Response of Hot Pepper Yield, Fruit Quality, and Fruit Ion Content to Irrigation Water Salinity and Leaching Fractions

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Abstract. It has been proved that irrigation with high saline water and leaching fraction (LF) affect crop yield, but the effects of irrigation water salinity (ECiw) and LF on fruit quality remain largely elusive. We therefore investigated the effects of ECiw and LF on the yield, fruit quality, and ion content of hot peppers. An experiment using irrigation water with five levels of salinity (ECiw of 0.9, 1.6, 2.7, 4.7, and 7.0 dS·m⁻¹) and two LFs (0.17 and 0.29) was conducted in a rain shelter. The experiment took the form of a completely randomized block design, and each treatment was replicated four times. We increased the salinity of the irrigation water by adding 1:1 milliequivalent concentrations of NaCl and CaCl₂ to a half-strength Hoagland solution. The plants were irrigated for 120% and 140% evapotranspiration, corresponding to an LF of 0.17 and 0.29. Results showed that the total fruit yield decreased significantly with an increase in the ECiw as a result of reduction both in the fresh weight of fruit and the number of fruit per plant. An increase in the ECiw also led to a decrease in the total dry biomass of fruit and plant, as well as decreasing water use efficiency (WUEF). Salinity reduced the appearance of the fruit by both decreasing the length (F₁) and maximum width (F₃M₃) of the fruit. However, increased ECiw also improved the taste of the hot peppers by increasing the total soluble solid (TSS) content, as well as adding to their nutritional quality with a higher content of Vitamin C (VC). Their storage quality was also improved because of an improvement in the firmness of the fruit (F₅) as well as a reduction in the fruit water content (F₅W). An increase in the LF led to an increase in the total fruit yield, total dry biomass of fruit and plant, and WUEF; it also increased the F₅M₃ and VC content, and decreased the F₃M₃ and fruit shape index (F₅S). The threshold-slope linear response and sigmoidal-sharp models were both a good fit for the measured total fruit yield, and the LF had no significant effect on the model parameters. The relative TSS and F₅ increased linearly as the electrical conductivity (EC) of soil-saturated paste extract (ECₑ) increased, whereas they decreased linearly as the relative seasonal evapotranspiration (ETₑ) increased regardless of the LFs. The relative F₅, F₁, and F₃M₃ decreased linearly with the increased ECₑ and increased linearly with the increased ETₑ, regardless of the LFs. The relative fruit Na⁺ concentration increased linearly as the ECₑ increased. The regression correlations between the total fruit yield, fruit quality parameters, ion contents, and ECₑ or ETₑ, could provide important information for salinity and irrigation water management with a compromise between the hot pepper yield and fruit quality.

In many parts of the world, saline water collected from field drainage has been successfully used for irrigation (Grattan et al., 1994). However, plants may suffer from osmotic stress, ionic imbalance, and the inhibition of nutrient absorption when irrigated with saline water, with an adverse effect on fruit yield (Ben-Gal et al., 2008; Munns, 2002). To alleviate the effects of salinity stress on plants, the application of extra water for the leaching of salts (e.g., Na⁺, Ca²⁺, and Mg²⁺) from the root zone is a common method of reducing the salt content in the surface soil (Chen et al., 2016). An appropriate LF will maintain tolerable root-zone salinity (Dudley et al., 2008), in turn, enhancing the fruit yield. peppers (Capsicum annuum L.) are considered moderately sensitive to salt stress (Rameshwaran et al., 2016). The threshold-slope linear response model (Maas and Hoffman, 1977) and the sigmoidal-sharp salinity response model (Van Genuchten and Hoffman, 1984) are commonly used to describe yield–salinity relationship. The LF may affect the yield of peppers, but whether the LF also has an effect on the parameters of these models is unclear.

