# Ion Concentration Changes in Plants of Varying Tolerance under Saline Environment

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**ABSTRACT**

Two widely cultivated plant species (*Buddleja alternifolia* Maxim. and *Weigela florida* 'Red Prince') with different salinity tolerances were grown in coastal saline soils around Bohai Gulf, China, using drip irrigation at five levels of salinity: 0.8, 3.1, 4.7, 6.3, and 7.8 dS/m. The soil salinity (electrical conductivity of soil saturated extract, ECe), soil pH, plant survival rate, and ion concentration changes in plants were investigated. The results showed that a low soil salinity environment with ECe < 4 dS/m for all saline water treatments was quickly created and maintained especially in the root zone, which confirmed the effectiveness of drip irrigation in salt leaching. Liquid acid added with drip irrigation is proposed in the early reclamation period to avoid alkalization. Ion homeostasis differed with plant salinity tolerance, increasing of $K^+$, $Ca^{2+}/Na^+$, and $K^+/Na^+$ in plant tissues and decline of $Na^+$ in the leaf for *B. alternifolia* were correlated with higher survival rates compared with that of *W. florida* (Red Prince). Fertilization with $K^+$ and $Ca^{2+}$ was proposed to reduce the deleterious effects of salinity, especially for salt-sensitive plants. Irrigation water of salinity up to 7.8 and 3.1 dS/m could be applied in the field to *B. alternifolia* and cultivar Red Prince, respectively, while maintaining a >75% survival rate.

## Core Ideas

- Two widely cultivated plant species with different salinity tolerance were grown on coastal saline soils.
- Five levels of water salinity were set for reclamation of saline land using drip irrigation.
- Ion homeostasis in two plants organs differed with plant salinity tolerance.
- The threshold of water salinity for two plants was determined.

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SALINITY IS a major environmental factor limiting agricultural and vegetative ecological reconstruction, and it has received increasing attention around the world with the rising demand for food, a good living environment, and ecological landscapes (Meena et al., 2018). In coastal regions of China, soil salinity and saline groundwater are two major factors restricting crop production and especially vegetation construction with rapid industrialization and urbanization (Chen et al., 2015; Li et al., 2015). Saline soil reclamation methods and saline water irrigation thresholds have become a topic of interest to the Chinese government and scientists.

Crops and other plants are often affected by salinity, which can cause physiological drought due to a marked decline in soil water potential, or ionic poisoning caused by excessive accumulation of $Cl^-$ or $Na^+$ in organs, or nutrient imbalance caused by impaired uptake of some nutrients (Marschner, 1995; Musacchi et al., 2006). The role of individual ions in plant growth and the selectivity of their influx and accumulation under saline conditions have always been an area of research interest (Shuyskaya et al., 2017), and the functions of some ions and correlations with salinity tolerance have been defined. For example, $K^+$ is an essential nutrient supporting optimal growth, yield, and life cycle completion of plants (Aleman et al., 2011); $Ca^{2+}$ is considered an essential macro-element functioning as a secondary messenger of cyclic guanosine monophosphate pathway signaling (Shuyskaya et al., 2017). For salt-tolerant plants, it has been shown that $Na^+$ is removed from the cytoplasm more efficiently and the required $K^+$ concentration maintained compared to salt-intolerant plants. The $K^+/Na^+$ ratio has been used as a criterion for salinity tolerance and ion homeostasis of plants (Ma et al., 2012).

The availability and uptake of nutrients by plants in a saline environment are affected by many factors in the soil–plant environment, and plants also differ in the rate at which they absorb an available nutrient element, and in the manner by which they distribute nutrients within the plant (Grattan and Grieve, 1999; Meena et al., 2016b). Plants often experience deficiencies in growth and ion absorption, which can be attributed to plant type, plant tissue, salinity level and composition, micronutrient concentration, growing conditions, and the study duration (Grattan and Grieve, 1999). Many studies on crops or plants have been conducted regarding the response of ion absorption

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**Abbreviations:** ECe, electrical conductivity of soil saturated extract; ECiw, electrical conductivity of irrigation water; SMP, soil matric potential; SAR, sodium adsorption ratio.

Table 1. Soil mechanical composition, bulk density, electrical conductivity of saturated paste extracts ($EC_e$), pH of saturated paste (pHs), and sodium adsorption rate of saturated paste extracts (SAR) in initial soil.

| Soil depth | Soil mechanical composition | | | Soil texture | Bulk density | $EC_e$ | pHs | SAR |
|---|---|---|---|---|---|---|---|---|
| | <0.002 mm | 0.002–0.05 mm | 0.05–2 mm | | | | | |
| cm | % | | | | g/cm$^3$ | dS/m | | (mmol/L)$^{0.5}$ |
| 0–10 | 0.30 | 40.20 | 59.50 | Sandy loam | 1.29 | 27.55 | 7.93 | 52.34 |
| 10–20 | 0.51 | 43.68 | 55.91 | | 1.32 | 26.98 | 7.91 | 54.56 |
| 20–30 | 0.50 | 43.45 | 56.05 | | 1.41 | 28.56 | 8.04 | 55.23 |
| 30–40 | 0.50 | 41.32 | 58.18 | | 1.51 | 26.83 | 8.10 | 55.66 |
| 40–60 | 0.60 | 43.55 | 55.95 | | 1.66 | 27.45 | 7.88 | 53.87 |
| 60–100 | 0.50 | 43.82 | 53.68 | | 1.70 | 27.28 | 7.88 | 49.39 |
| 0–100 | 0.50 | 43.10 | 56.40 | | 1.57 | 27.39 | 7.93 | 52.31 |

to salinity in soil or irrigation water; but there is a dearth of information on the effects of salinity from both soil and irrigation water, especially in field conditions.

