Soil Salt Distribution and Tomato Response to Saline Water Irrigation under Straw Mulching

Yaming Zhai¹,², Qian Yang³, Yunyu Wu¹,²

¹ Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China, Hohai University, Nanjing, 210098, China, ² College of Water Conservancy and Hydropower, Hohai University, Nanjing 210098, China, ³ Henan Vocational College of Agriculture, Department of Gardening, Zhengzhou, China

Abstract

To investigate better saline water irrigation scheme for tomatoes that scheduling with the compromise among yield ($Y_t$), quality, irrigation water use efficiency ($IWUE$) and soil salt residual, an experiment with three irrigation quotas and three salinities of irrigation water was conducted under straw mulching in northern China. The irrigation quota levels were 280 mm (W1), 320 mm (W2) and 360 mm (W3), and the salinity levels were 1.0 dS/m (F), 3.0 dS/m (S1) and 5.0 dS/m (S2). Compared to freshwater, saline water irrigations decreased the maximum leaf area index ($LAI_{m}$) of tomatoes, and the $LAI_{m}$ presented a decline tendency with higher salinity and lower irrigation quota. The best overall quality of tomato was obtained by S2W1, with the comprehensive quality index of 3.61. A higher salinity and lower irrigation quota resulted in a decrease of individual fruit weight and an increase of the blossom-end rot incidence, finally led to a reduction in the tomato $Y_t$ and marketable yield ($Y_m$). After one growth season of tomato, the mass fraction of soil salt in plough layer under S2W1 treatment was the highest, and which presented a decline trend with an increasing irrigation quota. Moreover, compared to W1, soil salts had a tendency to move to the deeper soil layer when using W2 and W3 irrigation quota. According to the calculation results of projection pursuit model, S1W3 was the optimal treatment that possessed the best comprehensive benefit (tomato overall quality, $Y_t$, $Y_m$, $IWUE$ and soil salt residual), and was recommended as the saline water irrigation scheme for tomatoes in northern China.

Introduction

Agricultural waters account for 95% of the total water consumption in the world [1]. For China, particularly those irrigation areas of northern China, inadequate rainfall and limited surface water supply have seriously impeded the development of agriculture [2]. Since 1992, the irrigation areas in northern China suffered severe drought, leading to a great loss of grain...
yields that was approximate 17 500 million kilogram every year. Because of the water shortages, some areas in northern China maintained the development of agriculture by excessively exploiting the underground water, and this resulted in a 500 000 km² ground falls in the border regions of Beijing, Tianjing and Hebei province [3–4]. Presently, China has applied various technologies to deal with the water shortage problems in the northern irrigation areas, including the water conservancy engineering [5–6], the biological water-saving technology [7–8], the optimize arrangement of crops [9], the reclamation of sewage [10] and the saline water irrigation technology [11–12].

Although irrigation with saline water relieves fresh water resource shortages in varying degrees, the improper use of saline water (such as the use of saline water with excessive salinity or insufficient irrigation with saline waters) may result in combinations of water and saline stress that lead to the secondary salinization and a series of environmental problems [13–14]. Therefore, the dynamic and distribution of soil salts under saline water irrigation were extensively studied [2, 13, 15–16]. The water-salt dynamic models were used to understand the distribution of soil salts under saline water irrigation, thus providing a reference for the decision of saline water irrigation scheme [13].

Tomatoes are sensitive to salts that they can not survive under high salinity condition or only survive with decreased yields [17]. To alleviate the deleterious effects of the salt, several methods such as mixed irrigation with freshwater and saline water [18], and rotated irrigation with freshwater and saline water [19] have been applied. Some studies have specifically examined the effects of saline water irrigation on tomato growth, development, quality, yield and blossom-end rot incidence (BER) [20–23]. Tomato organoleptic parameters, such as soluble solids, fructose, glucose, titratable acid, and amino acid contents, increase with increasing salinity [20, 24–28]. Of these factors, suitable salt stress can be applied to improve the fruit quality. Although positive indicators of tomato quality have been obtained under saline conditions, it has been reported that tomato yield is negatively affected by increasing salinity [17, 29]. Furthermore, although the tomato BER is commonly considered as a physiological disorder that caused by calcium deficiency [30], salt stress is one of the main environmental factors to aggravate BER [31–32].