Irrigation with saline water may in many cases improve fruit quality. The fruit quality parameters of tomatoes (Solanum lycopersicum L.) including total acidity, TSS, sugar content, pigment content, and organic acid content were improved by saline water irrigation (Gough and Hobson, 2015; Plaut and Yehezkel, 2004). It also improved the quality of the melons (Citrullus vulgaris L.) by increasing F₅, dry matter, acidity, TSS, and total sugar content (Colla et al., 2006; Navarro et al., 1999). For peppers, however, there is limited literature that is mainly concerned with sweet peppers or bell peppers, and it is not inconclusive. Navarro et al. (2010) and Rubio et al. (2009) found that irrigation with saline water (3.0 dS·m⁻¹ NaCl) had no effect on the TSS, F₅, and pH of sweet peppers. However, Navarro et al. (2002) found that saline water irrigation (from NaCl or Na₂SO₄) decreased the quality of sweet peppers by reducing pulp thickness, F₅, TSS, and fructose, glucose, and amino acid contents. On the other hand, saline water irrigation improved the fruit quality of bell peppers giving higher TSS, VC content (ascorbic acid), total sugar content, and acidity (Pattil et al., 2014), and improved the quality of sweet peppers causing a higher myoinositol, fructose, and glucose content (Rubio et al., 2009). The quantitative relationship between the fruit quality parameters of hot peppers and the ECₑ or evapotranspiration, which are useful relationship to know for the management of saline irrigation for high-quality hot pepper production, have not been documented. In addition, we studied Na⁺, K⁺, and Ca²⁺ concentrations and K⁺/Na⁺ ratio in hot peppers to further understand the mechanisms causing the effects of the ECₑ and LF on yield and quality.

The objectives of this study are 1) to assess the effects of ECₑ and LF on the yield, fruit quality, and ion content of hot peppers; 2) to study the responses of a total yield of hot peppers to salinity and to calibrate the yield indices of both a threshold-slope linear response model and sigmoidal-shape model; and 3) to establish the quantitative relationships between fruit quality, ion content, and ECₑ or seasonal evapotranspiration.

Materials and Methods

Experimental setup. The experiment was conducted from Apr. 28 to July 22, 2015, in a rain shelter at the Agro-Meteorology Research Station in Nanjing City, Jiangsu Province, China. The white plastic pots (top diameter 26 cm x bottom diameter 22 cm x height 27 cm), with a 2-cm hole in the bottom of each pot to allow for drainage were used. Each pot was filled with 11 kg of air-dried soil with a sandy loam texture sifted through a 5-mm sieve. The bulk density of the soil was 1.47 g·cm⁻³, the field water capacity was...
Table 1. Effects of irrigation water salinity (EC iw) and leaching fraction (LF) on yield parameters and water use efficiency (WUE F) of hot pepper using two-way analysis of variance (ANOVA).

| Factors  | Number of fruits per plant | Fresh fruit wt (g) | Total fruit yield (g/plant) | Total fruit dry biomass (g/plant) | Plant dry biomass (g/plant) | WUE F (kg·m⁻³) |
|----------|----------------------------|-------------------|-----------------------------|---------------------------------|---------------------------|----------------|
| EC iw (dS·m⁻¹) |                            |                   |                             |                                 |                           |                |
| 0.9      | 23.5 ab                    | 28.2 a            | 656.1 a                     | 48.5 a                          | 88.0 a                    | 26.1 a         |
| 1.6      | 21.0 ab                    | 27.9 a            | 577.7 b                     | 42.6 b                          | 80.5 b                    | 23.4 b         |
| 2.7      | 19.6 b                     | 24.6 b            | 481.9 c                     | 41.2 b                          | 72.5 c                    | 21.4 c         |
| 4.7      | 17.8 b                     | 21.8 c            | 385.3 d                     | 36.3 c                          | 62.6 d                    | 20.6 c         |
| 7.0      | 13.6 c                     | 19.1 c            | 257.3 e                     | 25.9 d                          | 44.1 e                    | 15.4 d         |
| LF       |                            |                   |                             |                                 |                           |                |
| 0.17     | 18.4                       | 24.0              | 449.2 b                     | 37.2 b                          | 66.3 b                    | 20.9 b         |
| 0.29     | 19.9                       | 24.7              | 494.1 a                     | 40.6 a                          | 72.8 a                    | 22.4 a         |
| ANOVA    |                            |                   |                             |                                 |                           |                |
| EC iw × LF | NS                        | NS                | ***                         | *                              | *                         | *              |
| LF × EC iw | NS                        | NS                | NS                          | NS                             | NS                        | NS            |

*, **, and *** represent significant differences between means at 0.05, 0.01, and 0.001 level of probability, respectively; NS, nonsignificant. Different letters within a column for each experimental factor indicate significant difference at \( P < 0.05 \) by Duncan’s multiple range tests.