It is against this background that we have studied two widely cultivated plant species at different levels of salinity tolerance (*W. florida* cv. Red Prince and *B. alternifolia* Maxim.), which we grew on coastal saline soils using drip irrigation at five levels of salinity. The objectives of this study were to: (i) determine the effect of salinity on plant growth and ion concentration changes, and (ii) identify the regulatory mechanism based on ion concentration changes and the threshold of irrigation water salinity for plants.

## MATERIAL AND METHODS

### Site Description

A 2-yr field experiment was performed in the industrial area of Caofeidian district around Bohai Gulf in China. The plot was part of reclaimed land with a typical semi-humid monsoon climate. The soil was sandy loam and severely saline with electrical conductivity of soil saturated extract (ECe) > 26 dS/m in 0 to 100 cm of the soil profile. Soil characteristics before the experiment are shown in Table 1.

### Experimental Design

*Weigela florida* cv. Red Prince and *B. alternifolia* were tested because they differ in salinity tolerance and are widely cultivated in coastal land. They were planted in July 2013 at a spacing of 0.5 by 0.8 m in four rows on raised beds, with each plot measuring 3.0 by 3.0 m. Each plot consisted of four beds, with 0.8 m between the centers of two adjacent beds (Fig. 1). Each bed was 0.3 m wide and 3.0 m long. Each plant was transplanted into a pit with the depth of 15 cm and width of 20 cm and then non-saline sandy loam soil with ECe of 0.63 dS/m was placed in the space between the root ball and the saline soil (Fig. 1). The soil was made up of sand (52.23%), silt (42.37%), and clay (5.40%). The aim was to form a non-saline root environment for plant root growth during the early stages of salt leaching.

A layer of gravel (particle size 3–5 cm) with a bed of coarse sand (particle size 0.2–0.4 cm) underneath was created at a depth of 100 cm to break up the capillaries in the soil because the water table was shallow, varying in 1.2~1.5 m through the whole experimental period, and highly saline. Plastic tubing was placed at the edge of the low end of the gravel-sandy layer to discharge the leached saline water. The drainage surplus collected through plastic tubing was drained to escape canal and then flow into the sea, which could avoid contaminating the downstream soils. For the regions farther away from the sea, one pool was dug in a low-lying place to collect the drainage surplus and the salt water will be further treated in the future. A rotary tiller was used to break the large clod and lumps of oyster shell in the topmost layer to improve infiltration.

Irrigation water was composed by mixing fresh well water and highly saline shallow groundwater in different proportions, and five levels of salinity (ECiw) were used in the experiment: 0.8, 3.1, 4.7, 6.3, and 7.8 dS/m. Ionic composition of irrigation water was shown in Table 2. Each treatment has three replications in 15 plots and was laid out permanently following a completely randomized block design. Each treatment had a separate gravity-fed drip irrigation system consisting of a tank installed 0.8 m above the ground. Drip tubes with emitters every 20 cm along the length of the tubes were placed at the center of the beds (Fig. 1). A vacuum

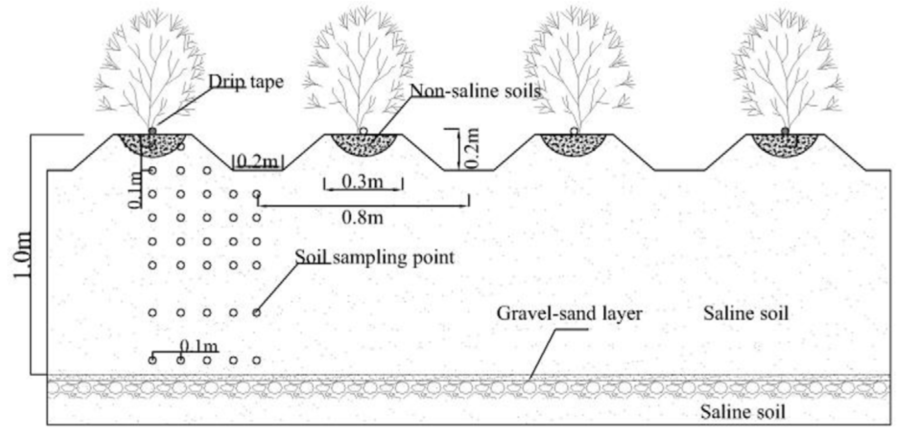

Fig. 1. Planting pattern and soil samplings distribution.

Table 2. Ionic composition of irrigation water

| ECiw† | Ionic concentration |  |  | $Mg^{2+}$ | $SO_4^{2-}$ | pH | SAR |
|---|---|---|---|---|---|---|---|
|  | $Na^+$ | $K^+$ | $Ca^{2+}$ |  |  |  |  |
| dS/m | ——— mmol/L ——— |  |  |  |  |  | $(mmol/L)^{0.5}$ |
| 0.8 | 11.88 | 0.35 | 1.35 | 0.41 | 0.17 | 8.92 | 8.95 |
| 3.1 | 25.07 | 0.52 | 2.50 | 2.10 | 2.51 | 8.67 | 11.69 |
| 4.7 | 35.72 | 0.74 | 3.72 | 3.39 | 4.22 | 8.66 | 13.39 |
| 6.3 | 48.61 | 1.04 | 3.89 | 5.39 | 6.21 | 8.59 | 15.96 |
| 7.8 | 59.79 | 1.25 | 5.46 | 6.68 | 8.13 | 8.50 | 17.16 |

† ECiw, electrical conductivity of irrigation water; SAR, sodium adsorption rate of saturated paste extracts.

gauge tensiometer was buried 20 cm directly below the emitter in each treatment to control the soil matric potential (SMP), and its readings recorded twice daily (at 0800 and 1800 h). Irrigation was started whenever the observed value exceeded the set value, which was –5 kPa in the first year and –10 kPa in the second year according to earlier studies (Sun et al., 2013). The amount of water for each round of irrigation in all treatments was 10 mm, which was determined according to the ability to retain moisture in the soil (soil water reserves) and the maximum daily evapotranspiration of plants in the local area. Irrigation with saline water was terminated from November, and 24 mm of irrigation with fresh water (0.8 dS/m) was applied for each treatment in winter. Irrigation with saline water was resumed in April, and before that the same quantity (24 mm) of fresh water was maintained to ensure adequate levels of moisture for fresh growth in spring.