On the other hand, water is also an important factor that affects the growth and development of tomatoes [33]. A reasonable irrigation quota is beneficial for the tomatoes to obtain high yield and good quality. Study on the tomato deficit irrigation has shown that the soluble solid, vitamin C, sugar, acid, and sugar to acid ratio in the fruits increase with a lower water supply, resulting in an improved overall quality of tomatoes [34–35]. Moreover, under deficit irrigation condition, the acid invertase, neutral invertase, proline, glucose and fructose in the tomato fruits are increased, and this helps the tomato plants to be more adaptive to the drought stress [36–37]. However, low water supply reduces the tomato yields, which decreases the weight of single fruit but has no significant effects on the fruit number [33, 38]. On the contrary, excessive water supply leads to the spindling of tomatoes, limits the tomato physiological and reproductive growth, finally causes a low tomato yield [39–40]. In addition, water supply has certain connections with the tomato BER, while water whether to directly affect the BER is still not fully understood [41]. Besides, under the condition of irrigation combined with mulching, soil salt was found to move towards the edge of the mulch, thus the salinity within the plant root-zone was decreased, which created a suitable environment for the growth of tomato [42].

Presently, there are some studies focused on the regularity of soil salt distribution under the saline water irrigation, but which under special control conditions such as straw mulching have been less studied. Besides, although many studies have independently investigated the tomato responses to different salinity of irrigation waters and different irrigation amount, few...
studies have looked into their combined effects on the tomato growth, quality, yield and BER. And most of all, in southern China, it is important for the irrigation agriculture to find a tomato irrigation scheme that not only maintains normal output but also with a better fruit quality, a higher IWUE and a relatively lower salt residual in plough layer. In this experiment, the tomatoes were treated with different irrigation water salinities and irrigation quotas under a mulch of dry straws, and the tomato responses and the soil salt distribution under these treatments were compared and analyzed. For crop performance, we hypothesized that all environmental factors have the same effects on tomato growth and development. The objectives of this study were to understand the soil salt distribution laws and the tomato responses to different saline water treatments, and to find out improved saline water irrigation methods with best comprehensive effects that improve the fruit quality, increase the tomato IWUE and relatively reduce the soil salt residual but do not significantly decrease the tomato yields in northern China. These treatments were compared with a freshwater (F) irrigation treatment.

Materials and Methods

Experiment Conditions

The experiment was carried out in 2014 (May-September) at Modern Agriculture Park of Xinzhou city, Shanxi Province, northern China (The experiment was permitted by the owner of the land named Dong Quiuye). The experimental site belongs to a temperate continental monsoon climate and enjoys four clear seasons. The annual mean temperature of the experimental site is 4.3°C-9.2°C and the mean precipitation is 345 mm-588 mm (data from 1960–2010). In addition, heavy rains in the experimental site have the characters of small area, short duration, strong intensity and unevenness in time and space, they mainly happened during July-August, accounting for 83.7% of the total rainy days. The soil type in the experimental fields is sandy loam, with bulk density of 1.34 g/cm³, organic matter of 1.36%, salt content of 1.13 g/kg, alkali-hydrolyzale N of 94.58 mg/kg, available P of 18.44 mg/kg, and available K of 77.86 mg/kg, in 0–20 cm soil layer.

Experimental Design

The experiment was conducted in a plastic-covered greenhouse, and the tomato type for experiment was “Yinshidahong”. After the soils were ploughed uniformly, the seedlings were transplanted to the experimental blocks. During the seedling stage, the same field managements were applied among different treatments. Soil ridges were constructed for tomatoes, and the ridges were 4.4 m length and 0.6 m width, with a 1.4 m distance between them. Two lines of tomatoes were transplanted to one ridge with the line spacing of 0.3 m and the row spacing of 0.4 m, and the planting density was about $3.6 \times 10^4$ plants/hm². To provided the nutrients necessary for tomato plant growth, the experiment fields were fertilized with 700 kg/hm² of N: P₂O₅: K₂O = 1:2:2 compound fertilizer. The 3–5 cm dry straws of paddy rice were used as the mulch material, of which the mulch amount was 4000 kg/hm², mulching uniformly at 20 days after seedling transplanting.

According to the experience from early study [43], we designed three saline water treatments: 1.0 dS/m (F), 3.0 dS/m (S1), 5.0 dS/m (S2), combined with three irrigation quotas: 280 mm (W1), 320 mm (W2), 360 mm (W3), grouped as 9 treatments, each treatment was replicated 3 times, as shown in Table 1. Three ridges of tomatoes were gathered as one treatment, which was applied with the same salinity and irrigation quota. Flood irrigation according to the local practice was applied. For the treatments with different irrigation quotas, the irrigation times was the same (13 times), while the irrigation amount each irrigation time was different. An impermeable membrane at a depth of 60 cm was used between the different treatments to
prevent lateral seepage of the irrigation water. In this experiment, the freshwater (F) was the local underground water with the EC of 1.0 dS/m, saline water (S) were prepared with these underground waters. Details regarding the saline water were presented in Table 2.

