Effects of Uneven Vertical Distribution of Soil Salinity on Blossom-end Rot of Tomato Fruit

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Abstract. Soil salinity influences plant growth and crop yield significantly. Former studies indicated that uneven salt distribution in the root zone could relieve salt stress. But, how uneven salt distribution influences Na+ and Ca2+ concentration in the stem, leaf, and fruit and whether this influence would bring effects on fruit blossom-end rot (BER) still needs to be further studied. Under consideration of this, pot experiment with four treatments, T1:1, T1:5, T2:4, and T3:3, was conducted by setting the upper soil layer salinity at 1‰, 5‰, 2‰, and 3‰, and the lower soil layer at salinities of 1‰, 5‰, 4‰, and 3‰, respectively. Compared with the uniform salt concentration in the root zone (T3:3 treatment), the incidence of BER in the T1:5 and T2:4 treatments decreased by 60% and 35%, respectively. The fruit Na+ concentration and Na+/Ca2+ ratio were positively correlated with the incidence of BER. The value of the upper-root selective absorption Ca2+ over Na+ (SCa/Na(upper root)) for T1:5 was 0.8 times more than that of T1:1. The results showed that the incidence of BER was positively correlated with root dry matter and SCa/Na(upper root) weighted mean salinity. The overall results suggested that uneven salt distribution in the root zone could promote the Ca2+ absorption, Ca2+/Na+ ratio, and selective absorption Ca2+ over Na+ and consequently decrease the incidence of BER in tomato fruit.

Salt stress adversely affects plant growth and causes 7% decrease in crop yield all over the world (Latef and Chaoxing, 2011; Maggio et al., 2004). Plants suffer from salt stress in the following ways: 1) the decrease in the osmotic potential in the rooting medium makes it difficult for roots to absorb water, 2) the toxic effect of a high concentration of Na+ triggers a series of toxicity events and causes damage to the systems that absorb and use Ca2+ ion, and it negatively affects crop growth and development, because Ca2+ is essential for various physiological and biochemical processes (Ebrahimi and Bhatla, 2012; Gama et al., 2007; Hilge, 2012; Munns and Tester, 2008). Furthermore, a high rate of BER occurrence has been associated with a low Ca2+ concentration in the fruit tissue (Ho and White, 2005).

Overirrigation with fresh or brackish water before planting is a common practice for growing crops in areas with high salinity (Dong et al., 2010). Using this approach, excessive irrigation reduces the surface soil salinity to maintain plant growth. However, this method does not always work because salts will move upward by capillary rise in response to higher potential evapotranspiration and accumulate near the soil surface (Imada et al., 2015; Rengasamy, 2006; Salama et al., 1999). To solve this problem, a capillary barrier (CB) is often chosen to prevent salt accumulation in the surface soil layer, which is a phenomenon of hydraulic for disrupted capillary water continuity (Ityel et al., 2014). Rooney et al. (1998) found a decrease of 66% in capillary water moving upward, which led to a lesser soil salt content in the surface by using a CB above the shallow groundwater table. When compared with the treatment without a CB, Ityel et al. (2012) found that the buried isolation layer could lead to a 24% increase in yield of pepper plants. In addition, recent studies indicated that root of plants could easily penetrate through the isolation layer if it was designed properly (Chen et al., 2016; Dara et al., 2015). Under CB conditions, soil salt always moves downward with water (Zhao et al., 2014, 2016). Once the root penetrates through the layer, the distinct salt concentrations for the upper and lower soil layers could result in the vertical heterogeneous distribution of salinity in the root environment (Qiao et al., 2006; Zhang et al., 2010). The results of former researchers had indicated that when compared with uniform salinity, an unequal salt distribution in the soil would improve the growth of oranges (Zeki and Parsons, 1990), cucumbers (Sonneveld and de Kreij, 1999), tomatoes (Tabatabaie et al., 2004), and Atriplex nummularia (Bazihizina et al., 2009). Our former study also showed that an uneven salt distribution in the soil could enhance the growth of tomatoes (Chen et al., 2016). Recent studies of Dong et al. (2008, 2010) showed that under plastic mulching, furrow seeding could increase the cotton yield in saline environments because this method resulted in an unequal salt distribution in the root zone. Previous studies mainly focused on the responses of plants to the horizontal uneven salt distribution in the root zone (Bazihizina et al., 2009; Dong et al., 2008; Kong et al., 2011), whereas there have been few studies on the vertical uneven salt distribution (Bazihizina et al., 2012b; Bingham and Garber, 1970), which was presumably because of difficulties in applying and maintaining the treatments.