### Observations and Measurements

The number of surviving plants for each plant species was monitored throughout the 2 yr for calculation of the survival rate. Precipitation was recorded using automatic weather stations (Vantage Pro2; Davis Instruments, Hayward, CA) and the total rainfall was 514.9 and 415.6 mm in 2013 and 2014 (Fig. 2), respectively. An auger was used to sample soil at the end of each year in each plot, and samples for each treatment were pooled to give one bulk sample per treatment. The distribution of sampling points is shown in Fig. 1.

All soil samples were air-dried and sieved (pore size 1 mm). Contents of soluble salts were estimated by the method of saturated extracts of soil in water. The ECe and pH were measured with a conductivity meter (DDS-11A; Rex, Shanghai, China) and a pH meter (PHS-3C; Rex), respectively, and the sodium adsorption ratio (SAR) of the saturated extract was calculated as described by Rhoades et al. (1992).

At the end of 2014, a standard plant (the growth of plant can represent the average level of the community in the plot) in each plot was sampled and divided into leaves and stems, and a dead plant was collected for treatments with survival rate of 0. A representative subsample of each plant organ after drying was ground in a mill (Retsch MM200; Retsch, Haan, Germany) to pass a 0.2-mm mesh, the three replicate samples were mixed into one sample per treatment, and then digested in concentrated nitric acid at 130°C for elemental analysis (i.e., $K^+$, $Ca^{2+}$, $Na^+$, $Mg^{2+}$, $S^{2-}$, and $Fe^{2+}$) using inductively coupled plasma spectrometry (Optima 5300DV, Perken, Elmer, MA).

### Statistical Analyses

All data were recorded and categorised using Excel (Microsoft Office 2007) and figures were created using Origin 8.0 (OriginLab, Northampton, MA). The average ECe values in the 0- to 35- and 0- to 100-cm layers of the soil were calculated using the weighted average method (Dou et al., 2011). Ionic ratios ($X/Na^+$) were calculated by dividing X concentration with $Na^+$ concentration.

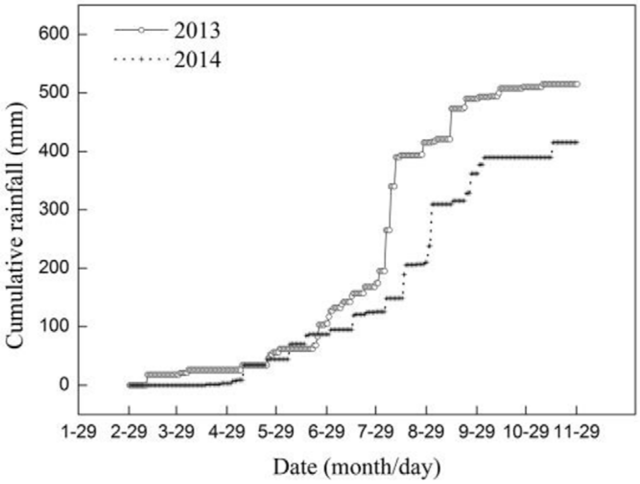

Fig. 2. The cumulative rainfall for the year of 2013–2014.

## RESULTS AND DISCUSSION

### Soil Salinity

The initial soil salinity was high, with average ECe of 27.70 and 27.39 dS/m in 0 to 35 and 0 to 100 cm soil, respectively. After 5 mo, the average ECe was 1.15 to 1.93 and 1.33 to 2.39 dS/m for *B. alternifolia* for five irrigation water salinity treatments in 0 to 35 and 0 to 100 cm soil (Fig. 3A), respectively; the corresponding values for *W. florida* cv. Red Prince were 0.89 to 1.70 and 1.18 to 2.62 dS/m (Fig. 3B). In the present study, it showed that soil salinity increased due to irrigation with saline water in shallow soil profiles, but with no significant trends in whole soil profiles (Fig. 3), which can be attributed to salt increasing with highly saline irrigation water. This influence was greater in shallow soil and weaker with depths, probably because soil salinity was characterized by spatial variability, which was even greater in the vertical dimension.

After 17 mo, the average ECe was 1.78 to 3.88 and 3.05 to 4.45 dS/m for *B. alternifolia* for the five irrigation water salinity treatments in 0 to 35 and 0 to 100 cm soil (Fig. 3C), respectively; with corresponding values for *W. florida* cv. Red Prince of 1.89 to 3.68 and 2.86 to 4.35 dS/m (Fig. 3D). Soil salinity changes showed similar trends with soil depth and the level of salinity of irrigation water. However, salt accumulated in the whole soil layer for all treatments at the end of 2014, likely because the lower threshold SMP of –10 kPa was applied, which led to weaker salt leaching compared to the threshold of –5 kPa. More importantly, the 415.6 mm of rainfall in 2014 was less than the 514.9 mm in 2013(Fig. 2), which meant less salt was removed through leaching. In addition, plants grew strongly and consumed more water in 2014, resulting in less water used for salt leaching (Li et al., 2016).

