	39 f–h	50 abc	50 ab	Intolerant
Perle d'Or	30 f–h	42 e–h	67 abc	58 ab	Intolerant
Spice	32 e–h	47 e–h	38 c	51 ab	Intolerant
Souvenir de St. Anne's	36 d–h	31 gh	39 c	38 b	Intolerant

[z]Means with the same letters were not different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$.

Table 2. Relative shoot dry weight (DW), total shoot length, flower number, and flower DW of 10 Earth-Kind® rose cultivars (classified as salt-tolerant, moderately tolerant, and intolerant) irrigated with saline solution at electrical conductivity of 10.0 dS·m^{-1} in El Paso (n = 10).

Cultivars	Relative shoot DW (%)	Relative total shoot length (%)	Relative flower number (%)	Relative flower DW (%)	Salt-tolerant
Belinda's Dream	75 a[z]	68 ab	83 ab	97 ab	Tolerant
Climbing Pinkie	78 a	89 a	100 a	100 a	Tolerant
Ducher	48 ab	68 ab	48 b	45 b	Moderate
Duchesse de Brabant	66 ab	75 ab	75 ab	79 ab	Moderate
Georgetown Tea	55 ab	74 ab	68 ab	57 b	Moderate
La Marne	45 ab	76 ab	52 b	41 b	Moderate
Marie Daly	44 ab	69 ab	50 b	38 b	Moderate
Monsieur Tillier	64 ab	73 ab	69 ab	60 b	Moderate
Cecile Brunner	35 b	50 b	47 b	36 b	Intolerant
Else Poulsen	38 b	59 b	49 b	38 b	Intolerant

[z]Means with the same letters were not different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$.

Pavie' as salinity level increased from 1.4 to 6.4 dS·m^{-1}. Marosz (2004) found that flowering of *P. fruticosa* 'Longacre' was unaffected by salinity treatment, whereas *C.* 'Urysynow' and *C. horizontalis* did not flower at EC of 6.0 and 12.0 dS·m^{-1}. Cabrera and Perdomo (2003) reported that flower number of 'Bridal Pink' (grafted on *R.* 'Manetti' rootstock) rose was unaffected by EC up to 7.0 dS·m^{-1}. Cut flower yield did not decrease for *R. hybrida* 'Long Mercedes' grafted on rootstock *R. indica* at EC of 2.5 dS·m^{-1} (Nirit et al., 2006). In the current study, flower number was not or little affected by saline solution for 'Belinda's Dream', 'Climbing Pinkie', 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' in College Station and for 'Belinda's Dream' and 'Climbing Pinkie' in El Paso (Tables 1 and 2). 'Cecile Brunner', 'Spice', and 'Souvenir de St. Anne's' had the greatest reductions in flower number at EC of 10.0 dS·m^{-1} in College Station, whereas 'Cecile Brunner' and 'Else Poulsen' had the greatest reductions in flower number in El Paso (Tables 1 and 2).

Visual quality and leaf chlorophyll content (SPAD readings). There was a strong positive correlation of visual quality score in the 10 same rose cultivars between College Station and El Paso, TX, and the correlation coefficient is 0.85 ($P = 0.002$). There were interactions between salinity treatment and rose cultivar for visual quality score and SPAD readings in both locations. With saline solution treatment, severe foliar salt damage such as leaf burn and necrosis on lower and old leaves was observed in many cultivars. In College Station, the plants irrigated with control solution did not have any foliar damage except 'La Marne', 'Mutabilis', 'Marie Daly', and 'Perle d'Or' (Table 3), because these four cultivars had some foliar damage from spider mites (data not shown). With saline solution, 'Mrs. Dudley Cross' and 'Reve d'Or' had the least foliar salt damage with an average visual score of 4.0 and 4.3, respectively (Table 3). 'Belinda's Dream', 'Climbing Pinkie', and 'Sea Foam' had an average visual score of 3.6, 3.6, and 3.7, respectively (Table 3). Relative chlorophyll contents measured as SPAD readings were not reduced by saline solution in 'Belinda's Dream', 'Climbing Pinkie', 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' (Table 3). In El Paso, with saline solution, 'Belinda's Dream' and 'Climbing Pinkie' had an average visual score of 3.3 and 3.7, respectively (Table 4). Leaf SPAD readings were not or little affected by saline solution for 'Belinda's Dream' and 'Climbing Pinkie' (Table 4).