The cultivated areas for tomatoes (Solanum lycopersicum L.) have increased significantly across the globe, and greenhouse cultivation has become economically important (He et al., 2007). Tomato is one of the most commonly cultivated crops in saline areas, and it is moderately tolerant of salinity (1.3 D·m⁻¹ < EC of the saturated soil extract < 6.0 D·m⁻¹) (Amjad et al., 2014; Cuartero and Fernández-Munoz, 1998; Lu et al., 2010). Several studies have focused on the effects of salt stress on the growth and yield of tomato plants. Above an EC of 2.5 D·m⁻¹, a 10% yield decrease per additional D·m⁻¹ was obtained (Bazihizina et al., 2012a). As one of the most important physiological disorders of tomato fruit, BER may reduce the marketable yield by up to 50% and influence the farmer’s income (Taylor et al., 2004). Researchers have found that high salinity would increase the incidence of BER (Abdul and Suleiman, 2004; Reina-Sanchez et al., 2005), which was generally believed to result from plasma membrane breakdown in response to a low calcium
concentration in the fruit tissue (Ho and White, 2005). Soil salinity will make negative effects on the fruit Ca\(^{2+}\) absorption and concentration, whereas Ca\(^{2+}\) is essential for proper membrane function (Abdul and Suleiman, 2004; de Freitas et al., 2011; Suzuki et al., 2003). It has also been shown that the Ca\(^{2+}\) accumulation in fruit was significantly connected to the amount of absorbed water and the transpiration of plants (Keiser and Mullen, 1993; Sun et al., 2013). On the other hand, Na\(^+\) toxicity would damage the Ca\(^{2+}\) absorption and utilization systems. Bazhihiza et al. (2009) and Flores et al. (2002) found that when plant roots were subjected to an unequal salt distribution, the water absorption of the whole plant was higher than when the roots were subjected to uniform salinity and a compensatory increase in water uptake through the untreated part of the plant was observed. In addition, plant sodium content was usually lower in nonuniform treatments when compared with a uniform soil salt distribution (Bazhihiza et al., 2009; Dong et al., 2010). We assumed that the above effects, which were brought on by nonuniform salinity, would promote plant Ca\(^{2+}\) absorption and concentration.

Based on the theoretical understanding of plant responding to uneven salt stress in the root -zone, we hypothesized that 1) an unequal salt distribution in the vertical direction could promote plant Ca\(^{2+}\) absorption, 2) the selective absorption of Ca\(^{2+}\) over Na\(^+\) (S\(_{Na/Ca}\)) might affect the ion concentration, and the incidence of BER in tomatoes, the values of root dry matter and selective uptake of Ca\(^{2+}\) over Na\(^+\) weighted mean salinity (RSWMS) were also taken into consideration when the relationship between fruit BER and the soil salinity were analyzed.

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**Materials and Methods**

**Growing conditions**

This experiment was conducted from April to June 2014 in a greenhouse located at the Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Nanjing, Jiangsu Province, Southern China. The polyethylene pots having a height of 42 cm, upper and lower diameters of 30 and 25 cm, respectively, were used for the experiment. A type of sandy soil with two different salt contents (0.94% and 6.22%, respectively) was collected from the coastal area of Dongtai, Jiangsu Province. For the salt distribution in the upper and lower soil layers, which were chosen for continuously monitoring volumetric soil water content (\(\theta_s\)). Water consumption was calculated from \(\theta_s\), and the volume of the soil, \(\theta_v\), was kept around 50% of the water-holding capacity (\(\theta_h\)) from transplanting to 26 d after transplanting (DAT). From 27 DAT to the end of the experiment, the lower and upper limit of \(\theta_s\) in each pot was set to 60% of \(\theta_h\) and 80% of \(\theta_h\), respectively.