Salt leaching occurred at all depths for 0.8 to 7.8 dS/m levels of irrigation water salinity (Sun et al., 2013; Chen et al., 2015). The saline soil became less so (from 4 to 2 dS/m) or even non-saline (<2 dS/m) in all treatments after 5 mo of irrigation. Although rainfall significantly reduced and the threshold SMP

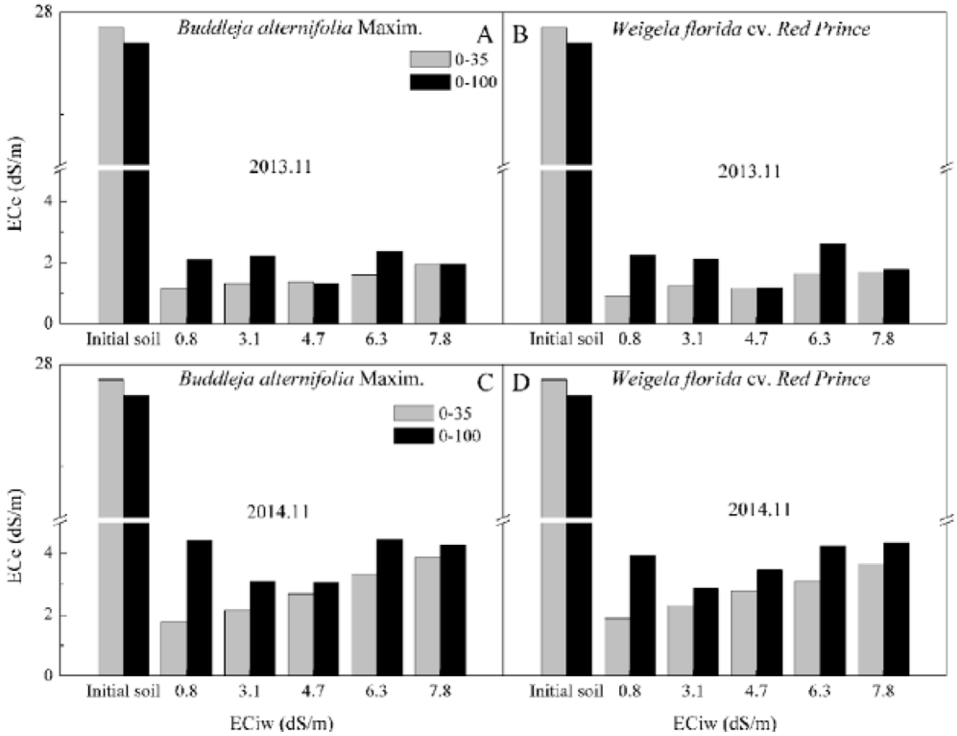

Fig. 3. The average electrical conductivity of soil saturated extract (ECe) values of 0- to 35- and 0- to 100-cm soil profile in (A) 2013.11 and (C) 2014.11 for *Buddleja alternifolia* Maxim., and in (B) 2013.11 and (D) 2014.11 for *Weigela florida* 'Red Prince'.

was lower in 2014, average ECe was <4.0 and <4.5 dS/m in the 0 to 35 and the 0 to 100 cm layer, respectively. A better salt leaching effect was obtained under drip irrigation even with saline water of 7.8 dS/m (Kang et al., 2012; Chen et al., 2015). In addition, due to the effects of the gravel–sandy layer and the enhanced soil infiltration capacity of the treated soil, the effect of rainfall on salt leaching is promoted and the rainfall greatly dilutes the salinity from soil and irrigation water, especially for the treatments with higher salinity irrigation water. In the present study, and lower levels of soil salt were quickly created and maintained, which was important for salinity sensitive plants cultivated in saline soils.

## Soil pH

The average pH was 7.96 and 7.93 in the 0 to 35 and 0 to 100 cm soil before planting shrubs. After 5 mo, average pH was 8.08 to 8.25 and 7.99 to 8.14 for *B. alternifolia* for the five irrigation water salinity treatments in 0 to 35 and 0 to 100 cm soil layers (Fig. 4A), respectively; and for *W. florida* cv. Red Prince was 8.01 to 8.31 and 8.02 to 8.16 (Fig. 4B). After 17 mo, average pH was 8.19 to 8.61 and 8.01 to 8.26 for *B. alternifolia* for the five irrigation water salinity treatments in 0 to 35 and 0 to 100 cm soil layers (Fig. 4C), respectively; values for *W. florida* cv. Red Prince were 8.18 to 8.54 and 8.14 to 8.27 (Fig. 4D).

This showed that soil pH increased with the time of drip irrigation, and an alkalizing phenomenon occurred for all treatments at the end of 2014. It was likely that the reduction in soil salinity and higher pH of irrigation water for the levels of 0.8 to 7.8 dS/m (with values all >8.5) affected the pH in the soil profile (Sun et al., 2012; Li et al., 2015). Interestingly, soil pH showed a decreasing trend with increasing salinity of irrigation water for both plants in all soil profiles at the end of 2014, and it may be affected by the pH of irrigation water as the irrigation water pH decreased from 8.92 to 8.50 with irrigation water salinity increasing from 0.8 to 7.8 dS/m (Meena et al., 2016a). Alkalization during the early period of salt leaching could affect the growth of acid-tolerant plants; however, with reclamation time, soil pH usually decreases and becomes stable, as shown by Sun et al. (2012) and Li et al. (2015). We suggest that liquid acid could be applied with drip irrigation to regulate soil alkalization, which will be important for acid-tolerant plant growth.