In College Station, 'Cecile Brunner', 'Perle d'Or', and 'Spice' had the most severe foliar salt damage with an average visual score of 1.8, 1.2, and 1.4, respectively (Table 3). 'Else Poulsen', 'Madame Antoine Mari', and 'Souvenir de St. Anne's' had severe foliar salt damage with an average visual score of 2.4, 2, and 2.4, respectively (Table 3). In El Paso, 'Cecile Brunner' and 'Else Poulsen' had severe foliar salt damage with an average visual score of 2.1 and 3, respectively (Table 4).

Plant salt tolerance can be assessed based on the degree of foliar salt damage (Niu and Cabrera, 2010). Elevated salinity stress leads to foliar salt injury, which causes reduction in visual quality. In a study by Niu et al. (2013), the rose cultivars Carefree Beauty, Folksinger, and Winter Sunset had severe visual damage at EC of 3.1 dS·m^{-1}, whereas 'Belinda's Dream', 'Little Buckaroo', 'Rise N Shine', and 'Sea Foam' showed little or no visual damage at EC up to 6.4 dS·m^{-1}. Niu et al. (2012a) found that there was little or no visual foliar damage at EC of 8.1 dS·m^{-1} in 'NuMex Cinco de Mayo', 'NuMex Thanksgiving', and 'NuMex Twilight' ornamental chile peppers (*Capsicum annuum*), whereas 'NuMex Memorial Day' had the most severe foliar damage with an average score of 2.5 at elevated salinity. In the current study, saline solution caused little visual salt damage in 'Mrs. Dudley Cross' and 'Reve d'Or' in College Station. We also observed severe foliar salt damage in 'Cecile Brunner' and 'Else Poulsen' in College Station and El Paso with saline solution treatment (Tables 3 and 4).

Salt stress stimulates chlorophyll degradation, resulting in leaf chlorosis (Santos, 2004). Although there were no relationships between chlorophyll contents and SPAD readings for rose species in previous studies, leaf SPAD readings have been a useful

Table 3. Visual foliar salt damage ratings and SPAD readings of 18 Earth-Kind® rose cultivars (classified as salt-tolerant, moderately tolerant, and intolerant) irrigated with saline solution at electrical conductivity (EC) of 1.2 (control, nutrient solution) and 10.0 dS·m^{-1} (EC 10) in College Station (n = 7).

	Visual score[z]		SPAD		
Cultivars	Control	EC 10	Control	EC 10	Salt-tolerant
Belinda's Dream	4.6	3.6	49.7 a[y]	48.0 a	Tolerant
Climbing Pinkie	4.3	3.6	44.5 a	42.1 a	Tolerant
Mrs. Dudley Cross	4.7	4	57.1 a	55.6 a	Tolerant
Reve d'Or	5	4.3	52.5 a	50.6 a	Tolerant
Sea Foam	4.9	3.7	55.4 a	57.0 a	Tolerant
Ducher	4.8	2.6	49.8 a	40.8 b	Moderate
Duchesse de Brabant	4.9	3.5	53.4 a	44.6 b	Moderate
Georgetown Tea	4.8	3.2	52.8 a	42.3 b	Moderate
La Marne	3.7	2.4	54.1 a	40.8 b	Moderate
Mutabilis	3.8	3.2	52.6 a	41.2 b	Moderate
Marie Daly	3.9	2.2	50.9 a	37.6 b	Moderate
Monsieur Tillier	4.8	3.5	61.9 a	53.1 b	Moderate
Cecile Brunner	4.4	1.8	52.4 a	40.6 b	Intolerant
Else Poulsen	4.2	2.4	47.8 a	34.4 b	Intolerant
Madame Antoine Mari	4.6	2	54.5 a	45.4 b	Intolerant
Perle d'Or	3.9	1.2	45.7 a	36.8 b	Intolerant
Spice	4.2	1.4	49.5 a	44.2 b	Intolerant
Souvenir de St. Anne's	4.5	2.4	53.5 a	43.1 b	Intolerant

[z]1 = over 50% foliar damage (salt damage: burning and discoloring) or dead; 2 = moderate (25% to 50%) foliar damage; 3 = slight (less than 25%) foliage damage; 4 = good quality with little foliar damage (acceptable as landscape performance); 5 = excellent without foliar damage.
[y]Means with the same letters between treatments were not different tested by Student-Newman-Keuls multiple comparison at *P* = 0.05.