0.27 (cm⁻³·m⁻³), the wilting point was 0.04 (cm⁻³·m⁻³), and the soil pH was 7.4. The available N, P, and K contents of the soil were 28.0, 16.3, and 47.7 mg·kg⁻¹, respectively, and soil organic matter content was 7.3 g·kg⁻¹.

Hot pepper plants (cultivar Bocuiwang) of a similar height were selected and transplanted into plastic pots on Apr. 28, 2015, one plant per pot. Before transplanting, all the pots were saturated with tap water. Each plant was irrigated using tap water at 5 d after transplanting (DAT) with an irrigation amount of 0.17 and 0.29 times the ET, corresponding to an LF of 0.17 and 0.29, respectively.

Measurements and method

Yield, dry biomass, and WUE F. The hot pepper fruits were harvested during their whole growth stages five times in total, starting on 8 June 2015. The weight of each fruit and the number of per plant were measured at each harvesting to evaluate the mean weight of the fruit and the total fruit yield. The fruit gathered at each harvesting was then dried in an oven at 70 °C to obtain a constant dry weight. The same procedure was performed at the end of the experiment on the roots, stems, and leaves of each plant. WUE F was calculated as the ratio between the total fruit yield and the seasonal ET.

Fruit quality parameters. The fruit quality parameters were measured during the fruit maturation and harvesting stages. The TSS of the hot peppers was measured using a handheld refractometer (WZ–108; Beijing Wancheng Beizen Precise Instruments Co., Ltd., China). The VC was determined using a fruit firmness tester (GY–3; Sanhe Instruments Co., Ltd., China) and applying a cylindrical probe to the fruit shoulder. The content of VC was determined using the titrimetric method (AOAC, 1984). The water content of the fruit (Wm) was determined using the oven-drying method described previously at each harvesting.

The fruit was harvested on 8 June 2015, and the number of fruits per plant was counted. The weight of each fruit and the number of per plant were measured at each harvesting event to evaluate the mean weight of the fruit and the total fruit yield.
Table 3. Effects of irrigation water salinity ($EC_{iw}$) and leaching fraction (LF) on ion content of hot peppers using the two-way analysis of variance (ANOVA).

| Factors | Ca$^{2+}$ (mg·g$^{-1}$ DW) | K$^{+}$ (mg·g$^{-1}$ DW) | Na$^{+}$ (mg·g$^{-1}$ DW) | K$^{+}$/Na$^{+}$ |
|---------|----------------|----------------|----------------|----------------|
| EC$_{iw}$ (dS·m$^{-1}$) | | | | |
| 0.9 | 1.48 | 20.80 | 0.114 c | 192.56 a |
| 1.6 | 1.31 | 22.25 | 0.143 c | 146.48 b |
| 2.7 | 1.37 | 21.75 | 0.266 bc | 97.55 c |
| 4.7 | 1.28 | 21.11 | 0.303 b | 72.87 ed |
| 7.0 | 1.75 | 21.61 | 0.585 a | 39.80 d |
| LF | | | | |
| 0.17 | 1.44 | 21.7 | 0.27 | 110.58 |
| 0.29 | 1.45 | 21.4 | 0.29 | 104.80 |

ANOVA

| Factor | NS | NS | NS | NS |
|--------|----|----|----|----|
| EC$_{iw}$ | NS | NS | *** | *** |
| EC$_{iw}$ × LF | NS | NS | NS | NS |

*** represents significant differences between means at 0.001 level of probability; NS, nonsignificant.

Different letters within a column for each experimental factor indicate significant difference at $P < 0.05$ by Duncan’s multiple range tests.

Fig. 1. Calculated threshold-shape linear response salinity model and sigmoidal-shape salinity response model based on irrigation water salinity ($EC_{iw}$, A), EC of soil saturated paste extract ($EC_{e}$, B) and drainage water salinity ($EC_{dw}$, C) regardless of the leaching fractions (LFs); the values of $EC_{dw}$ and $EC_{e}$ that are used were measured at the end of the experiment.

Fig. 2. Relationship between the relative total fruit yield ($Y_{r}$) and relative seasonal evapotranspiration ($ET_{r}$); LF is the leaching fraction.

and the $F_{0.05}$ that is defined as the ratio of $F_{MW}$ to $F_{1}$ was calculated.