## Plant Survival Rate

Changes in the survival rates of the two shrubs following irrigation with saline water during 2013–2014 are shown in Fig. 5. The rates were all 100% for *B. alternifolia* irrigated with water salinity of 0.8 to 7.8 dS/m during 2013–2014 (Fig. 5A), confirming that *B. alternifolia* is salt tolerant, and is therefore widely cultivated in coastal saline regions. In the present study, survival rates of *W. florida* cv. Red Prince differed from that of *B. alternifolia*. Survival rates for all treatments in 2013 were >90%, but decreased obviously in 2014 with values declining from 100% to 0 as irrigation water salinity increased (Fig. 5B). The significant reduction in survival rate in 2014 was likely due to three reasons: first, a lower SMP was controlled in 2014, which means that water stress will enhance the salinity stress and have a depressing effect on plants (Li et al., 2015); second, non-saline soils were added in plant holes when planting to create a healthy root zone micro-environment, and as the plant grew, the roots extended into saline soils and subjected to the salinity stress due to low salinity tolerance of the plant, which also confirmed that *W. florida* cv. Red Prince was sensitive to salinity; third, it is reported that plants were more sensitive to salinity during emergence and early stage of seedling growth (Rhoades et al., 1992), and in this study, some plants died in the germination period in spring of 2014.

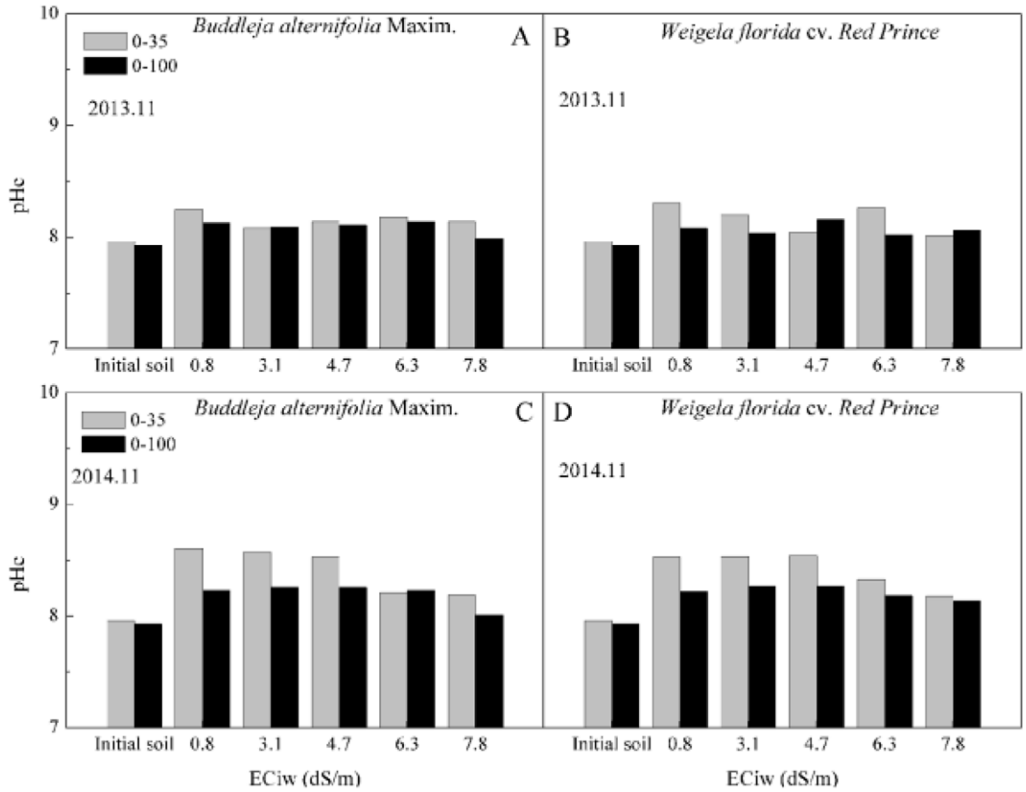

Fig. 4. The average pH of saturated paste extracts (pHe) values of 0- to 35- and 0- to 100-cm soil profile in (A) 2013.11 and (C) 2014.11 for *Buddleja alternifolia* Maxim., and in (B) 2013.11 and (D) 2014.11 for *Weigela florida* 'Red Prince'.

The response of the two plants to saline water irrigation showed that SMP above –5 kPa in the first year and –10 kPa in the second year, and 10 mm of irrigation water of salinity up to 7.8 dS/m, could be used for *B. alternifolia*, and up to 3.1 dS/m could be used for *W. florida* cv. Red Prince, while maintaining a >75% survival rate.

## Ion Changes

Salinity can induce elemental nutrient deficiencies or imbalances in plants. These specific effects vary among species and even among varieties of a given plant. Nutrient imbalances in the plant may result from the effects of salinity on nutrient availability, the uptake and/or distribution of a nutrient within the plant, and/or increasing the internal plant requirement for a nutrient element resulting from physiological inactivation (Wesley and Kenneth, 2011). Thus ions change and accumulation differed in plants with different salinity tolerances.

Ions concentrations in stem and leaf at the end of 2014 in relation to ECiw for *B. alternifolia* and *W. florida* cv. Red Prince are shown in Fig. 6. The $Ca^{2+}$, $Fe^{2+}$, $K^{+}$, $Mg^{2+}$, $Na^{+}$, and $S^{2-}$ all