The lateral tomato plant branches were removed during the growth period, and topping treatments were applied in a timely manner. Each tomato plant was allowed to reserve 4 fruit sequences. Pest control was conducted according to the actual situation in the experimental fields.

Measurements

The concentrations of K$^+$ and Na$^+$ in the saline water were measured using flame photometry method. The concentrations of Ca$^{2+}$ and Mg$^{2+}$ were measured using the atomic absorption spectrophotometry method. The concentrations of Cl$^-$, SO$_4^{2-}$ were measured using the anionic chromatography method. The concentrations of CO$_3^{2-}$ and HCO$_3^-$ were measured using the double indicators-neutralization titration method [44].

The leaf area index (LAI) was measured at every stage using an LAI 2000 Plant Canopy Analyzer (Li-Cor Biosciences USA). The maximum LAI ($LAI_m$) of each treatment was extracted for analysis.

The tomato yield ($Y_t$), BER, and marketable tomato yield ($Y_m$) were determined at the harvest stage, and tomato fruits were picked manually every 3–5 days. For each harvest, the number and weights of good fruits and the fruits with BER were recorded. $Y_m$ was calculated as follows (The malformed fruits were very little and ignored here) [29]:

$$Y_m = Y_t (1 - BER)$$

To determine the tomato quality in each treatment, 20 tomato fruits with red or orange colors were collected randomly to measure the quality indexes. The quality indexes included the volume ($V_F$), density ($\rho_F$), soluble solids content ($D_s$), total acidity content ($G$), vitamin C content ($V_C$) and sugar/acid ratio (RSA). The $V_F$ was measured using the displacement method, and the $\rho_F$ was calculated based on the tomato volume and weight. In addition, $D_s$ was measured using an ACT-1E digital refractometer (ATAGO Company, Japan), and the total sugar content was measured using the Fehling reagent titration method. The $G$ was measured using the sodium hydroxide titration method, and the $V_c$ content was measured using the 2, 6-dichloroindophenol titrimetric method [17, 45].

Table 1. Experimental design.

| Treatment | FW1 | FW2 | FW3 | S1W1 | S1W2 | S1W3 | S2W1 | S2W2 | S2W3 |
|-----------|-----|-----|-----|------|------|------|------|------|------|
| EC (dS/m) | 1.0 | 1.0 | 1.0 | 3.0  | 3.0  | 3.0  | 5.0  | 5.0  | 5.0  |
| Irrigation quota (mm) | 280 | 320 | 360 | 280  | 320  | 360  | 280  | 320  | 360  |

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Table 2. The ionic compositions of the different irrigation water treatments.

| EC (dS/m) | Ionic content (mmol/L) |
|-----------|------------------------|
|           | Na$^+$      | K$^+$    | Mg$^{2+}$ | Ca$^{2+}$ | CO$_3^{2-}$ | HCO$_3^-$ | Cl$^-$ | SO$_4^{2-}$ |
| 1.0       | 2.6         | 0.9      | 3.8       | 0.5       | 0.4         | 5.8      | 2.4    | 1.4        |
| 3.0       | 13.2        | 3.7      | 7.3       | 2.0       | 0.4         | 12.9     | 9.5    | 5.4        |
| 5.0       | 25.9        | 5.9      | 10.2      | 2.7       | 0.4         | 22.3     | 16.2   | 9.1        |


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IWUE (kg/m³) was calculated as [46]:

\[ IWUE = \frac{Y}{I} \]

Where, \( I \) was the irrigation amount (m³) during the whole growth stage of tomatoes. The soil samples for measuring the mass fraction of salt in the soil profile (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm) was collected on September 18th, after the last harvest of tomatoes.

Data Analysis

The data were statistically compared using a one-way ANOVA with Duncan’s Multiple Range Test at the 0.05 probability level (using the SPSS software, Version 17.0) [47]. The quality indexes for the Principal Component Analysis (PCA) were also obtained from the SPSS software. The principal components of the quality indexes were extracted following the principle of "eigenvalue > 1, cumulative contribution rate > 80%" [48].

Projection pursuit (PP) Model

The PP model is a well-developed method for selecting the optimal scheme when there were various schemes with various evaluation indexes. Here, the PP model is used to select the optimal irrigation scheme from the 9 treatments of this experiment, and the optimal irrigation scheme should possess the best integrated benefits based on the evaluation indexes including the tomato comprehensive quality, \( Y_t, Y_m \), IWUE and the soil salinity after irrigation.

