Chinese rose (Rosa chinensis) growth and ion accumulation under irrigation with waters of different salt contents

Xiaobin Li a,b, Shuqin Wan a,b, Yaohu Kang a, Xiulong Chen a,b, Linlin Chu a

a Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
b University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form 7 September 2015
Accepted 21 September 2015
Available online 2 October 2015

Keywords:
Saline silt-soil
Drip-irrigation
Chinese rose
Saline water
Growth
Ions

ABSTRACT

Soil salinity and saline groundwater are major constraints to the cultivation of landscape plants in coastal regions. Soil tillage, drip-irrigation and a gravel–sand layer were used for reclamation of high saline silt-soils in a coastal region of China. Chinese roses (Rosa chinensis), a salt-sensitive species, were planted in the reclaimed soil under field conditions to determine the effects of salinity on rose growth and ion uptake, using five salinity levels of 0.8, 3.1, 4.7, 6.3 and 7.8 dS/m of drip irrigation. Tensiometers were buried at a depth of 20 cm to control the soil matric potential (SMP), keeping the SMP over −5 kPa the first year, and over −10 kPa the second year. Chinese rose relative leaf water deficit, dry matter production, number of flowers, root development and distribution and other plant growth parameters were assessed. Sodium (Na), chloride (Cl), potassium (K), magnesium (Mg) and calcium (Ca) concentrations in roots, stems and leaves were determined. The increasing salinity of irrigation water had adverse effects on rose growth and ion balance, and salt stress had the greatest impact on relative leaf water deficit value. When irrigated with saline water, most roots penetrated beyond 16–19 cm depth into the high-salinity subsoil, which was disadvantageous to the absorption of water and nutrients. The SMP should be controlled at −5 to −10 kPa in the second year for irrigation with saline water of >3 dS/m, to promote a greater concentration of roots in the lower-salt top soil. Rose plants stored most absorbed Na and Cl ions in roots and stems, and Ca, Mg and K in leaves; however, leaf damage still occurred due to greater reductions in Ca/Na, Mg/Na and especially K/Na ratios. Increasing Na concentration and decreasing K/Na ratio had an adverse impact on dry matter production. Therefore, soluble potash should be applied for saline water irrigation to increase the selective absorption ratio of K, to better counteract the effect of the high Na concentrations in this soil.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Soil salinity is a major environmental factor limiting the productivity of crops and appearance of landscape plants in many coastal regions of the world, where there are large areas of saline land. In China, saline land is common along the 6000 km of coastline bordering the Pacific Ocean from Jiangsu Province to Liaoning Province (Yu and Chen, 1999). These coastal soils are usually quite saline (Chen et al., 2015), with pH of 7.5–8.5 (Wang et al., 1993). The average sodium adsorption ratio (SAR) is >30 (mmol/L)0.5, especially in silt-soil, which has marked detrimental effects on soil structure and consequently on root growth (Rengasamy et al., 2003). Saline groundwater is another factor restricting growth of crops and landscape plants in coastal regions. In coastal areas the groundwater table is persistently high, at only 0.5–3 m depth, and has an electrical conductivity (EC) within 2.5–20.5 dS/m (Chen et al., 2015). However, saline water can be successfully used for irrigation (Malash et al., 2008; Meiri et al., 1992), especially in areas with shortages of fresh water. Many crops, such as cotton (Wang et al., 2012), cowpea (Neves et al., 2009), Bermuda grass and Duncan paspalum (Robinson et al., 2004), corn (Yazar et al., 2003), barley (Khoshgofarmanesh et al., 2003), and beet (Ammari et al., 2013) have been irrigated with the saline water.
With the rapid industrialization and urbanization in coastal saline regions, there is an urgent need to improve the landscape to meet the demand for living environments in cities and surrounding districts (Li et al., 2015). Roses are some of the most popular flowering plants in the world. However, they are generally sensitive to salinity of >3.0 dS/m. Although, some rose cultivars can tolerate an EC of 3.5 dS/m without reduction in yield and quality (Cabrera and Perdomo, 2003), the excessive concentration of some ions in saline soil, due to the irrigation with saline water, is toxic to rose vegetative growth, root development and flowering (Cai et al., 2014).