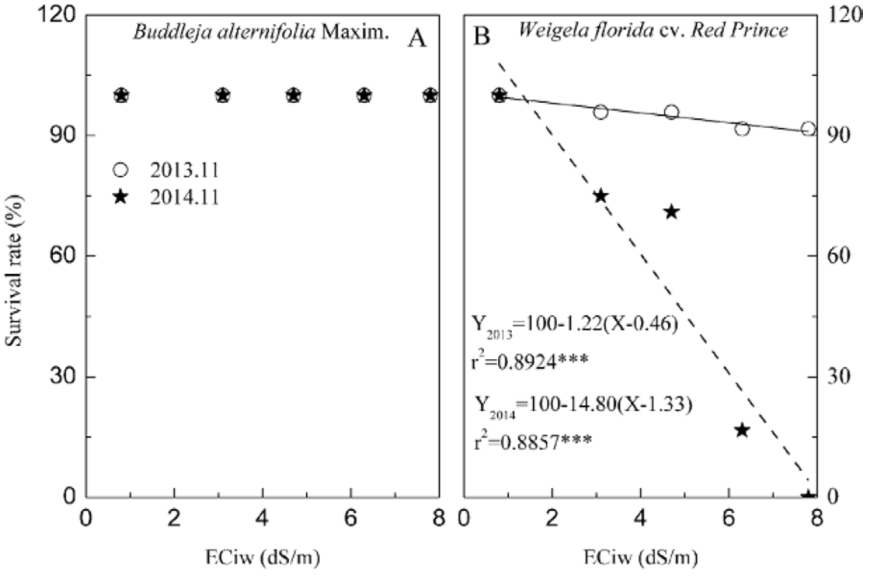

Fig. 5. The response of survival rates of 2013 and 2014 to electrical conductivity of irrigation water (ECiw) for (A) *Buddleja alternifolia* Maxim. and (B) *Weigela florida* 'Red Prince', ***$p < 0.001$

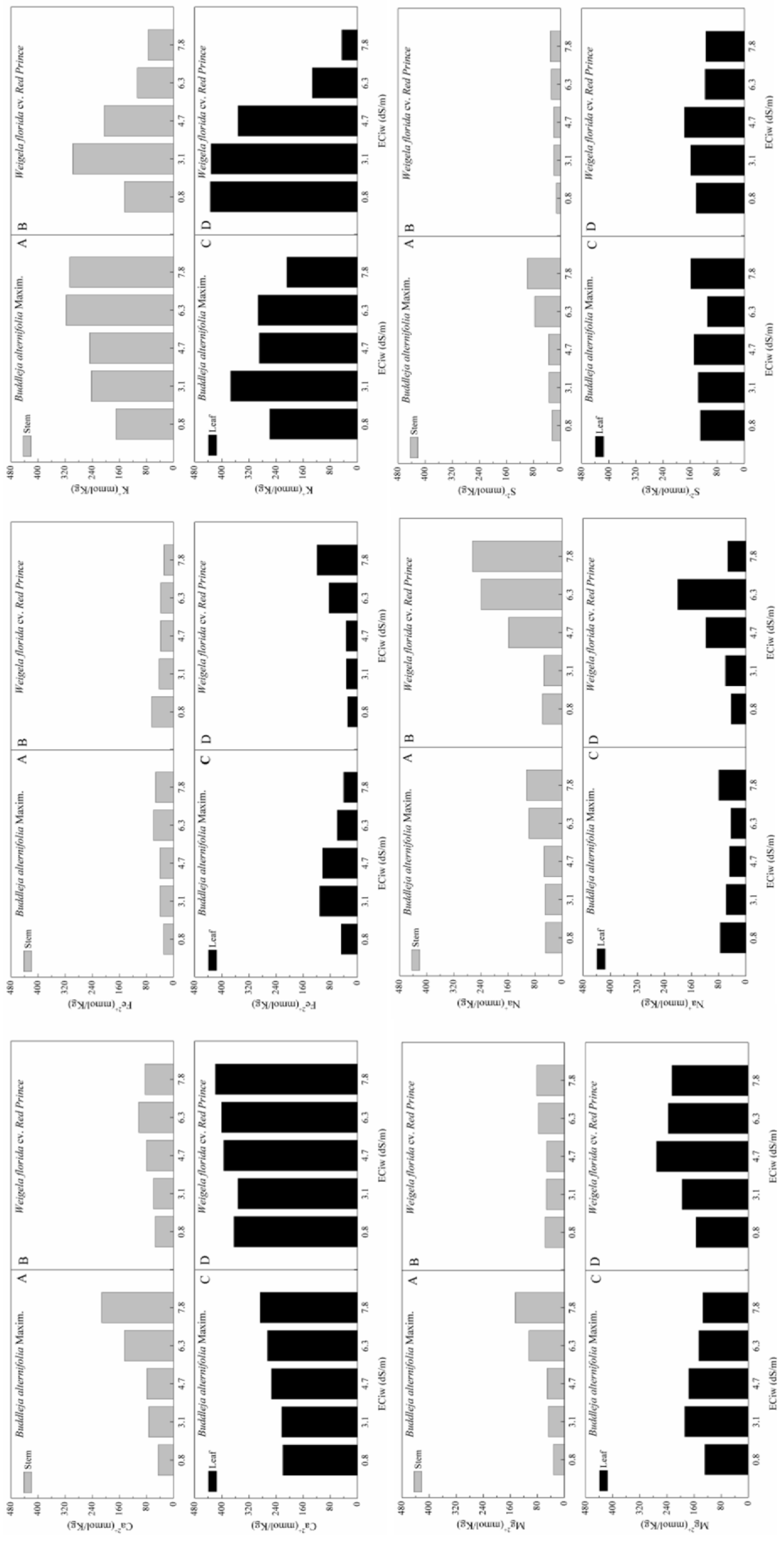

Fig. 6. Ions ($Ca^{2+}$, $Fe^{2+}$, $K^+$, $Mg^{2+}$, $Na^+$, $S^{2-}$) concentration in stem and leaf at the end of 2014 in relation to electrical conductivity of irrigation water (ECiw) for *Buddleja alternifolia* Maxim. and *Weigela florida* 'Red Prince'.