The essence of PP model is to use computer technology to project high dimensional data to lower dimensional space, and search for the projection which could well reflect the characters of high dimensional data, then study the structures of high dimensional data in a low dimensional space. The modeling method is as follows [49–50]:

1. Establish the evaluation matrix. Suppose the number of treatments is \( n \), number of evaluation indexes is \( p \), the \( j \)th index of \( i \)th sample is \( x_{ij}^* \), then the evaluation indexes could be expressed by an \( n \times p \) matrix \( X^* \).

2. Quantify the evaluation indexes. In order to eliminate the differences of dimension, following measures are taken:
   For the "the larger the better" index:
   \[ x_{ij} = \frac{x_{ij}^* - \min(x_{ij}^*)}{\max(x_{ij}^*) - \min(x_{ij}^*)} \]

   For the "the smaller the better" index:
   \[ x_{ij} = \frac{\max(x_{ij}^*) - x_{ij}^*}{\max(x_{ij}^*) - \min(x_{ij}^*)} \]

   A new \( n \times p \) matrix \( X \) can be obtained based on the qualified indexes.

3. Linear projection. The essence of linear projection is to observe the data from different angles, to search for the best projective direction which could well reflect the characters of
the data, therefore, suppose the unit vector \( a = \{a_1, a_2, \ldots, a_p\} \) as the one dimensional projective direction, and \( z_i \) as the one dimensional projective eigenvalue.

\[
z_i = \sum_{j=1}^{p} a_j \cdot x_{ij} \quad (i = 1, 2, 3 \cdots, n; \ j = 1, 2, 3 \cdots, p)
\]

4. Constructs an object function for projection. Express the object function \( Q(a) \) as the product of distances between classes and density between classes:

\[
Q(a) = S_z \cdot D_z
\]

Where \( S_z \) is the standard value of projective eigenvalue \( z_i \), also named distances between classes, \( D_z \) is the density between classes of \( z_i \).

\[
S_z = \sqrt{\frac{\sum_{i=1}^{n} (z_i - E(z))^2}{n-1}}
\]

Where \( E(z) \) is the average of the array \( \{z_i \mid i = 1 \sim n\} \).

\[
D_z = \sum_{i=1}^{n} \sum_{k=1}^{n} (R - r_{ik}) \cdot f(R - r_{ik})
\]

Where, \( R \) is window radius of local density;

\[
r_{ik} = |r_i - r_k|
\]

\[
f(t) = \begin{cases} 
0 & t \geq 0 \\
1 & t < 0 
\end{cases}
\]

\( i, \ k = 1, 2, 3 \cdots n. \)

5. Optimize the object function by maximization:

\[
\max Q(a) = S_z \cdot D_z
\]

\[
s.t. \sum_{j=1}^{p} a^2(j) = 1,
\]

\[
|a(j)| \leq 1
\]

6. Evaluation. The contribution of evaluation index can be obtained according to the best projective direction, and the stand or fall of the treatments can be also obtained based on the \( z_i \) value.

In this study, the PP model was built using the Matlab software (Version 7.1), and the Real Adaptive Parallel Genetic Algorithm (RAGA) was used to optimize the PP model. Before
optimizations, the main parameters were set as: the original population size \( n \) = 400, the probabilities of crossover \( P_c \) = 0.8, the probabilities of mutation \( P_m \) = 0.8, the number of excellent individuals \( N_e \) = 20, \( \alpha \) = 0.05 and accelerating times \( N_a \) = 20 [51].

**Results**

**Effects of different treatments on the LAI\(_m\) of tomato**

**Fig 1** shows the effects of different saline water treatments on the LAI of tomatoes. The LAI at 10 days after transplant were in a range of 0.53–0.84, and LAI at 30 days after transplant ranged from 1.39 to 1.99. Under the same irrigation quota, the tomato LAI\(_m\) decreased as the increase of salinity. LAI\(_m\) under W1 irrigation quota presented most dramatic decrease, which of S2 was 13.2% lower than that of F, indicating that low irrigation quota combined with high salinity limited the increase of tomato leaf area. On the other hand, under the three salinity levels, the tomato LAI\(_m\) all increased as the increase of irrigation quota, of which 5 dS/m increased the tomato LAI\(_m\) most significantly that was 17.0% compared between W1 and W3. This probably due to the salt leaching effects of high irrigation quota that relieved the salt stress for the tomato growth and development.