**Fruit BER**

Tomato plants were harvested on June 15. The number and fresh weight of normal or BER fruit were measured from four samples of each treatment, respectively. Incidence of BER and BER fruit fresh yield (BER FY) percentage were calculated as:

\[
\text{Incidence of BER} = \frac{n_1}{n_1 + n_2} \tag{1}
\]

\[
\text{BER FY percentage} = \frac{y_1}{y_1 + y_2} \tag{2}
\]

where, \(n_1\) and \(y_1\) represents the number and fresh weight of BER fruit, respectively, and \(n_2\) and \(y_2\) represents the number and the fresh weight of non-BER fruit, respectively.

**Dry biomass of plant organs.** After washing carefully with tap water, root systems in upper and lower soil layers were collected, and the aboveground part was also separated into stems, leaves, and fruits. Dry biomass of plant samples was determined after oven drying the samples at 70°C until they reached a constant weight.

**Na\(^+\) and Ca\(^{2+}\) concentrations in organs and soil.** After drying the samples, organs
were grinded to pass through a 2-mm sieve. After 1 g of dried samples was digested with nitric acid and perchloric acid, the solution was diluted with deionized water to 100 mL. Soil samples were taken from the gap of the root, after air-drying the samples, soil was grinded to pass through a 1-mm sieve, and 2 g of soil were mixed with 10 mL of demonized water. Na⁺ and Ca²⁺ concentrations in organs and soil were measured using inductively coupled plasma optical emission spectrometry (ICP-OES, 710 Series; Agilent Technologies).

Selective uptake of Ca²⁺ over Na⁺. According to Pitman (1982), the selective uptake of Ca²⁺ over Na⁺ in the upper roots, lower roots, stem, fruits, and leaves was calculated as

| Treatment | Upper soil layer | Lower soil layer | Whole soil layer |
|-----------|-----------------|-----------------|-----------------|
|           | Root dry matter (g) | Water consumption (L) | Root dry matter (g) | Water consumption (L) | Root dry matter (g) | Water consumption (L) |
| T1:1      | 5.78 ± 0.94 ab   | 18.58 ± 0.38 b   | 4.23 ± 0.95 a    | 15.39 ± 0.52 a    | 10.01 ± 1.73 a    | 33.97 ± 0.22 a   |
| T1:5      | 6.93 ± 1.30 a    | 25.18 ± 0.33 a   | 1.65 ± 0.41 b    | 8.44 ± 0.12 c    | 8.57 ± 1.49 ab   | 33.62 ± 0.23 a   |
| T2:4      | 7.44 ± 1.20 a    | 16.11 ± 0.18 c   | 2.64 ± 0.55 b    | 7.86 ± 0.24 d    | 10.08 ± 1.73 a   | 23.97 ± 0.34 b   |
| T3:3      | 4.82 ± 1.26 b    | 12.38 ± 0.47 d   | 1.71 ± 0.65 b    | 10.57 ± 0.34 b   | 6.53 ± 1.71 b    | 22.94 ± 0.66 c   |

The treatment symbols T1:1, T1:5, T2:4, and T3:3 represent the soil salt content of the upper and lower layers at the initiation of the treatment, which were 1% and 1%, 1% and 5%, 2% and 4%, and 3% and 3%, respectively. The data are mean ± sd (n = 4). Values followed by different superscript letters within a row are significantly different at 5% according to Duncan’s multiple range tests, whereas the lowercase letters indicate P < 0.05, and uppercase letters indicate a P < 0.01.
The selective uptake of Ca$^{2+}$ over Na$^+$ from the roots, stems, fruits, and leaves, respectively; Na$^{\text{lower-root}}$, Na$^{\text{stem}}$, Na$^{\text{fruit}}$, and Na$^{\text{leaf}}$ represent the Na$^+$ concentrations of the upper layer soil, lower soil layer, upper roots, lower roots, stems, fruits, and leaves, respectively; Na$^{\text{upper-root}}$, Na$^{\text{upper-soil}}$, Na$^{\text{stem}}$, Na$^{\text{fruit}}$, and Na$^{\text{leaf}}$ represent the Na$^+$ concentrations of the upper layer soil, lower soil layer, upper roots, lower roots, stems, fruits, and leaves, respectively.