Many studies were reported in literature on rose growth under saline conditions. These studies were based either on soilless saline solution culture or soil culture using added sodium chloride (NaCl) in greenhouse conditions and, sometimes with NaCl added at various ratios to irrigation water to create various salinity levels (Cabrera and Perdomo, 2003; Cai et al., 2014; Feiglin et al., 1989; Hughes and Hanan, 1978b; Ishida et al., 1979; Massa et al., 2009; Muhammad Jafar et al., 1991; Niu et al., 2008, 2013). There is little information about the effect of saline water irrigation on roses in field condition. Under field conditions, salinity is a dynamic property in the root zone resulting from evaporation of the soil solution, water extraction, selective plant uptake from plant roots and replenishment by irrigation or rainfall (Tanji, 2002). Meanwhile, environmental conditions such as temperature, light intensity, humidity and wind speed can considerably affect plant response to salinity (Niu and Cabrera, 2010; Zollinger et al., 2007). Moreover, the negative relationships between soil salt or salinity and plant growth, dry matter production and ion balance have been confirmed in crops and plants (Chauhan et al., 2008; Jaskani et al., 1991; Karlberg et al., 2007; Malash et al., 2008; Mantell et al., 1985; Muhammad Jafar et al., 1991; Sonneveld et al., 1999; Valdez-Aguilar et al., 2011); however, it is not clear which indicator is the most sensitive to salt stress based on these parameters. Determination of the most salt-sensitive indicator would help in early diagnosis of plant status to salt stress, and to make further adjustment to avoid yield loss.

In the present study, Chinese rose (Rosa chinensis), a sensitive landscape flower plant to soil salinity, was planted in coastal regions with very heavy saline silt-soil to: (1) investigate the effects on plant dry matter production, number of flowers and root development and distribution, of irrigating with waters of five different salt loads; (2) study the effect of salinity on the uptake of major ions and the effect of ion levels on dry matter production.

2. Materials and methods

2.1. Experimental site

During 2012–2013, a field experiment was conducted in the International Eco-City of Caofeidian District (39°20′ N, 118°54′ E) in the south of Tangshan city, east China, and north of Bohai Gulf bordering the Pacific Ocean. The study area is characterized by a temperate semi-humid monsoon climate with annual precipitation of approximately 550 mm, with most rainfall during June–September.

According to Wang et al. (1993), the saline soil of the experimental site is a typical coastal saline soil developed from beach mud, with the main ions being chloride (Cl) and sodium (Na). Before water irrigation treatment, the soil texture and soil bulk density were determined (Table 1). The soil in the experimental field was silt-soil, with clay (0.002 mm) content of 0.7%, silt (0.002–0.05 mm) of 80.7% and sand (0.05–2 mm) of 18.6%, and had a characteristic silty texture and poor ventilation and permeability. The bulk density of saline soil was in the range of 1.4–1.65 g/cm³ in the 0–30 cm soil profile, and 1.6–1.8 g/cm³ in 30–120 cm.

### Table 1

| Soil depth (cm) | Soil texture in % (USDA) | Soil texture | Bulk density (g/cm³) At the beginning of the experiment (June 2012) | After soil reclamation and freshwater irrigation (July 2012) |
|----------------|-------------------------|--------------|------------------------------------------------|-----------------------------------------------------------|
|                | <0.002 mm | 0.002–0.05 mm | 0.05–2 mm | EC<sub>x</sub> (dS/m) | pHs | SAR (mmol/L)<sup>0.5</sup> | EC<sub>x</sub> (dS/m) | pHs | SAR (mmol/L)<sup>0.5</sup> |
| 0–10           | 0.7       | 80.2          | 19.1     | 32.34 | 7.97 | 58.86 | 9.12 | 7.89 | 29.74 |
| 10–20          | 0.7       | 80.3          | 19.0     | 30.05 | 7.94 | 57.43 | 10.67 | 7.94 | 32.77 |
| 20–30          | 0.8       | 79.6          | 19.6     | 25.03 | 8.13 | 56.57 | 14.82 | 7.87 | 39.77 |
| 30–40          | 0.7       | 81.4          | 17.9     | 24.80 | 8.19 | 56.05 | 18.62 | 7.77 | 46.97 |
| 40–60          | 0.6       | 81.2          | 18.8     | 26.78 | 8.04 | 59.29 | 22.00 | 7.67 | 51.34 |
| 60–80          | 0.8       | 80.5          | 18.7     | 29.34 | 7.97 | 55.53 | 23.00 | 7.64 | 51.55 |
| 80–100         | 0.6       | 82.1          | 17.3     | 26.77 | 8.02 | 58.08 | 22.83 | 7.62 | 51.94 |
| 100–120        | 0.9       | 80.1          | 19.0     | 29.56 | 7.91 | 58.20 | 22.87 | 7.64 | 51.88 |

Note: EC<sub>x</sub> is electrical conductivity of saturated paste extracts; pHs is pH of saturated paste; and SAR is sodium adsorption rate of saturated paste extracts.
5 days, all treatments were uniformly irrigated to maintain the SMD at −5 kPa if the SMD fell below −5 kPa, until all plants were successfully established in the experimental soil. About ~36 mm of freshwater was applied over a period of 25 days to provide favorable soil moisture for seedling survival.