The Na$^{+}$, K$^{+}$, and Ca$^{2+}$ content of the hot peppers. The dried fruits were mixed and then ground into powder and stored at room temperature before digestion. The dried samples (0.1 g) were digested in high-purity HNO$_{3}$ at a 5% (v/v) HNO$_{3}$ concentration that was heated using a heating block. The Na$^{+}$, K$^{+}$, and Ca$^{2+}$ concentrations in the digestion were measured using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP–OES, Perkin Elmer Optima 8000). For quality control, procedural blanks, standard reference materials, and sample replicates were randomly inserted.

Yield response functions. In this study, the data of the relative total fruit yield ($Y_{r}$) were fitted to the yield reduction models. One was the threshold-slope linear response model proposed by Maas and Hoffman (1977):

$$Y_{r} = Y_{m} \left(1 - \frac{EC_{e}}{EC_{o}}\right)$$

where $Y_{m}$ is the maximum total fruit yield, mainly represented by an $EC_{iw}$ of 0.9 dS·m$^{-1}$; $Y_{i}$ is the observed total fruit yield for the saline treatment; $EC_{o}$ (dS·m$^{-1}$) is the threshold EC, and $b$ (m·dS$^{-1}$) is the slope parameter, indicating the yield loss per unit increase in the EC beyond the threshold value; $EC_{e}$ is the root-zone salinity above which the yield is zero.

Another model was the sigmoidal-sharp salinity response model proposed by Van Genuchten and Hoffman (1984):

$$Y_{r} = \frac{1}{1 + (EC_{e}/EC_{o})^{s}}$$

where $EC_{o}$ represents the $EC_{e}$ value when $Y_{r} = 0.5$; and $s$ is a dimensionless empirical parameter.

We applied these two models to analyze the effect of salinity on the $Y_{r}$. We also used $EC_{iw}$ and drainage water salinity ($EC_{dw}$) instead of $EC_{e}$ in Eqs. [2] and [3] to assess the effects of $EC_{iw}$ and $EC_{dw}$ on the $Y_{r}$.

Water stress caused by salinity. Stewart and Hagan (1973) proposed a model to predict the yield from ET. The publication FAO 33 introduced a relationship between the relative yield decrease for water stress combining a yield response factor ($K_{y}$) and relative seasonal ET ($ET_{r} = ET_{i}/ET_{m}$, where $ET_{i}$ and $ET_{m}$ are observed seasonal ET values for saline treatments and maximum ET, respectively) to assess plant tolerance to water stress (Doorenbos and Kassam, 1979). This model has already been used to analyze salinity in many previous studies (Heidarpour et al., 2009; Kiremit and Arslan, 2016) and was used in this study:

$$1 - Y_{r} = K_{y} (1 - ET_{r})$$

Statistical analysis. SPSS (Version 21.0; IBM Corp., Armonk, NY) was used to give two-way analyses of variance using the general linear model-univariate procedure to determine the effects of the $EC_{iw}$ and LF on the following characteristics of the hot peppers: number of fruit per plant; fresh fruit weight; total fruit yield; total fruit dry biomass; plant dry biomass; WUEF; TC; VC; $F_{0}$; $F_{WC}$; $F_{MW}$; $F_{SI}$; and the Na$^{+}$, K$^{+}$, and Ca$^{2+}$ concentrations and K$^{+}$/Na$^{+}$ ratios of hot peppers. The correlations between hot pepper fruit quality parameters, ion contents, and ET or $EC_{e}$ were analyzed by linear regression, as were the relationship between relative yield and relative seasonal ET, and the yield response function proposed by Maas and Hoffman (1977). The yield response function suggested by Van Genuchten and Hoffman (1984) was analyzed using nonlinear regression in SPSS.

Results

Effects of the $EC_{iw}$ and LF on fruit yield parameters and WUEF. The hot pepper yield parameters and WUEF are given in Table 1. They were markedly restricted by the $EC_{iw}$. Across the LFs, the number of fruit per plant and the weight of fresh fruit decreased significantly by 16.5% to 42.0% and 12.7% to 32.3%, respectively, when the $EC_{iw}$ was higher than 1.6 dS·m$^{-1}$, whereas the total fruit

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yield decreased by 12.0% to 60.8% in the ECiw of 1.6–7.0 dS·m⁻¹, compared with the ECiw of 0.9 dS·m⁻¹.