Different forms to represent heterogeneous salinity in the root zone. Surface salinity and the highest salinity (HS) were the upper and lower layer soil salt content, respectively. Arithmetic mean salinity (AMS) was calculated as the average of the upper and lower soil salt content. Refer to Minhas and Gupta (1993), RWMS was calculated as:

$$\text{RWMS} = \frac{r_1 \times S_{Ca/Na}^1 + r_2 \times S_{Ca/Na}^2}{r_1 + r_2}$$

where $r_1$ and $r_2$ are the dry weights of the upper and lower roots, respectively, $S_{Ca/Na}^1$ and $S_{Ca/Na}^2$ is the selective uptake of Ca$^{2+}$ over Na$^+$ from the soil in upper and lower roots, respectively, and $S_{Ca/Na}^1$ and $S_{Ca/Na}^2$ are the salt contents of the upper and lower soil layers, respectively.

### Statistical analysis

One-way analysis of variance was performed using the general linear model-univariate procedure with SPSS 13.0 software (SPSS, Chicago, IL). The mean values of each treatment were compared using Duncan’s multiple range test at $P < 0.05$. Linear regression was also carried out in SPSS.

### Results

As shown in Table 1, when compared with T$_{3:3}$ (4.82 g), the upper-root dry matter of T$_{1:5}$ (6.93 g) and T$_{2:4}$ (7.44 g) was significantly higher. For the root dry matter of the lower layer, no difference was found between T$_{1:5}$, T$_{2:4}$, and T$_{3:3}$, whereas all of them were significantly lower compared with T$_{1:1}$. Water consumption of the upper soil layer significantly decreased from 25.18 L (T$_{1:5}$) to 18.58 L (T$_{1:1}$), 16.11 L (T$_{2:4}$), and 12.38 L (T$_{3:3}$), respectively. The water consumption of the lower layer in T$_{1:1}$ was 15.39 L, which was significantly higher compared with the other three treatments. When considering the whole root zone, T$_{1:1}$ and T$_{1:5}$ consumed significantly more water compared with T$_{2:4}$ and T$_{3:3}$.

BER fruit number (A), non-BER fruit number (B), incidence of BER (C), BER fresh yield (D), non-BER fresh yield (E), and BER FY percentage (F) are shown in Fig. 1. When soil salt was equally distributed, with an increase in the average salt concentration in the whole soil profile, the average number and fresh yield of BER fruit dramatically increased from 0.25 and 8.42 g of T$_{1:1}$ to 4.00 and 145.40 g of T$_{3:3}$. Similarly, the incidence of BER and BER FY percentage significantly increased from 1.79% and 17.00% of T$_{1:1}$ to 35.24% and 39.12% of T$_{3:3}$, respectively. As shown in Fig. 1, the incidence of BER and BER FY percentage of T$_{1:5}$ was 14.24% and 20.91%, respectively, and those percentages were significantly lower as compared with T$_{3:3}$.

Na$^+$ and Ca$^{2+}$ concentrations in different plant organs are shown in Fig. 2. The increase in salinity had a significant effect on plant Na$^+$ concentration. When soil salt increased from 1$\%$ of T$_{1:1}$ to 3$\%$ of T$_{3:3}$, the Na$^+$ concentrations in the stems, leaves, and fruits significantly increased from 0.108, 0.234, and 0.058 mm to 0.540, 1.308, and 0.168 mm, respectively. When the average salt content in the whole soil layer was similar, the Na$^+$ concentration in the above-ground parts decreased as the soil salt distribution diversity increased. The Na$^+$ concentrations in stems, leaves, and fruits for T$_{1:5}$ were 39%, 65%, and 69% of T$_{2:4}$, and 31%, 54%, and 58% of T$_{3:3}$, respectively, and the differences were significant. In addition, the unequal salt distribution had a significant effect on fruit Ca$^{2+}$ concentration with a 47.6% higher in T$_{1:5}$ than T$_{3:3}$. The upper root Ca$^{2+}$ concentration of T$_{1:1}$ and T$_{1:5}$ was higher compared with T$_{2:4}$ and T$_{3:3}$, whereas the lower roots of T$_{1:5}$ showed the lowest amounts among the treatments.