**Effects of different treatments on tomato quality**

**Fig 2** gives the values of quality indexes with different irrigation treatments. Overall, lower irrigation quota or higher salinity increased the \( \rho_p \), \( D_s \), \( G \), \( V_C \) and RSA but decreased the \( V_F \) of tomatoes. From the effects of irrigation quota and salinity and their combinations on the tomato quality, it was concluded that the salinity of irrigation waters significantly affected the \( \rho_p \), \( V_F \), \( D_s \), \( G \), \( V_C \) and RSA of tomatoes, and the irrigation quota significantly affected the \( \rho_p \), \( V_F \), \( D_s \), \( V_C \) and RSA of tomatoes, but their combined effects had no significant effects on these quality indexes of tomatoes.
The PCA model was used to extract the principal components of the tomato quality indexes, and the comprehensive indexes of tomato quality with different irrigation treatments were shown as Fig 3. The calculated eigenvalue and accumulating contribution rate was 4.861 and 81.01%, respectively, which retained great original information of tomato quality indexes.
A higher comprehensive quality index indicates a higher comprehensive quality (the 6 indexes observed) of the tomatoes. Therefore, in this study, the irrigation treatment with lowest irrigation quota but highest salinity (S2W1) resulted in an overall better tomato quality, comprehensive quality index reaching 3.61; followed by S1W1, with the comprehensive quality index of 3.12; FW3 obtained the most unsatisfactory overall quality of tomatoes, the comprehensive quality index of which was only 1.00. This indicates that decreased the irrigation quota or increased the salinity of irrigation waters resulted in an overall better tomato quality.

**Fig 3.** Effects of different treatments on the comprehensive index of tomato quality according to the calculations of principal component analysis (W1, W2 and W3 represent the three irrigation quotas of 280, 320 and 360 mm respectively, F, S1 and S2 represent the three water salinities of 1.0, 3.0 and 5.0 dS/m).

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**Effects of different treatments on** $Y_t$ **and** $Y_m$

Table 3 shows the effects of different irrigation treatments on the tomato $Y_t$ and $Y_m$. Under the same irrigation quota, the total tomato $Y_t$ and $Y_m$ with S1 salinity had not presented significant

| Treatment | 50–80 DAT | 80–110 DAT | Total |
|-----------|-----------|------------|-------|
|           | $Y_t$ (t/ha) | $Y_m$ (t/ha) | $BER_i$ (%) | $Y_t$ (t/ha) | $Y_m$ (t/ha) | $BER_i$ (%) | $Y_t$ (t/ha) | $Y_m$ (t/ha) | $BER_i$ (%) |
| FW1       | 44.2bc     | 41.6c      | 5.8  | 64.7ab | 60.6bc | 6.3 | 108.9cd | 102.3cd | 6.1 |
| FW2       | 50.3b      | 47.7b      | 5.2  | 61.1bc | 58.0c | 5.1 | 111.4bc | 105.7bc | 5.2 |
| FW3       | 58.1a      | 55.3a      | 4.8  | 67.7a | 65.1a | 3.9 | 125.8a | 120.4a | 4.3 |
| S1W1      | 40.2cd     | 37.5cd     | 6.8  | 61.0bc | 56.4c | 7.5 | 101.2de | 93.9de | 7.2 |
| S1W2      | 44.6bc     | 42.0c      | 5.9  | 54.4cd | 51.0cd | 6.2 | 99.0def | 93.0def | 6.0 |
| S1W3      | 53.3ab     | 50.4ab     | 5.5  | 66.3a | 63.0ab | 5.0 | 119.6ab | 113.3ab | 5.2 |
| S2W1      | 38.4d      | 34.8d      | 9.4  | 51.0d | 44.1de | 13.6 | 89.4f | 78.9g | 11.8 |
| S2W2      | 46.8bc     | 42.7c      | 8.8  | 44.2e | 39.4e | 10.9 | 91.0ef | 82.1fg | 9.8 |
| S2W3      | 45.7bc     | 41.5c      | 9.2  | 54.4cd | 49.1cd | 9.7 | 100.1de | 90.6ef | 9.5 |

Note: W1, W2 and W3 represent the three irrigation quotas of 280, 320 and 360 mm respectively, F, S1 and S2 represent the three water salinities of 1.0, 3.0 and 5.0 dS/m. The values of $Y_t$ and $Y_m$ are the means of three replications. For $Y_t$ or $Y_m$, means followed by the same letters (a, b, c, d, e, f) are not significantly different at the 5% level according to Duncan’s Multiple Range Test. DAT represent days after transplant.

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(P > 0.05) decline trend compared with F salinity, however, the tomato $Y_t$ and $Y_m$ with S2 salinity were significantly (P ≤ 0.05) lower that that with F salinity (by 17.91–20.48% and 22.89–24.76%, respectively). Under the same salinity of irrigation waters, the tomato $Y_t$ and $Y_m$ overall increased with higher irrigation quota. For the single factor of tomato yield, FW3 was proved to be the better treatments that the tomato $Y_t$ and $Y_m$ of which reached 125.8 t/hm$^2$ and 120.4 t/hm$^2$. Besides, it was found that the BER obviously increased under S2 salinity, and was by 9.48–11.74% higher compared with F, which finally led to a negative effect on the tomato $Y_m$ of S2.