The dry biomass of both the fruit and plants decreased significantly with an increase in the ECiw, with the highest values obtained from the ECiw of 0.9 dS·m⁻¹ and the lowest from the ECiw of 7.0 dS·m⁻¹. The ECiw led to a reduction of 10.3% to 41.0% in WUEF, whereas it had no effect on the parameters of these relationshps.

Across the different ECiw, a high LF significantly increased the total fruit yield, the dry biomass of the fruit and plants, and the WUEF, whereas it had no effect on the number of fruits per plant and the weight of the fresh fruit. There was no interaction between the ECiw and LF in terms of yield parameters and WUEF.

Effects of the ECiw and LF on quality parameters. Hot pepper quality is a comprehensive index and consists of interactions among varying single quality attributes. The taste quality (TSS), nutritional quality (VC), storage quality (Fn, and FWC), and external quality (FL, FMIW, and FS) were all analyzed in this study. Table 2 shows fruit quality parameters using different levels of ECiw and LFs. The ECiw showed a marked influence on fruit quality parameters across the LFs. The TSS content in the ECiw of 2.7–7.0 dS·m⁻¹ increased significantly by 8.8% to 29.7% when compared with the ECiw of 0.9 dS·m⁻¹, whereas a significant increase in the VC content was only observed in the ECiw of 1.6–7.0 dS·m⁻¹. A higher ECiw led to a higher FSI and FN value. However, if the ECiw was increased from 0.9 to 7.0 dS·m⁻¹, the FWC decreased significantly from 92.83% to 89.87%. Increases in the ECiw correspond to an increase in the CEC, but to a reduction in the FMIW and FMIW.

Across the ECiw, there were no significant differences in the FL, TSS, and FS between the two LFs, whereas an increase in the LF led to an increase in the VC and FWC, and a decrease in the FMIW and FS. The ECiw and LF had no interactions in terms of the TSS, VC, Fn, FWC, and FMIW, whereas there were interactions with respect to the FL and FS.

Effects of the ECiw and LF on the ion content of the fruit. Change in the ECiw showed no effect on the Ca²⁺ and K⁺ contents of the fruit (Table 3). However, as the ECiw increased, the Na⁺ content in the fruit increased, whereas the K⁺/Na⁺ ratio decreased. Change in LF showed no significant differences in the ion content in the fruit.

Salinity response models and water stress caused by salinity. Figure 1 shows the Yr data plotted against the ECiw, ECe, and ETr, respectively. Values of Yr data decreased as the ECiw, ECe, or ETr increased, with these data falling into a curve regardless of the LFs. Figure 1 also shows the fitted threshold-slope linear model and sigmoidal-shape model curves. Both models seem to accord reasonably well with the measured Yr data within our ECiw treatments, with the LF having no significant effect on these model parameters.

The relationship between the Yr and the ETd of the hot peppers is shown in Fig. 2. There was a significant (P < 0.001) linear correlation between the Yr and the ETd with a slope of 1.65 (Ky value) regardless of the LFs, indicating that hot peppers are highly sensitive to water stress caused by salinity.

The quantitative relationship between fruit quality parameters and the ECe and ETd. Figure 3 shows the relationship between the fruit quality parameters of the hot peppers and the ECe across the LFs. The relative TSS and FS showed a significant positive linear correlation with the ECe (Fig. 3A and B). A significant negative linear correlation was observed between the relative FMIW, FL, FMIW, and the ECe (Fig. 3C–E). However, there was no significant (P > 0.05) correlation between the relative FSI and VC and the ECe (Fig. 3F and G). The LF had no effect on the parameters of these correlations.

Figure 4 shows the relationship between the fruit quality parameters of the hot peppers and the ETd across the LFs. An increase in the ETd leads to a significant linear decrease in the relative TSS, VC, Fn, FWC, and FMIW, whereas there is a significant linear increase in the relative FW, FL, and FMIW (Fig. 4C–E). No significant (P > 0.05) correlations were found between the relative FW and VC and the ETd (Fig. 4F and G). The LF had no effect in terms of the parameters of these relationshps.