The correlation between Ca$^{2+}$ and Na$^+$ concentrations and incidence of BER were analyzed when the data from four different treatments were pooled in this experiment.
(Fig. 3). A significant negative relationship was found between the Ca\(^{2+}\) concentration and the incidence of BER \((P < 0.05)\). In addition, positive linear relationships between the incidence of BER and Na\(^+\) concentra-
tion and the Na\(^+/\)Ca\(^{2+}\) ratio were also found \((P < 0.01)\).

As shown in Table 2, the Ca\(^{2+}/\)Na\(^+\) of T1:5 in the upper root was the highest among the treatments, whereas the lower root parts showed the opposite trend. The Ca\(^{2+}/\)Na\(^+\) of the aboveground biomass decreased with the increase in average soil salinity, where the Ca\(^{2+}/\)Na\(^+\) of stems, leaves, and fruits of T1:1 showed the highest values among the treatment. When the average salt content in the soil profile was similar, unequal salt distribution for treatment T1:5 led to a significantly higher Ca\(^{2+}/\)Na\(^+\) in stems, leaves, and fruits when compared with T2:4 and T3:3.

As shown in Table 3, selective uptake of Ca\(^{2+}\) over Na\(^+\) \((\text{SCa/Na(Na)}\) in the upper roots of T1:5 was 82.7%, 72.0%, and 166.1% more than T1:1, T2:4, and T3:3, respectively, which suggested that the upper-root system of T1:5 suffered less salt stress compared with the other treatments. The opposite trend was observed in the lower-root system and S(Ca/Na(lower root)) of T1:5 significantly decreased to 42.76, whereas the values for T1:1, T2:4, and T3:3 were 85.56, 62.70, and 91.52, respectively.

As shown in Fig. 4, the correlation between incidence of BER and SS, RWMS, RSWMS was significant, and the highest correlation coefficient was found in RSWMS \((R^2 = 0.91)\). In addition, there was no significant relationship between the incidence of BER and AMS or the HS.

**Discussion**

Increased salinity will promote the occurrence of fruit BER (Van Ieperen, 1996). Reina-Sanchez et al. (2005) found the average number of BER fruits in four tomato cultivars increased with salinity changing from 2% in 0 mM Na\(^+\) conditions to 16% in 75 mM. In our study, under a homogeneous distribution of salt in the vertical direction of the root zone, the incidence of BER and the BER FY percentage of T1:2 showed a significantly increased with 42.76, whereas the values for T1:1, T2:4, and T3:3 were 85.56, 62.70, and 91.52, respectively.

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Table 2. Ca\(^{2+}/\)Na\(^+\) ratio of the upper root layer, lower root layer, stems, leaves, and fruits in T1:1, T1:5, T2:4, and T3:3.

| Treatment | Upper root Ca\(^{2+}/\)Na\(^+\) | Lower root Ca\(^{2+}/\)Na\(^+\) | Stem Ca\(^{2+}/\)Na\(^+\) | Leaf Ca\(^{2+}/\)Na\(^+\) | Fruit Ca\(^{2+}/\)Na\(^+\) |
|-----------|-------------------------------|-------------------------------|-----------------|-----------------|-----------------|
| T1:1      | 4.89 ± 1.60 b                 | 5.35 ± 1.35 ab                | 6.22 ± 0.81 a   | 12.33 ± 0.77 a  | 4.14 ± 0.48 a   |
| T1:5      | 8.93 ± 4.05 a                 | 2.67 ± 0.64 b                 | 3.22 ± 0.23 b   | 5.90 ± 0.81 b   | 1.53 ± 0.29 b   |
| T2:4      | 5.19 ± 1.91 b                 | 3.92 ± 1.15 bc                | 2.29 ± 0.42 c   | 5.02 ± 0.17 c   | 0.77 ± 0.13 c   |
| T3:3      | 3.36 ± 0.62 b                 | 5.72 ± 0.96 a                 | 1.47 ± 0.02 d   | 0.26 ± 0.01 c   | 0.63 ± 0.20 c   |