increased in the stem with rising salinity levels of irrigation water for *B. alternifolia*, but $Fe^{2+}$ and $K^+$ decreased for *W. florida* cv. Red Prince. It can be attributed to different salinity tolerance regulation mechanisms. The mobility of $Fe^{2+}$ is low in plants, and it is an essential element for the formation of chlorophyll; however, the role of $Fe^{2+}$ in the salinity tolerance mechanism is unknown, and the results of effects on $Fe^{2+}$ from salinity differed in plant types. For example, salinity increased the $Fe^{2+}$ concentration in shoots of pea (*Pisum sativum* L.) (*Dahiya* and *Singh*, 1976), tomato (*Lycopersicon esculentum* Mill.), soybean [*Glycine max* (L.) Merr.], and squash (*Cucurbita* spp.) (Mass et al., 1972), while decreased in concentration in shoots of barley (*Hordeum vulgare* L.) and corn (*Zea mays* L.) (*Hassan* et al., 1970). The $Fe^{2+}$ in stem increased for *B. alternifolia* with higher survival rates while decreased for *W. florida* cv. Red Prince with lower survival rates under salinity stress, which indicated that the absorption of $Fe^{2+}$ is a way to improve salinity tolerance for some shrubs.

Maintenance of adequate $K^+$ concentrations is essential for plant survival in saline habitats (Grattan and Grieve, 1999). Potassium is the most prominent inorganic plant solute, and makes a major contribution to the low osmotic potential in the stele of roots, which is a prerequisite for turgor-pressure-driven solute transport in the xylem and the water balance of plants (Marschner, 1995). Numerous studies have shown that high $K^+$ concentrations in tissues are associated with salinity tolerance in many plants (Khatun and Flowers, 1995; Grewal, 2010; Li et al., 2016). Thus, reduction in $K^+$ concentration in the stem, with increases in irrigation water salinity for *W. florida* cv. Red Prince, may be another reason for the lower survival rate, and further confirmed its lower salinity tolerance compared with *B. alternifolia*.

The macro-element $Ca^{2+}$ is an essential second messenger of cyclic guanosine monophosphate pathway signaling, which provides a

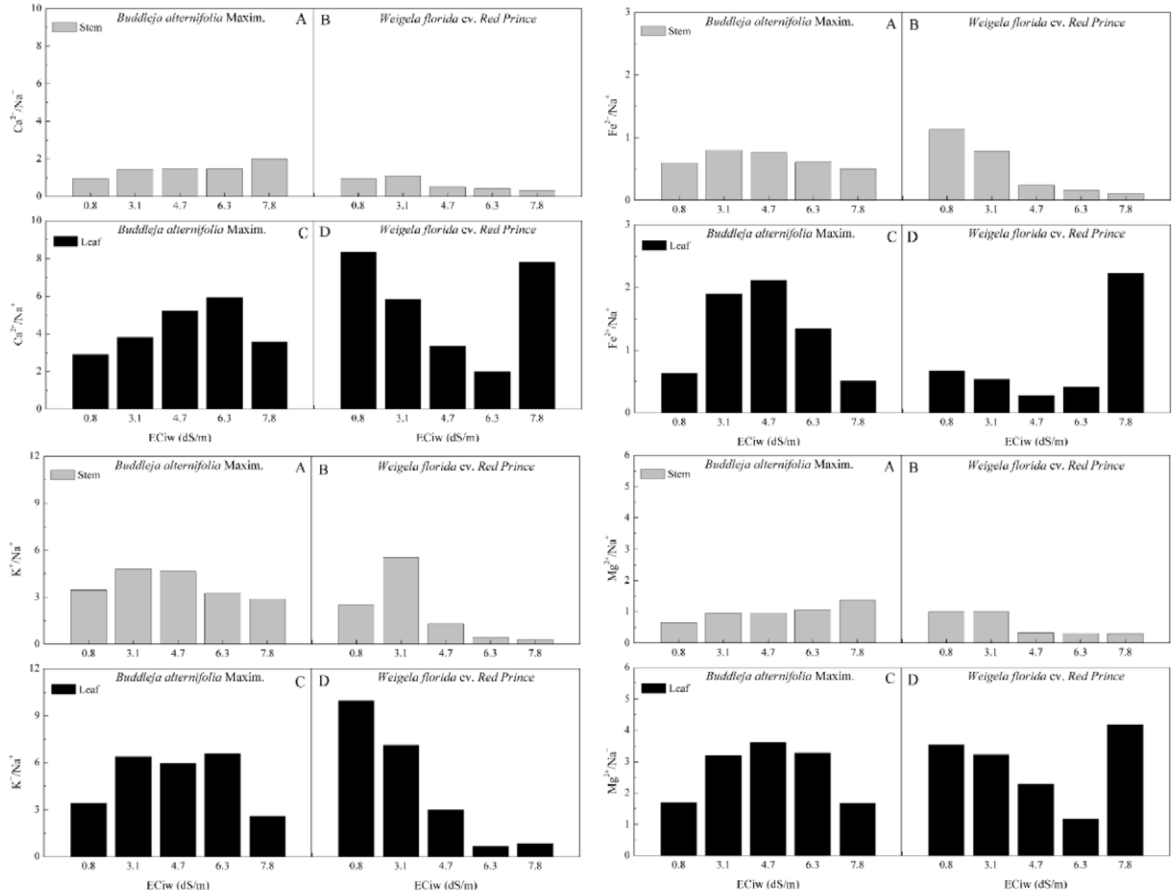

Fig. 7. The $Ca^{2+}/Na^+$, $Fe^{2+}/Na^+$, K+/$Na^+$, and $Mg^{2+}/Na^+$ ratios in stem and leaf in relation to electrical conductivity of irrigation water (ECiw) for *Buddleja alternifolia* Maxim. and *Weigela florida* ‘Red Prince’.

physiological response to a wide range of environmental impacts (Shuyskaya et al., 2017). It has been reported that $Ca^{2+}$ is involved in post-transcriptional regulation of $K^+$ transport systems (Aleman et al., 2011), and enhanced $Ca^{2+}$ levels have adverse effects on $K^+$ absorption (Grattan and Grieve, 1999). In the present study, $Ca^{2+}$ concentration values for *B. alternifolia* were 145.16 and 211.93 mmol/kg in the stem with ECiw of 6.3 and 7.8 dS/m, which were higher than that in *W. florida* cv. Red Prince with values of 102.46 and 84.11 mmol/kg. This may have induced the increasing $K^+$ concentration for *B. alternifolia* and could be considered a mechanism of salinity tolerance. In this study, salinity tolerance appeared to be related to higher $Ca^{2+}$ and especially $K^+$ concentration in tissues of *B. alternifolia*, implying that $K^+$ and $Ca^{2+}$ fertilization may reduce the deleterious effects of salinity (*Li* et al., 2016), but this may also differ by plant species.