The quantitative relationships between the ion content of the fruit and the ECe and ETd. The relative Na⁺ content in the fruit increased linearly with the ECe but decreased linearly with the ETd, regardless of the LFs (Fig. 5A and C). Increases in the ECe led to a significant linear decrease in the relative K⁺/Na⁺ (Fig. 5B), whereas it increased linearly as the ETd increased irrespective of the LFs (Fig. 5D). There was no correlation between the K⁺ or Ca²⁺ content in the fruit and the ECe or ETd (figure not shown).
Discussion and Conclusions

Water is a crucial factor affecting the hot pepper yield and fruit quality. A salt-induced water deficit (as reflected by the high \( K_y \) of 1.65 in Fig. 2) is one of the major constraints in the way of plant growth, inhibiting the crop yield. However, a water deficit caused by high salinity may also improve fruit quality (Adams and Ho, 2015; Chen et al., 2016; Rubio et al., 2009). The simultaneous control of yield and fruit quality is usually a challenge, however, as a result of the inverse relationship between yield and fruit quality (Wang et al., 2011).

The total fruit yield and dry biomass of the plants both decreased significantly as a result of an increase in the EC\(_{iw}\) (Table 1). A reduction in the number of fruits per plant contributed nearly as much to a reduced total fruit yield as a result of salinity as did the weight of the fresh fruit (Table 1). The reduction in the weight of the fresh fruit through the EC\(_{iw}\) was because of a reduction in the F\(_{WC}\) rather than in the mean dry biomass of the fruit (Table 2, data for the mean dry biomass of the fruit are not shown). The reduction of the total fruit yield under saline irrigation could be explained as a salt-induced water deficit, the accumulation of Na\(^+\) in plants and the inhibited uptake of K\(^+\) (Chen et al., 2016; Garcia-Legaz et al., 2005). These changes have an adverse effect on gas exchange and plant growth, in turn affecting yield. The WUE\(_F\) of hot peppers was remarkably restricted by the EC\(_{iw}\) because salinity reduces total fruit yield more than it reduced water loss.

A high yield, in conjunction with high-quality fresh fruit, is crucial for increasing the economic benefits for farmers (Chen et al., 2016). In this study, except for the external quality (reflected as F\(_L\), F\(_{MW}\), and F\(_{SI}\)), the storage quality (F\(_n\) and F\(_{WC}\)), taste quality (TSS), and nutritional quality (VC) increased significantly with increased EC\(_{iw}\). The lower \( \psi_s \) of soil water and consequently, the lower availability of soil water for the fruit caused by salinity leads to a reduction in cell size and intercellular volume and in turn reduce the F\(_{WC}\), F\(_n\), and F\(_{MW}\). The F\(_n\) value was increased with the increase in the EC\(_{iw}\) because salinity reduced the F\(_n\) more than it reduced the F\(_{MW}\) (Table 2). The decrease in the F\(_{WC}\) might imply the occurrence of osmotic adjustment (Johnson et al., 2006). F\(_n\) is one of the main attributes determining the storage capacity of fruits: a higher F\(_n\) could reduce the mechanical damage and improve the storage durability of fruits (Flores et al., 2003). In this study, the F\(_n\) increased significantly by 9.0% to 22.2% in the EC\(_{iw}\) of 2.7–7.0 dS·m\(^{-1}\), compared with the EC\(_{iw}\) of 0.9 dS·m\(^{-1}\) across the LFs. The possible reasons are that 1) as a small fruit tends to have a high F\(_n\), the increased cellular density due to the reduction in fruit size under saline treatment increases the F\(_n\) (Wang et al., 2011); 2) the increased water stress caused by salinity during fruit enlargement and maturity enhances the F\(_n\) (Chen et al., 2013; Patanè and Cosentino, 2010); and 3) Belakbir et al. (1998) showed that the F\(_n\) in peppers is related to the level of Ca\(^{2+}\) in the fruit, and that salinity is able to reduce F\(_n\) by reducing the availability of Ca\(^{2+}\) in the fruits. However, in this study, the Ca\(^{2+}\) in fruit was unaffected by salinity, indicating that the Ca\(^{2+}\) in the fruits is not the reason for the increased F\(_n\) in saline irrigation. High F\(_n\) and low F\(_{WC}\) in salinity treatment indicate the fact that irrigation with saline water is able to improve the quality of fruit storage.