The soil salt distribution

Fig 4 showed the salt distribution in soil profile. After a growth season of tomatoes, the soil salts mainly accumulated in the plough layer, mass fraction of which in 0–20 cm, 20–40 cm, 40–60 cm and 60–80 cm layer was 1.11–1.84 g/kg, 0.91–1.45 g/kg, 0.87–1.39 g/kg and 0.72–1.21 g/kg. Under the same irrigation quota, the soil salt mass fraction increased as the salinity of irrigation water increased, of which S2 was 28.83–44.88%, 18.85–39.56%, 29.91–42.53% and 34.61%–44.04% higher compared to F, respectively in the four layers. On the other hand, under the same salinity of irrigation water, salts were presented to move to the deeper soil layer when with higher irrigation quota. W2 and W3 irrigation quota decreased the soil salts in 0–20 cm and 20–40 cm layer compared to W1, but which significantly increased the salts in 40–60 cm and 60–80 cm layer, this indicated that a higher irrigation quota was more effective to leach the salts in plough layer and reduce their accumulation.

Optimal selection of saline water irrigation treatments

The comprehensive quality, $Y$, $Y_m$, IWUE (27.80 kg/m$^3$–38.89 kg/m$^3$) and soil salt content of plough layer (0–20 cm) were served as the evaluation indexes for the comprehensive benefit

Fig 4. The salt distribution of soil profile after the tomato harvest (W1, W2 and W3 represent the three irrigation quotas of 280, 320 and 360 mm respectively, F, S1 and S2 represent the three water salinities of 1.0, 3.0 and 5.0 dS/m. Each value is the mean ± SD (n = 3)).

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assessment of the irrigation treatments. The maximal projective index value that calculated by PP model was 0.2793, the best projective direction $a^{(j)} = (0.0105, 0.6211, 0.5597, 0.1548, 0.5262)$, and the projective value of S1W1, S1W2, S1W3, S2W1, S2W2 and S2W3 were ordered to be $z^{(i)} = (0.9311, 0.9311, 1.8075, 0.0871, 0.3671, 0.7981)$. A higher projective value indicates a better comprehensive benefit of saline water irrigation treatment. Therefore, S1W3 is the optimal treatment, followed by S1W1 and S1W2.

For S1W3, $Y$ and $Y_m$ had not decreased significantly as the salinity of irrigation water increased, and were both the highest among the six saline water irrigation treatments. Besides, although the comprehensive quality index and IWUE of S1W3 were not in a superior level relative to other treatments, the index weight (projective direction) of comprehensive quality index (0.0105) was the lowest, thus did not significantly changed the evaluation results. According to the calculations of PP model, 3.0 dS/m salinity of irrigation waters combined with 360 mm irrigation quota was recommended as the best saline water irrigation scheme for the tomato in northern China.

**Discussion**

Although the water resources in the world are abundant, the available water resources are insufficient. The total amount of water resources in the world is 1 400 million km$^3$, of which the freshwater resources only accounted for 2.8%, and the surface water and shallow ground water that are available accounted for 0.35% of the freshwaters [52]. Agriculture needs a large amount of water and is facing more shortage than other sectors. Presently, 80% of the world’s irrigation system adopts the diversion irrigating method, and the irrigated agriculture will continue to play an important role in meeting the needs of the world population for food [53]. In China, severe droughts often happen in the northern irrigated areas, which limit the sustainable development of agriculture. As a practical method for saving freshwater resources, saline water irrigation in northern China gradually become a hot topic, but until now there were no accepted criterions for saline water management. Thus, it is important to develop suitable management methods for using saline water to meet the challenges of sustainable irrigated agriculture that conserve water resources and have minimum impacts on the soil environment and the crop growth and development.

Our study demonstrated that the lower irrigation quota and higher salinity increased the $\rho_F$, $D_S$, $G$, $V_C$ and RSA but decreased the $LAI_m$ and $V_F$ of tomatoes, but there were no significant combining effects on the quality indexes. This was probably because that the tomatoes adjusted initiative to adapt the water stress when under a lower irrigation quota, the content of osmo-regulation substances such as proline, glucose and fructose in tomatoes increased, which had positive effects on the tomato quality [54]. High salinity of irrigation water increased the sugar concentration might due to the enhanced activity of sucrose invertase [55]. A similar study conducted by Beckles [56] also showed that increasing the soil electrical conductivity (EC), either by applying a high ionic solution or by restricting watering, resulted in a higher sugar concentration per fruit.