### 2.3. Saline water irrigation

The second part of this experiment was saline irrigation with water of different salt contents. To determine the effective use of irrigation with saline water on Chinese rose, during 2012–2013, five treatments with EC of irrigation water (EC<sub>iw</sub>) of 0.8, 3.1, 4.7, 6.3 and 7.9 dS/m were designed (coded S1–S5). Ionic composition of irrigation water is shown in Table 2.

Water treatments based on different EC<sub>iw</sub> were initiated on 1 July 2012, and when the SMD reached the threshold value, 6 mm of irrigation was applied to all treatments. The 6 mm irrigation depth was determined according to the ability to retain moisture in the soil (soil water reserves) and the maximum daily evapotranspiration of plants in this local area. Each treatment was connected to an individual gravity drip-irrigation system, which irrigated the plants from a 200-L tank. Other management issues of this experiment were as described in Li et al. (2015).

### 2.4. Observations and measurements

Soil cores were obtained from each plot using an auger (2.0 cm diameter, 15 cm high) on 1 June, 13 July and 28 October 2012; and on 18 March and 11 November 2013. The samples were obtained at 0, 10, 20 and 30 cm from the emitters and all sample depths were the same: 0–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100 and 100–120 cm. The three replicate soil samples were mixed into one sample per treatment.

All soil samples were air-dried and passed through a 1-mm sieve. Soluble salt estimates were based on extracts of saturated soil. EC was determined using a conductivity meter (DDS-11A, REX, Shanghai, China).

In this experiment, average EC<sub>c</sub> values within the whole soil profile (depth of 0–120 cm) and the root zone (identified as about 40 cm horizontal to the center of two rows at a depth of 0–40 cm) were integrated to account for both spatial and temporal variations. The average EC<sub>c</sub> values in the soil profile were calculated:

\[
EC_c(t) = \frac{\sum_{j,k} EC_c(t, j, k) \times S(j, k)}{\sum_{j,k} S(j, k)}
\]

where \(t\) represents the time when soil samples were obtained, \(j\) the four (n) distances from the emitter where soil samples were obtained, \(k\) the seven (m) depths of soil samples and \(S(j, k)\) the depth interval of the soil sample.

In addition, average EC<sub>c</sub> value for 2 years was calculated:

\[
EC_c(TY) = \frac{\sum_j |EC_c(j)| + |EC_c(O)| + |EC_c(M)| + |EC_c(N)|}{2} \times 110 + \frac{|EC_c(O)| + |EC_c(M)| + |EC_c(N)|}{2} \times 142 + |EC_c(M)| + |EC_c(N)| \times 240 \times 492
\]

where EC<sub>c</sub>(j), EC<sub>c</sub>(O), EC<sub>c</sub>(M) and EC<sub>c</sub>(N) refer to the spatial weighted mean value of the soil profile on 13 July and 28 October 2012, and 18 March and 11 November 2013, respectively. 110, 142 and 240 are the intervals between two sampling times, and they are the days between 13 July and 28 October 2012, 28 October 2012 and 18 March 2013, 18 March and 11 November 2013, respectively. 492 is the sum of the days.

The number of surviving rose plants was counted to calculate the survival rate, and the height and stem diameter were measured and flower number was recorded in 2012–2013. The branches were counted in 2013. At the end of 2013, plants (one plant per replicate) were destructively harvested and divided into leaves, stems and roots. Fresh weight was measured, and after drying in a ventilated oven at 70 °C for 48 h, dry weight of each organ was determined. A representative sub-sample of each plant organ was ground in a mill (Retsch MM200, Retsch, Germany) to a 0.2-mm mesh. A standard plant was chosen in each replicate, and root distribution was observed by taking soil samples to a depth of 50 cm in 10-cm increments in a square of 30 cm × 30 cm using the plant as center. Roots were divided into coarse and fine (diameter <2 mm) roots when root length was counted.