Unlike Navarro et al. (2010) and Rubio et al. (2009), who found that low levels of EC\(_{iw}\) (less than 3 dS·m\(^{-1}\)) did not increase the TSS content in sweet peppers, in this study, the EC\(_{iw}\) promoted the TSS content in hot peppers (Table 2). A reduced water uptake in plants irrigated using saline water leads to an increase in soluble concentrations and in turn increases the TSS content (Malash et al., 2008). The reduction of the F\(_{WC}\) in hot pepper fruits undergoing salinity treatment (Table 2) might also have contributed to the increased TSS content.

A higher VC content was observed in hot pepper fruits (Vanderslice et al., 1990). VC is considered to be an important nutritional quality owing to its antioxidant characteristics (Wang et al., 2011). The VC content in the EC\(_{iw}\) of 7.0 dS·m\(^{-1}\), in this study, was increased significantly by 48.6%, compared with the EC\(_{iw}\) of 0.9 dS·m\(^{-1}\) across the LFs. The possible reasons are that 1) the salinity reduced water uptake by roots, resulting in water stress (as reflected by \( K_y \) in Fig. 2), consequently increasing the VC content (Patanè et al., 2011); and 2) the leaf area reduced by the salinity could increase the light intensity and duration, in turn, promoting the accumulation of VC (Chen et al., 2013; Wang et al., 2011).

To provide an important basis for salinity irrigation and management, the quantitative relationship between yield, fruit quality, fruit ion content, and EC\(_{iw}\) or ET\(_F\), should be investigated. The response of a total yield of fresh hot peppers to salinity can be represented.
effectively by using a threshold-slope linear model or sigmoidal-shape model in terms of \(EC_{iw}, EC_{e}, \) or \(EC_{eW}\) within our experimental range regardless of the LFs. The \(b\) parameter for the threshold-slope-linear model based on \(EC_{iw}\) was 0.096 (9.6\%), which fell within the range of 8.4\% to 11.7\% as suggested by Chartzoulakis and Klapaki (2000), whereas the \(EC_{e}\) was much lower than their 1.8. The \(b\) and \(EC\) parameters for the threshold-slope linear model based on \(EC_{e}\) were 0.051 (5.1\%) and 1.1 dS m\(^{-1}\), respectively, i.e., lower than the 7.0\% to 16.0\% and 1.2–4.0 dS m\(^{-1}\) found in previous studies, as listed by Rameshwaran et al. (2016). The differences in the parameters across studies may be as a result of the varieties of pepper used, the irrigation method, soil fertilizer, climatic conditions, and the growth season (Chartzoulakis and Klapaki, 2000; Heidarpour et al., 2009; Rameshwaran et al., 2016). The \(b\) and \(s\) parameters for the threshold-slope-linear model and sigmoidal-shape model based on the \(EC_{eW}\) were lower than those based on the \(EC_{iw}\) and \(EC_{e}\), whereas the \(EC_{eW}a\) and \(EC_{eW50}\) were higher for the higher concentrations of \(EC_{eW}\) than those of the \(EC_{iw}\) and \(EC_{e}\).

Many chemical reactions take place and are ultimately responsible for the high quality of hot peppers at the onset of fruit ripening. The relative TSS and \(F_n\) increased linearly with the \(EC_{e}\) and \(EC_{eW}\) in their model or sigmoidal-shape model in terms of \(EC_{iw}\), \(EC_{e}\), or \(EC_{eW}\) within our experimental range regardless of the LFs. The \(b\) parameter for the threshold-slope-linear model based on \(EC_{iw}\) was 0.096 (9.6\%), which fell within the range of 8.4\% to 11.7\% as suggested by Chartzoulakis and Klapaki (2000), whereas the \(EC_{e}\) was much lower than their 1.8. The \(b\) and \(EC\) parameters for the threshold-slope linear model based on \(EC_{e}\) were 0.051 (5.1\%) and 1.1 dS m\(^{-1}\), respectively, i.e., lower than the 7.0\% to 16.0\% and 1.2–4.0 dS m\(^{-1}\) found in previous studies, as listed by Rameshwaran et al. (2016). The differences in the parameters across studies may be as a result of the varieties of pepper used, the irrigation method, soil fertilizer, climatic conditions, and the growth season (Chartzoulakis and Klapaki, 2000; Heidarpour et al., 2009; Rameshwaran et al., 2016). The \(b\) and \(s\) parameters for the threshold-slope-linear model and sigmoidal-shape model based on the \(EC_{eW}\) were lower than those based on the \(EC_{iw}\) and \(EC_{e}\), whereas the \(EC_{eW}a\) and \(EC_{eW50}\) were higher for the higher concentrations of \(EC_{eW}\) than those of the \(EC_{iw}\) and \(EC_{e}\).