Early study showed that when the insufficient water supply limited the vegetative growth of tomatoes, the fruits would continue to accumulate the organics to reduce the impacts of water deficit, in this period, the accumulated organics were used in the cell wall synthesis and other process related to the fruit development in order to make up for the loss of photosynthetic production decrease [57]. However, the long period of water deficit resulted in the elasticity loss of cell walls, thus led to the decreased yields. The salinity-induced yield reductions could result from decreased inflow of water into the fruits [58], and under saline water irrigation, the reduction in fruit yield corresponded to reductions in the fruit weight and number [59]. In this
study, high salinity combined with low irrigation quota (S2W1) obtained the lowest tomato yield, which was in consistent with the early studies.

BER is commonly regarded as a calcium-deficient physiological disease [60], and water and salt are two improvement environmental factors affected its incidence. Selby [61] noted that the BERi was related to the soil moisture, and further study demonstrated that the deficient or excessive water both increased the BERi. Mohamed [62] also found that the BERi under excessive water supply was significantly higher than that under normality. In our study, the BERi was negatively related to the irrigation quota, indicating that 360 mm irrigation quota was not excessive according to Mohamed's study. However, some studies proved that the water affected the BERi was an accidental phenomena [63–64]. In addition, our study also showed that the high salinity obviously increased the BERi (of which S2W1 was the highest), it might because that the high salinity of irrigation water impeded the water absorption of tomato fruits [65], thus the calcium was difficult to move from the tomato root to the fruit bottom [66].

After one season tomato cultivation, the salt mass fraction of different soil layers that using saline water were increased to various degrees compared to that of freshwater, and the salts mainly accumulated in the plough layer. Yang [67] conducted a similar study as us but obtained a much higher increase of soil salt mass fraction in the plough layer, this may have occurred because that the temperature was relatively lower at the end of our experiment, thus the soil resalinization was slighter. Moreover, soil salts had a tendency to move to the deeper soil layer when using 320 mm and 360 mm irrigation quota, this agrees with Wang's [68] study conclusions. In our study, the salt distribution might not be affected by only irrigation amount, but also by the mulching. Taia A. Abd El-Mageed [69] conducted a thorough experiment and pointed out that noticeable decrease in salts accumulation in the root zone could be associated with soil mulching application.

Projection pursuit model has been widely used in the optimization of irrigation regime. Hou [70] adopted the projection pursuit model to select the best drip irrigation scheme for crop. Other methods, such as principal component analysis, entropy weight coefficient model were also used for guiding the agricultural production [71]. The essence of these models was the same, namely realizing the reduction of high-dimensional data. When using the models to select an irrigation scheme, various indexes should be considered. However, most early studies noticed only the crop yield, water use and irrigation water consumption. Wu [72] took the crop growth, \(Y_t\), overall quality and water use into consideration when choosing a saline water irrigation regime, but has not involved the amount of residual salt in soil.

For northern China, a good scheme of saline water irrigation for tomatoes should not only consider the quality and \(Y_t\), but also involve the \(Y_m\), IWUE and the soil salt residual after irrigation. In this study, the optimal saline water irrigation scheme selected by the PP model was S1W3, 3.0 dS/m salinity combined with 360 mm irrigation quota. PP model avoided the one-sidedness of using the subjective weight independently, thus the results that were obtained were more reliable. The optimal treatment S1W3 in this study possessed the best comprehensive benefit (tomato overall quality, \(Y_t\), \(Y_m\), IWUE and soil salt residual), and was recommended as the saline water irrigation scheme for tomatoes in northern China. However, in this experiment, the irrigation waters were distributed evenly according to the whole growth stage of tomatoes, the uneven distribution of saline waters according to different growth stage of tomatoes may have different effects on the tomato growth and development. Therefore, more researches on this topic are needed in future.

**Conclusion**

Compared to freshwater, saline water irrigations decreased the \(LAIm\) of tomatoes, and \(LAIm\) presented a decline tendency with higher salinity and lower irrigation quota. The \(\rho_F\), \(D_o\), \(G\), \(V_C\) and
RSA increased but the $V_F$ decreased as the salinity increased and irrigation quota decreased. S2W1 treatment obtained the best overall quality of tomatoes, with the comprehensive quality index of 3.61. A higher salinity and lower irrigation quota caused a decrease in individual fruit weight and an increase in BER, finally led to a reduction in $Y_t$ and $Y_m$. After one growth season of tomato, the mass fraction of soil salts in plough layer with S2W1 treatment was the highest, and which presented a decline trend with increasing irrigation quota. Moreover, compared to W1, soil salts had a tendency to move to the deeper soil layer when using W2 and W3 irrigation quota. According to the calculation results of PP model, S1W3 was the optimal treatment, which possessed the best comprehensive benefit (tomato overall quality, $Y_t$, $Y_m$, IWUE and soil salt residual), and was recommended as the saline water irrigation scheme for tomatoes in northern China.