Effects of saline treatment on growth of rose shoots and distribution of roots were analyzed. Growth ratio (GR), root length density (RLD, cm/cm<sup>3</sup>), root distribution coefficient (β, dimensionless) and shoot water storage ratio (SWSR, %) were obtained using the following equations:

\[
GR = \frac{SD \times 10}{PH}
\]

\[
RLD = \frac{RL}{\sqrt{\pi}}
\]

\[
Y = 1 - \beta^d
\]

\[
SWSR = \frac{(FW_s - DW_s)}{FW_s} \times 100
\]

where SD is stem diameter (mm), PH is plant height (cm) and RL is root length (cm) for the excavated soil volume (V, cm<sup>3</sup>). Y is the cumulative root fraction (%) from the soil surface to depth d (cm) and was fitted to the data for each excavation. FW<sub>s</sub> and DW<sub>s</sub> are the fresh and dry weights of shoots, respectively (g/plant).

Twelve fully opened leaves were collected in 2012 and 2013. Relative leaf water content (RWC, %) and relative leaf water deficit values (RWD, %) were determined by these equations:

\[
RWC = \frac{(FW_l - DW_l)}{(TW_l - DW_l)} \times 100
\]

\[
RWD = \left[1 - \frac{(FW_l - DW_l)}{(TW_l - DW_l)}\right] \times \frac{TW_l}{FW_l} \times 100
\]

FW<sub>l</sub>, DW<sub>l</sub> and TW<sub>l</sub> are the fresh, dry and turgid weights of leaves, respectively (g/plant). Twelve leaf disks were collected into
weighed sealed vials and weighed for FWI, then floated on double deionized water for 12 h under light near the compensation point to attain maximum turgidity. These disks were blotted dry then weighed for TWI and oven-dried for DWI.

The oven-dried samples of leaves, stems and roots were digested in concentrated nitric acid at 130 °C for elemental analysis using inductively coupled plasma spectrometry (Optima 5300DV, USA) and a UV–vis spectrophotometer (HACH DR5000, USA).

2.5. Statistical analyses

Analyses of variance (ANOVARs) were carried out using SPSS 16.0 statistical software (SPSS Inc., Chicago, IL, USA). The significance of the effect of all variables was examined by one-way ANOVA. Figures were created using Origin 8.0 (Origin Lab Inc., MA, USA). The relationship equations that related the leaf, shoot and root parameters to the salinity level of water and soil were calculated.

3. Results

3.1. Soil salinity (ECₑ)

Before transplanting of roses, ECₑ values in the 0–40 and 0–120-cm soil profiles were relatively uniform, with average values up to 28.06 and 28.09 dS/m, respectively (Table 1). After the soil reclamation and freshwater irrigation stage, average ECₑ was 13–14 dS/m for S1–S5 in the 0–40 cm soil profile, which was 51.3–53.5% lower than soil ECₑ values before transplanting of roses. The corresponding values were 19–20 dS/m in the 0–120 cm soil profile, reduced by 28.7–31.7%.

In November 2013 (salt water irrigation stage), the heavy saline soils became mildly saline soil (2–4 dS/m). The average ECₑ values were 2.4–3.9 dS/m in the 0–40 cm soil profile for S1–S5 (Table 3), which were reduced by 71.6–81.7% compared with ECₑ in the soil reclamation and freshwater irrigation stage. The corresponding values were 3.7–8.1 dS/m in 0–120 cm soil profile (Table 3), reduced by 60.0–80.5%. Regardless of the salinity level of irrigation water, soil salinity decreased significantly with time under drip-irrigation.

3.2. Rose growth

The data of plant growth characteristics of Chinese rose for different treatments during the experiment and the ANOVA results are shown in Table 4. The average survival rate was 98.67% in 2012, with no difference in the five treatments, but it was significantly reduced in 2013 with increasing salinity of irrigation water. In 2013, S1 had the highest survival rate (96.67%) and S5 the lowest (8.89%) (Table 4).

Plant height and stem diameter increased significantly from 2012 to 2013, and showed a trend of reduction with increasing salinity of irrigation water. In the 2 years, the S1 and S2 treatments formed one group, with plant height and stem diameter values higher than these for the other treatments. Similar trends were observed for total length of branches and length of branches in 2013. GR increased with increasing salinity of irrigation water.
of root distribution (Table 6). Both total root and fine root lengths significantly decreased with increasing salinity of irrigation water—notably, fine root length significantly decreased in a linear fashion ($R^2 = 0.9734$). Total root lengths decreased from 3102.7 cm for 0.8 dS/m to 2220.2 cm for 7.8 dS/m. Fine root lengths correspondingly decreased from 2568.7 cm to 1888.7 cm. However, after an initial decrease, coarse root length tended to increase with increasing salinity of irrigation water (Table 6).