Ion concentration changes in the leaf with increasing water salinity differed with that in the stem. Only $Ca^{2+}$ and $S^{2-}$ concentrations rose with increasing saline water for *B. alternifolia*; and $Fe^{2+}$, $K^+$, and $Mg^{2+}$ initially increased and then decreased. It indicated that ions regulation and balances occurred in different plant tissues, and the ions were redistributed due to different tissues functions. The $Na^+$ decreased with increasing water salinity except for at 7.8 dS/m treatment. This was mainly due to that $Na^+$ accumulated in stem rather than in leaf with increase in salinity level for the salinity tolerance plant, which could effectively alleviate the toxic of $Na^+$ on leaves (Wesley and Kenneth, 2011). The reduction of $Na^+$ may be the reason of the decrease in $Fe^{2+}$, and $Mg^{2+}$, especially $K^+$, because $K^+$ could regulate the effects of $Na^+$ in stem. As the $Na^+$ declined, the $K^+$ also decreased. For cultivar Red Prince under saline irrigation, $Ca^{2+}$ and $Fe^{2+}$ increased; $Mg^{2+}$, $Na^+$, and $S^{2-}$ initially increased and then decreased; and $K^+$ decreased. Similar increasing trends for $Na^+$ occurred in stems for both shrubs, but with higher values when ECiw > 4.7 dS/m for *W. florida* cv. Red Prince than for *B. alternifolia*. Interestingly, $Na^+$ in leaves decreased with increasing salinity of irrigation water for *B. alternifolia* except for at 7.8 dS/m (possibly caused by higher salt stress), while it increased for *W. florida* cv. Red Prince except for at 7.8 dS/m (possibly due to sampling from dead plants, because the survival rate was 0 at the end of 2014). Reduced $Na^+$ concentration in the leaf and increased $K^+$ concentration in the stem with higher salinity irrigation for *B. alternifolia* was likely a kind of regulatory mechanism that correlated with salinity tolerance, which resulted in its higher survival rates. In contrast, increasing $Na^+$ concentration in leaf and especially in stem, and reduction of $K^+$ concentration in both stem and leaf, with higher ECiw for *W. florida* cv. Red Prince was likely the reason for its sensitivity to salinity and lower survival rate in 2014.

In the present study, increasing salinity of irrigation water was significantly related to declines in $Ca^{2+}/Na^+$, $Fe^{2+}/Na^+$, $K^+/Na^+$, and $Mg^{2+}/Na^+$ ratios in both leaf and stem for *W. florida* cv. Red Prince, except for some abnormal values at 7.8 dS/m irrigation (Fig. 7), likely caused by plant sampling problems. While obviously different changes were obtained for *B. alternifolia* as $Ca^{2+}/Na^+$, $Fe^{2+}/Na^+$, $K^+/Na^+$, and $Mg^{2+}/Na^+$, all showed a trend of initial increases followed by decreases in both the leaf and stem, except for $Ca^{2+}/Na^+$ and $Mg^{2+}/Na^+$ in the stem, which gradually increased (Fig. 7). The low $Ca^{2+}/Na^+$ ratio plays a significant role in growth inhibition, in addition to causing significant changes in morphology and anatomy of plants (Ashraf, 2004). The $K^+/Na^+$ ratio is used as a criterion for salinity tolerance and ion homeostasis of plants, and plant tolerance to salinity is correlated with the ability to maintain homeostasis between $Na^+$ and $K^+$. In the present study, the $Ca^{2+}/Na^+$ and $K^+/Na^+$ ratios decreased in tissues of *W. florida* cv. Red Prince and initially increased and then decreased for *B. alternifolia*, further indicating that ion homeostasis differed with the different salinity tolerance of plants and was closely related to plant salinity tolerance.

## CONCLUSIONS

A low soil salinity environment was created and maintained, especially in the root zone, by the method of water–salt regulation using drip irrigation with saline water for the reclamation of coastal saline soils. Soil pH increased first, resulting in alkalization in the early period of salt leaching. Thus, liquid acid added with drip irrigation is suggested to reduce soil alkalinity, which is essential for acid-tolerant plant growth. The high survival rate of *B. alternifolia* indicated that the plant was a salinity-tolerance plant, which may be related to the increase in $K^+$, $Ca^{2+}/Na^+$, and $K^+/Na^+$ in plant tissues. Therefore, $K^+$ and $Ca^{2+}$ fertilization can be suggested to improve the plant salinity tolerance, especially for salt-sensitive plants.

Irrigation water of salinity up to 7.8 and 3.1 dS/m could be applied to *B. alternifolia* and *W. florida* cv. Red Prince, respectively, while maintaining a >75% survival rate. So the regulatory method by controlling the SMP at 20-cm depth under the emitter combined with saline water drip irrigation can be widely applied for the re-vegetation in coastal saline wasteland, as long as suitable irrigation water salinity was scheduled according to the plant salt tolerance.

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