Rubio et al. (2009) showed that Ca\(^{2+}\) was lower in the fruits of salinized plants than in the fruits of plants irrigated with salt-free water. The fruit Ca\(^{2+}\) and K\(^{+}\) concentrations in this study were unaffected by the \(EC_{iw}\), however, indicating that the uptake of mineral nutrition was not limited to the sufficient mineral nutrition (half strength Hoagland solution) supply in the irrigation water. Insufficient Ca\(^{2+}\) results in blossom end rot, a physiological disorder affecting hot peppers that reduces the market yield and quality of the fruits (Chen et al., 2016; Rubio et al., 2009). No blossom end rot was observed in this study, which also reflected the fact that Ca\(^{2+}\) of the fruit was not limited. The Na\(^{+}\) concentration in the fruits increased as \(EC_{iw}\) increased, in line with the findings of Azuma et al. (2010). A linear positive correlation between the relative Na\(^{+}\) concentration in fruits and \(EC_{e}\) and linear negative correlation between relative K\(^{+}\)/Na\(^{+}\) ratio and \(EC_{e}\) suggest that Na\(^{+}\) caused salt toxicity including an ion imbalance and water deficit in the tissue of the fruit (Azuma et al., 2010).

An increase in the LF was observed to lead to an increase in the total fruit yield because of an increase in the total dry biomass of the fruit, whereas the LF had no effects on the number of fruits per plant and the weight of the fresh fruit (Table 1). Neither did the LF affect the total fruit yield, number of fruits per plant, and weight of the fresh fruit before the fifth harvesting, indicating that the LF needs sufficient time to affect the total fruit yield. The WUE\(_F\) of hot peppers was high in the high LF because it increased the total fruit yield more than it increased the seasonal ET. No significant differences in the TSS, \(F_n\), and \(F_L\) were observed across the two LFs, whereas an increase in the LF was found to lead to a significant decrease in the \(F_{MW}\) and \(F_{SI}\), whereas the \(F_{WC}\) and VC content increased. The increased \(F_{SI}\) in the lower LF was mainly as a result of a greater \(F_{MW}\). The low \(F_{WC}\) in the low LF would indicate that a low LF could improve the storage quality of the fruit. However, the mechanism of a high content of VC in the high LF remains elusive and merits further investigation. The LF had no effect in terms of the parameters using the threshold-slope-linear and sigmoidal-sharp models as well as the \(K_c\) value using the yield-moisture-stress relationship (Fig. 2) and the correlation between quality parameters and \(EC_e\) or \(ET_r\), indicating that the LF is not the main factor governing the difference in the parameter values for models across studies, neither did the LF effect on the correlation between the ion content of the fruit and the \(EC_e\) or \(ET_r\).

In summary, the threshold-slope linear and sigmoidal-sharp models both suited the measured \(Y_e\) reasonably well within our \(EC_{iw}\) range. The relative TSS and \(F_n\) increased linearly with the \(EC_e\) and decreased linearly with the \(ET_r\), whereas the relative \(F_{MW}\), \(F_L\), and \(F_{MW}\) decreased linearly with the \(EC_e\) and increased linearly with the \(ET_r\). The relative Na\(^{+}\) concentration in the fruit increased linearly, whereas the relative fruit K\(^{+}\)/Na\(^{+}\) ratio decreased linearly with an increased \(EC_e\). Interestingly, the LF had no effect on these correlations with respect to fruit yield, quality, ion content, and \(EC_e\) or \(ET_r\).

The total fruit yield and WUE\(_F\) decreased significantly as the \(EC_{iw}\) increased. Increased salinity reduced the external quality of hot peppers, whereas improved the taste, nutritional and storage quality of the hot peppers, and led to a higher accumulation of Na\(^{+}\) in the fruit. High LF increased the total fruit yield, WUE\(_F\), and nutritional quality but decreased in the \(F_{MW}\) and \(F_{SI}\). Therefore, it is suggested that high LF can be applied to obtain high yield and better-quality fruit when hot peppers are irrigated with water having a high level of saline content.

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