Table 4. Visual foliar salt damage ratings and SPAD readings of 10 Earth-Kind® rose cultivars (classified as salt-tolerant, moderately tolerant, and intolerant) irrigated with saline solution at electrical conductivity (EC) of 1.2 (control, nutrient solution) and 10.0 dS·m^{-1} (EC 10) in El Paso (n = 10).

	Visual score[z]		SPAD		
Cultivars	Control	EC 10	Control	EC 10	Salt-tolerant
Belinda's Dream	5	3.3	51.2 a[y]	47.3 b	Tolerant
Climbing Pinkie	5	3.7	41.5 a	37.2 a	Tolerant
Ducher	5	2.9	49.8 a	43.0 b	Moderate
Duchesse de Brabant	5	4.4	51.3 a	48.0 a	Moderate
Georgetown Tea	5	3.9	52.9 a	46.4 b	Moderate
La Marne	4.7	2.4	53.7 a	42.3 b	Moderate
Marie Daly	4	1.4	49.1 a	36.8 b	Moderate
Monsieur Tillier	5	3.9	56.6 a	51.6 a	Moderate
Cecile Brunner	4.5	2.1	51.9 a	38.1 b	Intolerant
Else Poulsen	4.9	3	45.0 a	37.0 b	Intolerant

[z]1 = over 50% foliar damage (salt damage: burning and discoloring) or dead; 2 = moderate (25% to 50%) foliar damage; 3 = slight (less than 25%) foliage damage; 4 = good quality with little foliar damage (acceptable as landscape performance); 5 = excellent without foliar damage.
[y]Means with the same letters between treatments were not different tested by Student-Newman-Keuls multiple comparison at *P* = 0.05.

parameter in salinity tolerance evaluation (Niu et al., 2008). Plants treated with saline solution were starting to senesce as a result of high salinity, evidenced by lower SPAD readings. In 10 herbaceous perennials and groundcovers, SPAD readings were unaffected by salinity treatment in *Gaillardia aristata* Pursh, *Lantana ×hybrida*, *Lonicera japonica* Thunb., and *Verbena macdougalii* Heller, whereas less salt-tolerant species, *Lantana montevidensis* (Spreng.) Brig. and *Glandularia ×hybrida* (Gronland & Rumpler) G.L. Nesom & Pruski, had reduced SPAD readings at elevated salinity stress (Niu et al., 2007). Increasing salinity stress was also shown to decrease leaf SPAD readings in two cherry (*Prunus cerasus* L.) rootstocks (Sotiropoulos et al., 2006). In a study by Niu et al. (2008), leaf SPAD readings decreased as salinity level increased from 1.6 to 6.0 dS·m^{-1}. The salt-tolerant cultivar, *R. ×fortuniana*, had higher leaf SPAD readings compared with two other rootstocks. In the current study, with saline solution treatment, leaf SPAD readings were not or little affected by saline solution for 'Belinda's Dream', 'Climbing Pinkie', 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' in College Station or for 'Belinda's Dream' and 'Climbing Pinkie' in El Paso, indicating that these rose cultivars can maintain green leaves with saline solution treatment (Tables 3 and 4).

Gas exchange. There were interactive effects of salinity treatment and cultivar on leaf gas exchange, P_n, g_S, and E. At saline solution of 10.0 dS·m^{-1}, the P_n, g_S, and E did not decrease in 'Belinda's Dream' and 'Climbing Pinkie' (Table 5). Compared with the control, the saline solution significantly reduced the P_n, g_S and E in 'Cecile Brunner', whereas 'Else Poulsen' had a reduction in P_n with saline solution (Table 5).

At elevated soil salinities, leaf gas exchange decreases for most crops. At high salinity, leaf photosynthesis can be reduced by lowered g_S caused by toxic ions (Munns, 2002; Netondo et al., 2004). In a study by Niu et al. (2012b), salinity stress at EC of 8.0 dS·m^{-1} reduced leaf P_n, g_s, and E in four maize inbred lines (CUBA1, B73, B5C2, and BR1) and four sorghum hybrids (SS304, NK7829, Sordan79, and KS585). Herralde et al. (1998) reported that *Argyranthemum coronopifolium* had reduced g_S and photosynthetic rate under saline stress (15 d of exposure to 140 mm NaCl followed by a recovery period of 11 d), indicating that there was a toxic effect of salt concentration. In the current study in El Paso, high salinity at EC of 10.0 dS·m^{-1} did not decrease P_n, g_S, and E in 'Belinda's Dream' and 'Climbing Pinkie', whereas 'Cecile Brunner' had great reduction in P_n, g_S, and E (Table 5).