The treatment symbols T1:1, T1:5, T2:4, and T3:3 represent the soil salt contents of the upper and lower layers at the initiation of the treatment, which were 1\%\(_{\text{so}}\), 1\%\(_{\text{so}}\), 2\%\(_{\text{so}}\), and 3\%\(_{\text{so}}\), respectively. Data are the mean ± SD \((n = 4)\). Values followed by different superscript letters within a row are significantly different at 5% according to Duncan’s multiple range tests, whereas the lowercase letters mean \(P < 0.05\) and uppercase letters mean \(P < 0.01\).

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Table 3. Upper and lower root, stem, leaf, and fruit Ca\(^{2+}/\)Na\(^+\) selectively absorption.

| Treatment | S(Ca/Na(upper-root)) | S(Ca/Na(lower-root)) | S(Ca/Na(stem)) | S(Ca/Na(leaf)) | S(Ca/Na(fruit)) |
|-----------|----------------------|----------------------|----------------|---------------|----------------|
| T1:1      | 78.23 ± 25.52 b      | 85.56 ± 21.56 ab     | 1.42 ± 0.64 a  | 2.00 ± 0.18 a  | 0.68 ± 0.11 a   |
| T1:5      | 142.99 ± 64.86 a     | 42.76 ± 10.23 c      | 0.43 ± 0.21 b  | 1.83 ± 0.21 a  | 0.48 ± 0.11 b   |
| T2:4      | 83.11 ± 30.60 b      | 62.70 ± 18.36 bc     | 0.47 ± 0.17 b  | 0.25 ± 0.10 b  | 0.35 ± 0.09 b   |
| T3:3      | 53.73 ± 9.97 b       | 91.52 ± 15.35 a      | 0.45 ± 0.07 b  | 0.18 ± 0.01 b  | 0.43 ± 0.14 b   |

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Ca$^2+$ concentration in the fruit when the soil than the upper layer of T 3:3 (Table 1).

A significant negative correlation between fruit salt concentration and Na$^+$ concentration in the fruit, and there was a 32.2% reduction in the Ca$^2+$ concentration in tomato fruits.

The selective uptake of Ca$^2+$ over Na$^+$ (SCa/Na) of the upper roots, lower roots, stems, leaves, and fruit is shown in Table 3. SCa/Na of the upper roots for T 1:5 were significantly higher compared with T 3:3, whereas a significantly lower value of T 1:5 compared with T 3:3 were observed in the lower root parts. As shown in Table 3, SCa/Na decreased with the increase in salt concentration in the soil, and similar results were found by Pitman (1982) and Zheng et al. (2010). Interestingly, it was observed that the upper root SCa/Na for T 1:5 were 1.83 times higher than T 1:1, even though both soil layers contained a similar salt concentration. This phenomenon could be partially explained by the higher water consumption in the upper soil layer of T 1:5 compared with T 1:1 (Table 1) because Ca$^2+$ uptake was tightly linked with water movement (Keiser and Mullen, 1993).

On the other hand, we also speculated that the difference between SCa/Na (upper root) of T 1:1 and T 1:5 might be related to some internal mechanism, and this speculation needs to be further investigated in the future study.

A significant correlation was observed between fruit incidence of BER and SS in Fig. 4A ($R^2 = 0.82, P < 0.01$), and a similar result was obtained by Bernstein and Francois (1973), who indicated that the surface soil salinity was the key factor driving water consumption by the plants. On the other hand, Minhas and Gupta (1993) held the opinion that plant growth was affected by RWMS of the soil. Similarly, in the current study, it was inferred that the relationship between incidence of BER and RWMS was also significant ($R^2 = 0.654, P < 0.01$).