RLD and percentage of root dry mass in 10-cm increments of soil layers were significantly affected by salinity (Fig. 3a and b). Increasing salinity of irrigation water reduced RLD for each layer in the 0–20-cm soil profile but increased RLD in the 30–50-cm profile, except for the S5 treatment in which RLD decreased throughout the soil profile (Fig. 3a). Interestingly, the fitted curve between percentage of root dry mass in each soil layer and soil depth for the S1 treatment nearly intersected at a point in a range of 16–19 cm of soil depth with other fitted curves of the S2–S5 treatments (Fig. 3b), indicating that more roots penetrated beyond 16–19 cm into the subsoil when irrigated with saline water of >3 dS/m. Increase salinity of irrigation water significantly reduced RLD for all 0–50-cm soil profiles ($R^2 = 0.9473$; Fig. 4). The relationship between RLD for all soil profiles and EC$_{w}$ was represented by a highly significant logarithmic function ($R^2 = 0.9473$). In the 0–50-cm soil profile, β showed a reducing trend after an initial increase with increasing salinity of irrigation water ($R^2 = 0.7396$; Fig. 4).

FW$_{w}$, DW$_{w}$ and root dry weight decreased as the salinity in irrigation water increased, but there were no significant differences among the S3–S5 treatments (Table 6), SWSR increased, but there were no differences among the S2–S5 treatments (Table 6). Root:shoot ratio increased as salinity of irrigation water increased, but there were no significant differences.

### 3.5. Ion concentrations in plants

Calcium (Ca), magnesium (Mg) and Na concentrations (unit: mmol/kg) in all plant organs increased significantly with increasing salinity of irrigation water (Fig. 5a, c and d). Notably, when irrigated with water of 7.8 dS/m, the Na concentrations in leaves, stems and roots were (231.1 ± 47.7%)%, (111.7 ± 32.4%)% and (51.4 ± 21.8%)% higher than those of 0.8 dS/m, respectively. Both Ca and Mg concentrations were lower in roots than in leaves (Fig. 5a and c), but Na concentration was higher in roots than in aerial organs (Fig. 5d). Cl concentration also increased as salinity of irriga-
Fig. 3. Root length density and percentage of root dry mass for each soil layer in relation to soil depth.

Fig. 4. Root length density (RLD) and root distribution coefficient ($\beta$) for all soil profiles in relation to irrigation water salinity ($EC_{w}$) (* $P<0.05$; ** $P<0.01$; *** $P<0.001$; ns: not significant).

4. Discussion

4.1. Rose growth and plant water status

The vegetative and reproductive growths of rose plants were significantly reduced by increasing salinity of irrigation water. The data suggested that rose was sensitive to soil salinity. However, average $EC_{w}$ values during the 2 years were 4.5–5.2 dS/m (Table 3), which were higher than the threshold value for roses reported as 1–2.4 dS/m in soilless cultures and 1–3.5 dS/m in soil as calculated using flower characteristics (Cabrera and Perdomo, 2003; De Kreij and Berg, 1990; Feigin et al., 1989; Hughes and Hanan, 1978b; Ishida et al., 1979; Sonneveld et al., 1999; Yaron et al., 1969; Zeroni and Gale, 1989). The reason can be attributed to the different irrigation managements, growing medium properties and environmental factors. It is likely that environmental conditions such as temperature, light intensity, humidity, rainfall and wind speed considerably affect plant response to salinity (Niu et al., 2007; Zollinger et al., 2007). Thus salt tolerance threshold of plants differs in different cultural environments, and salt tolerance can be improved by creating a suitable environment.

There were significant differences in survival rates between both experimental years (Table 4). The average $EC_{w}$ values were 5–7 dS/m for S1–S5 in 0–40 cm soil profile in November 2012 (Table 3), and the corresponding values decreased to 2–4 dS/m in March 2013 (Table 3). Although soil salinity decreased for all treatments from the first year to the second, markedly decrease in survival rates with increasing salinity of irrigation water occurred in the spring of 2013. This suggested that rose was more sensitive to salt at emergence stages of growth. Similar results were obtained by Rhoades and Mashali (1992), who reported that plants were more sensitive during emergence and early stages of seedling growth.