Conclusion

In summary, salt tolerance of Earth-Kind® rose cultivars was consistent in two locations with strong positive correlations of relative shoot DW, flower number, and visual quality score in the 10 same cultivars between two locations. In College Station and El Paso, 'Belinda's Dream' and 'Climbing Pinkie' had the highest relative shoot DW and flower number, and they had little or no reduction in SPAD readings. In addition to these two cultivars, 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' also had the highest relative shoot DW and flower number in College Station. In both locations, 'Cecile Brunner' and 'Else Poulsen' had the lowest relative shoot DW and flower number. The lowest relative shoot DW and flower number were

Table 5. Leaf gas exchange [net photosynthetic rate (P_n); stomatal conductance (g_S); transpiration rate (E)] of 10 Earth-Kind® rose cultivars (classified as salt-tolerant, moderately tolerant, and intolerant) irrigated with saline solution at electrical conductivity (EC) of 1.2 (control, nutrient solution) and 10.0 $dS \cdot m^{-1}$ (EC10) in El Paso.

	P_n		g_S		E		
Cultivars	Control	EC 10	Control	EC 10	Control	EC 10	Salt-tolerant
Belinda's Dream	11.4 a[z]	11.1 a	183.3 a	240.7 a	2.9 a	3.3 a	Tolerant
Climbing Pinkie	11.9 a	9.9 a	164.6 a	140.8 a	2.7 a	2.6 a	Tolerant
Ducher	11.2 a	7.9 b	149.2 a	138.6 a	2.3 a	2.5 a	Moderate
Duchesse de Brabant	14.9 a	12.8 a	256.8 a	182.4 b	3.3 a	2.8 a	Moderate
Georgetown Tea	15.3 a	13.7 a	254.0 a	258.2 a	3.6 a	3.2 a	Moderate
La Marne	16.0 a	11.1 b	271.2 a	179.7 b	3.5 a	3.1 a	Moderate
Marie Daly	10.3 a	5.9 b	181.2 a	116.2 b	2.8 a	2.1 b	Moderate
Monsieur Tillier	18.0 a	15.3 b	362.2 a	335.0 a	4.3 a	4.4 a	Moderate
Cecile Brunner	11.7a	6.2 b	234.3 a	119.3 b	3.1 a	2.3 b	Intolerant
Else Poulsen	13.1 a	9.5 b	205.0 a	197.2 a	3.1 a	3.1 a	Intolerant

[z]Means with the same letters between treatments were not different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$.

also observed in 'Madame Antoine Mari', 'Perle d'Or', 'Spice', and 'Souvenir de St. Anne's' in College Station. By comparing the growth and physiological responses at high concentration of saline solution among the 18 cultivars in College Station and 10 cultivars in El Paso, 'Belinda's Dream', 'Climbing Pinkie', 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' were the most salt-tolerant followed by 'Duchesse de Brabant', 'Mutabilis', 'Monsieur Tillier', 'Georgetown Tea', 'Marie Daly', 'La Marne', and 'Ducher'. 'Cecile Brunner', 'Else Poulsen', 'Madame Antoine Mari, 'Perle d'Or, 'Spice', and 'Souvenir de St. Anne's' were the least salt-tolerant among the cultivars investigated. Many landscapes have switched to use reclaimed water or no potable saline waters for irrigation. The typical salinity levels in reclaimed water are 1.3 to 2.0 $dS \cdot m^{-1}$. In areas with high soil salinity resulting from to poor-quality irrigation water, high evaporation, and insufficient rainfall for leaching, 'Belinda's Dream', 'Climbing Pinkie', 'Mrs. Dudley Cross', 'Reve d'Or', and 'Sea Foam' would be good selections for planting in landscapes, whereas 'Cecile Brunner' and 'Else Poulsen' are not recommended. Although Earth-Kind® roses are designated as rose cultivars with superior stress tolerance and outstanding landscape performance, some cultivars are not tolerant to poor-quality irrigation water such as 'Cecile Brunner', 'Else Poulsen', 'Madame Antoine Mari', 'Perle d'Or, 'Spice', and 'Souvenir de St. Anne's'. Because there was some foliage damage from spider mites in 'La Marne', 'Mutabilis', 'Marie Daly', and 'Perle d'Or' in College Station, further study may be needed to confirm the salt tolerance of these cultivars.

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