Interestingly, the relationship between the incidence of fruit BER and RWMS was closer than the other soil salinity indicators (Fig. 4, $R^2 = 0.91, P < 0.01$), which indicated that the RWMS might be a good indicator to represent the salinity stress degree in the root zone. A significant decrease in RWMS was also concluded when soil salinity changed from even distribution (T 1:3) to uneven distribution (T 1:5, $R^2 = 0.77, P < 0.01$). Negative effects induced by Na$^+$ on Ca$^2+$ uptake systems have long been recognized (Demidchik and Maathuis, 2007; Ebrahimi and Bhatla, 2012; Hilge, 2012). In this study, as shown in Fig. 2, Ca$^2+$ decreased with the increase in the Na$^+$ concentration in the fruit, and there was a significant negative correlation between fruit Na$^+$ and Ca$^2+$ concentration. Under the uniform distribution of salt in the root zone, with the increased salt concentration, the fruit Na$^+$ concentration increased from 0.058 mS m$^{-1}$ in T 1:1 to 0.164 mS m$^{-1}$ in T 3:3, whereas a 58.0% decrease was found in the fruit Ca$^2+$ concentration. Under the similar salt concentration in the whole soil profile, soil salt distribution also had a significant effect on the Na$^+$ and Ca$^2+$ concentration in the fruit when the soil salt content of the upper soil profile increased from 1% ($R^2 = 0.77, P < 0.01$) to 3% ($R^2 = 0.77, P < 0.01$).

Part when the other root system experienced to salinity. Thus, we believe that there may be other compensatory mechanism for water absorption in horizontal and vertical non-uniform salinity. The water consumption in the upper layer of T 1:5 was 103.3% higher than T 1:1, even though both soil layers contained a similar salt concentration. This phenomenon could be partially explained by the higher water consumption in the upper soil layer of T 1:5 compared with T 1:1 (Table 1) because Ca$^2+$ uptake was tightly linked with water movement (Keiser and Mullen, 1993). On the other hand, we also speculated that the difference between SCa/Na (upper root) of T 1:1 and T 1:5 might be related to some internal mechanism, and this speculation needs to be further investigated in the future study.

A significant correlation was observed between fruit incidence of BER and SS in Fig. 4A ($R^2 = 0.82, P < 0.01$), and a similar result was obtained by Bernstein and Francois (1973), who indicated that the surface soil salinity was the key factor driving water consumption by the plants. On the other hand, Minhas and Gupta (1993) held the opinion that plant growth was affected by RWMS of the soil. Similarly, in the current study, it was inferred that the relationship between incidence of BER and RWMS was also significant ($R^2 = 0.654, P < 0.01$).

Interestingly, the relationship between the incidence of fruit BER and RWMS was closer than the other soil salinity indicators (Fig. 4, $R^2 = 0.91, P < 0.01$), which indicated that the RWMS might be a good indicator to represent the salinity stress degree in the root zone. A significant decrease in RWMS was also concluded when soil salinity changed from even distribution (T 1:3) to uneven distribution (T 1:5, $R^2 = 0.77, P < 0.01$). Negative effects induced by Na$^+$ on Ca$^2+$ uptake systems have long been recognized (Demidchik and Maathuis, 2007; Ebrahimi and Bhatla, 2012; Hilge, 2012). In this study, as shown in Fig. 2, Ca$^2+$ decreased with the increase in the Na$^+$ concentration in the fruit, and there was a significant negative correlation between fruit Na$^+$ and Ca$^2+$ concentration. Under the uniform distribution of salt in the root zone, with the increased salt concentration, the fruit Na$^+$ concentration increased from 0.058 mS m$^{-1}$ in T 1:1 to 0.164 mS m$^{-1}$ in T 3:3, whereas a 58.0% decrease was found in the fruit Ca$^2+$ concentration. Under the similar salt concentration in the whole soil profile, soil salt distribution also had a significant effect on the Na$^+$ and Ca$^2+$ concentration in the fruit when the soil salt content of the upper soil profile increased from 1% ($R^2 = 0.77, P < 0.01$) to 3% ($R^2 = 0.77, P < 0.01$).

**Significance of lines at $P < 0.01$.**
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