In the current study, GR calculated from plant height and stem diameter increased with increasing salinity, indicating that salt stress had a greater negative effect on plant height than on stem diameter. This suggested that the saline water irrigation could also affect the plant shape, which plays an important role in landscape spatial structure.

Flower per plant was significantly reduced by salinity. Similar results were also found in other studies (Cai et al., 2014; Muhammad Jafar et al., 1991; Niu et al., 2013). The influence of
salinity on flowers was higher than that on vegetative growth, indicating that reduced reproductive growth may have important implications for the persistence of vegetative growth under continued saline irrigation (Rogers et al., 1994). Therefore, control of vegetative growth by pruning may be an effective measure to ensure relatively high production of rose flowers under saline irrigation.

Under our experimental conditions, irrigation with saline water had a negative effect on leaf water status: RWC decreased with increasingly saline water and RWD increased (Table 5). Although the average ECw values (2–4 dS/m) for S1–S5 in 0–40 cm soil profile in 2013 were lower than those (>7 dS/m) in 2012 (Table 3), both flowers per plant and leaf water status (RWC and RWD) were more closely related with ECw in 2013 (Table 5 and Figs. 1 and 2) than in 2012. The better relation between them was mainly related with the less rainfall and a lower SMP in 2013. Similar results were also found in wheat (Grewal, 2010). This suggested that water stress had a depressing effect on growth when subjected to different subsoil salinities.

### 4.2. Root characters and dry matter production

Salinity had severe detrimental effects on root growth and consequently affected water uptake, and finally the grain yield and water use efficiency (Grewal, 2010; Musacchi et al., 2006; Rogers et al., 1994). In the current study, the total root and fine root lengths decreased as salinity of irrigation water increased (Table 6), while coarse root length increased after an initial decrease (Table 6)—indicating that fine roots were more susceptible to salt injury than coarse roots. Similar results were reported by Musacchi et al. (2006) in pear and quince. In the present study, as the salinity level increased, RLD was reduced in the 0–20-cm soil layer and increased in the 20–50-cm except for the S5 treatment (Fig. 3a), while RLD for the whole soil profile was reduced when irrigated with saline water (Fig. 4). Chinese rose presented a different response against salinity than clover according to the comparison between our results and Roger’s (1994), in which white clover showed no difference in the pattern of root distribution between salinity levels or between cultivars at soil depths >15 cm.

Interestingly, most roots penetrated beyond 16–19 cm depth into the subsoil when irrigated with saline water of >3 dS/m (Fig. 3b), where the tensiometers were buried at a depth of 20 cm to control the SMP. This implied that it was effective to change the root dry matter distribution in soil layer by regulating the SMP through tensiometers when irrigating with saline water. Thus, in order to promote a concentration of roots in the top 0–20 cm of soil, a higher SMP should be applied, i.e., controlling the SMP at –5 to –10 kPa in the second year may be more profitable for irrigation with saline water of >3 dS/m in our experiment.

In this study although roots penetrated beyond the surface soil into the highly saline subsoil, there were no reductions in root growth—i.e., RLD in the 30–50-cm soil layer and percentage of root dry mass in the 20–50-cm (Fig. 3a and b)—instead, root growth in subsoil was promoted for S2–S4 treatments. Thus, the reductions

---

**Table 7**

| Treatments | Ca (mg) | | | K (mg) | | | Mg (mg) | | | Na (mg) | | | Cl (mg) | | |
|------------|--------|---|---|--------|---|---|--------|---|---|--------|---|---|--------|---|---|
|            | Leaves | Stems | Roots | Leaves | Stems | Roots | Leaves | Stems | Roots | Leaves | Stems | Roots | Leaves | Stems | Roots |
| S1         | 586.80 | 1342.38 | 140.72 | 745.22 | 2640.35 | 303.46 | 183.90 | 546.78 | 84.57 | 43.00 | 274.51 | 173.49 | 29.49 | 155.11 | 69.33 |
| S2         | 685.52 | 933.17 | 101.53 | 708.36 | 1233.93 | 246.23 | 196.64 | 356.57 | 62.87 | 40.66 | 184.29 | 157.17 | 35.79 | 180.29 | 55.06 |
| S3         | 370.88 | 613.52 | 75.11 | 398.70 | 729.61 | 135.56 | 106.24 | 253.25 | 44.56 | 36.55 | 189.51 | 111.14 | 22.09 | 98.54 | 40.73 |
| S4         | 674.03 | 511.04 | 74.35 | 706.43 | 514.16 | 130.28 | 204.90 | 154.73 | 48.32 | 80.89 | 175.10 | 117.04 | 42.54 | 105.42 | 35.02 |
| S5         | 356.68 | 544.77 | 74.55 | 344.98 | 482.53 | 108.28 | 103.22 | 219.14 | 42.48 | 65.37 | 177.77 | 103.03 | 19.14 | 59.31 | 33.45 |

---

**Fig. 5.** Ions concentration in roots, stems and leaves at the end of 2013 in relation to irrigation water salinity (ECw) (*P < 0.05; **P < 0.01; ***P < 0.001; ns: not significant).
in plant growth may be due to the absorption of excess ions from the high saline subsoil in the 30–50-cm soil layer where more root growth was observed when irrigated with saline water of <6.3 dS/m. For the S5 treatment, the decreased root growth may be attributed to the reduction in root growth in the entire soil profile and the excessive absorption of ions.

With increased salinity levels, β increased, further suggesting that rose plants were intolerant species and proportionately more deeply rooted when subjected to salinity (Gale and Grigal, 1987). However, β was reduced when irrigated with saline water of ≥6.75 dS/m (Fig. 4). This could be attributed to a significant reduction in root growth under higher salinity conditions, and was also consistent with the observed decrease in RLD in all soil layers when irrigated with saline water of 7.8 dS/m. Irrigation with increasing salinity caused plants to devote less dry matter to shoots and more to roots, resulting in an increasing root:shoot ratio with increasing salinity levels; however, there were no significant differences among the five treatments (Table 6).

4.3. Salt-sensitive indicators

Although there was a tendency for all organs to be affected by salinity, the various indicators responded differently when subjected to salinity. In the present study, reference ratio (RR: the reference value of plant indicators when irrigated with fresh water or low salinity water to the actual value of plant indicators at the given salinity level) was used to evaluate the effect of salinity on rose indicators. RWD was the most sensitive indicator, followed by flowers per plant, shoot dry weight and shoot fresh weight (data not shown). There was a highly significant exponential relationship between EC_{iw} and RWD or flowers per plant (data not shown). Using our previous finding that irrigation water salinity should not exceed 4.01 dS/m (Li et al., 2015), the RRs of RWD and flowers per plant should not exceed 1.68 and 0.48, respectively.

The advantages of using RWD and flowers per plant as indicators are non-destructive and non-invasive measurements easily to be determined using a light portable piece of equipment.

4.4. Ion concentrations, contents and selective ratios

Concentrations of Ca, Mg, Na and Cl were elevated in all organs of rose, while their contents in roots, stems and leaves (except for Na content of leaves) and total contents in the whole plant were significantly depressed by increasing salinity of irrigation water (data not shown). This implied that the detrimental effects on rose plant growth were mainly due to ion concentrations rather than contents. Munns et al. (1995) also reported that the plant growth reductions were mainly due to salt concentrations rising to toxic levels.

Most of the total Na and Cl amounts were present in roots and especially in stems, while only 8–21% was in leaves (Table 7). There were also higher Na and Cl concentrations in stems and especially in roots. The data suggested that the major strategy used to cope with salinity was to store most absorbed Na and Cl in the roots, followed by stems, thus avoiding excessive Na and Cl reaching the leaves—the organs most sensitive to salinity.

Leaf Cl and especially Na concentrations increased as salinity levels increased. Necrotic leaf tips and margins were observed at high salinity levels under our experimental conditions, probably due to accumulation of Cl and especially Na ions reaching toxic levels in leaf tissue (Grewal, 2010), although the concentrations in leaves were lower than those in stems and roots. This information is inconsistent with the finding by Cai et al. (2014) that leaf Cl and Na concentrations increased in six garden roses as salinity levels increased, but the concentration of Cl was much higher in leaves than that of Na. Our results also differed from those of other studies that found the scorching and salt burn damage in older foliage of roses receiving the highest salinity applications were due to Cl and not Na accumulation (Bernstein et al., 1972; Cabrera and Perdomo, 2003; Hughes and Hanan, 1978a; Yaron et al., 1969). In the present study, saline soil and saline water under field conditions were rich in other ions and these ions may regulate the uptake of Cl, further resulting in lower Cl concentrations in all plant organs; however, in other studies, roses were grown in solutions receiving NaCl as the sole salt and had lower levels of other nutrients. Thus adding nutrient elements could regulate the ion absorption of plant and reduce some ions below toxic levels.
K concentrations in roots decreased with increasing salinity levels, and especially in stems, but there were no adverse effects in leaf tissue, possibly because sampling occurred at the end of the growth season. The leaves with reduced K concentrations following salt stress had likely fallen off, and so there was no difference in K concentrations in those leaves remaining on plants. High K concentrations in tissues are associated with salt tolerance in many plant species (Grewal, 2010; Khatun and Flowers, 1995; Storey et al., 1993).

Increasing salinity of irrigation water was significantly related to linear declines in K/Na ratio, followed by Mg/Na and Ca/Na, especially in leaves. The low Ca/Na ratio plays a significant role in growth inhibition, in addition to causing significant changes in morphology and anatomy of plants (Ashraf, 2004). High K+/Na+ selectivity in plants under saline conditions has been suggested as an important selection criterion for salt tolerance (Ashraf, 2004), and has also been proposed as a physiological marker for the ion component of salt stress response (Muhling and Lauchli, 2002). Our experiment with roses indicated that salt sensitivity was associated with a decline in the K+/Na+ discrimination trait.

4.5. Correlation between dry matter production and ions

A significant accumulation of Na and reduction of K/Na ratio occurred in target organs such as leaves as salinity levels increased, which was considered a major sign of detrimental effects of salinity on roses. Rogers et al. (1994) reported that concentrations of Na and Cl in the shoots of white clover linearly increased with increasing soil ECe levels above 1 dS/m, and values were negatively related to shoot dry matter production. In the present study, K/Na ratio in stems had a slightly greater positive correlation with stem dry mass than the corresponding correlation in roots (Fig. 7a), and Na concentration in roots had a slightly greater negative correlation with root dry mass than the corresponding correlation in stems (Fig. 7c), while there was a low (although significant) correlation between leaf dry mass and Na concentration and/or K/Na ratio (Fig. 7a and c). This may be partially related to the loss of leaves observed in the experimental period due to injury from salt stress. Analyses on the combined root and stem datasets gave the best fit for linear relationships for root and stem dry mass with K/Na ratio in these organs ($R^2 = 0.9821$; Fig. 7b), while a power relationship gave the best fit for Na concentration ($R^2 = 0.9722$; Fig. 7d). These results suggested that effects determined by high Na concentration and low K/Na ratio were the major cause of declines in dry matter production. Unfortunately, the K/Na ratio in irrigation water or soil decreased with increasing salinity of irrigation water (data not shown), implying soluble potash is necessary for plants to improve the selective absorption ratio of K, to further enhance plants salt tolerance when irrigated with saline water.

5. Conclusions

An increase of irrigation water salinity resulted in adverse effects on rose growth, dry matter production, root distribution, plant water status, flower numbers and ion balance. Most roots penetrated beyond 16–19 cm depth and $\beta$ increased with salinity levels, suggesting that as a saline-intolerant species Chinese rose plants were proportionally more deeply rooted when subject to salinity. Controlling the SMP could be effective in promoting a concentration of roots in the top 0–20 cm depth (i.e., a low-salt environment) to adapt to salt stress. RWD was the most salt-sensitive indicator because it showed large differences among the different salinity treatments of irrigation water.

Chinese rose plants stored most absorbed Na and Cl in the roots, followed by stems, thus avoiding excessive amounts of Na and Cl reaching the leaves, which suggested a mechanism that prevented xylem loading and transporting to leaves. Ca, Mg and K concentrations were higher in leaves, followed by stems, and also suggested a mechanism to regulate ion balance in leaves and reduce damage from excess Na ions. However, leaf damage still occurred with higher salinity treatments due to large reductions in Ca/Na, Mg/Na and especially K/Na ratios in leaves. Na ions accumulated more in plant organs than Cl ions, indicating that other ions rich in saline soil and saline water under field conditions may regulate Cl uptake.
The increasing Na concentration and declining K/Na ratio had an adverse impact on dry matter production, implying soluble potash is necessary to enhance plants’ salt tolerance when irrigated with saline water.

The results of this study have important implications for planting Chinese rose in coastal regions soils of high ECe and SAR. Growing Chinese rose on these soils will be risky. However, irrigation with a combination of salt stress and MS may be a viable option. The results suggest that the potential of Chinese rose to withstand salinity and maintain a good yield is still promising. Further research is needed to optimize irrigation practices and fertilization strategies to improve the yield and quality of Chinese rose in saline environments.