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Author Contributions

Conceptualization: YZ.
Data curation: YZ YW.
Formal analysis: YZ.
Funding acquisition: YZ.
Investigation: YZ.
Methodology: YZ YW.
Project administration: YZ.
Software: YZ YW.
Validation: YZ.
Writing – original draft: YZ.
Writing – review & editing: QY.

References

1. O'Shaughnessy SA, Rush C. Precision Agriculture: Irrigation. In: Allen NKV, editor. Encyclopedia of Agriculture and Food Systems. Oxford: Academic Press; 2014. p. 521–35.
2. Wang Y-R, Kang S-Z, Li F-S, Zhang L, Zhang J-H. Saline Water Irrigation Scheduling Through a Crop-Water-Salinity Production Function and a Soil-Water-Salinity Dynamic Model. Pedosphere. 2007; 17 (3):303–17. http://dx.doi.org/10.1016/S1002-0160(07)60037-X.
3. Gao XB, Zhang FC, Wang C, Wang YX. Coexistence of High Fluoride Fresh and Saline Groundwaters in the Yuncheng Basin, Northern China. Procedia Earth and Planetary Science. 2013; 7(0):280–3. http://dx.doi.org/10.1016/j.proeps.2013.03.052.
4. Zhou J, Zhang Z, Sun G, Fang X, Zha T, McNulty S, et al. Response of ecosystem carbon fluxes to drought events in a poplar plantation in Northern China. Forest Ecology and Management. 2013; 300 (0):33–42. http://dx.doi.org/10.1016/j.foreco.2013.01.007.
5. Liu J, Zang C, Tian S, Liu J, Yang H, Jia S, et al. Water conservancy projects in China: Achievements, challenges and way forward. Global Environmental Change. 2013; 23(3):633–43. http://dx.doi.org/10.1016/j.gloenvcha.2013.02.002.
6. Wang C, Wang G, Feng Z, Ji X, Li Q, Zhang Z, et al. Strengthen Water Conservancy Construction, Use Water Resources Scientifically, and Develop Modern Agriculture. Procedia Environmental Sciences. 2011; 10, Part B(0):1595–600. http://dx.doi.org/10.1016/j.proenv.2011.09.253.

7. Shao H-B, Li-Ye C, Gang W, Jin-Heng Z, Zhao-Hua L. Where is the road to bio-water-saving for the globe? Colloids and Surfaces B: Biointerfaces. 2007; 55(2):251–5. http://dx.doi.org/10.1016/j.colsurfb.2006.12.001. doi: 10.1016/j.colsurfb.2006.12.001 PMID: 17240122

8. Wang H, Liu C, Zhang L. Water-saving agriculture in China: An overview. Advances in Agronomy. Volume 75: Academic Press; 2002. p. 135–71.

9. Qiu R, Song J, Du T, Kang S, Tong L, Chen R, et al. Response of evapotranspiration and yield to planting density of solar greenhouse grown tomato in northwest China. Agricultural Water Management. 2013; 130(0):44–51. http://dx.doi.org/10.1016/j.agwat.2013.08.013.

10. Yi L, Jiao W, Chen X, Chen W. An overview of reclaimed water reuse in China. Journal of Environmental Sciences. 2011; 23(10):1585–93. http://dx.doi.org/10.1016/S1001-0742(10)60627-4.

11. Li X, Kang Y, Wan S, Chen X, Chu L. Reclamation of very heavy coastal saline soil using drip-irrigation with saline water on salt-sensitive plants. Soil and Tillage Research. 2015; 146, Part B(0):159–73. http://dx.doi.org/10.1016/j.still.2014.10.005.

12. Liu S, Kang Y, Wang D, Liu S-p. Effect of saline water on cucumber (Cucumis sativus L.) yield and water use under drip irrigation in North China. Agricultural Water Management. 2010; 98(1):105–13. http://dx.doi.org/10.1016/j.agwat.2010.08.003.

13. Kumar P, Sarangi A, Singh DK, Panhar SS, Sahoo RN. Simulation of salt dynamics in the root zone and yield of wheat crop under irrigated saline regimes using SWAP model. Agricultural Water Management. 2015; 148(0):72–83. http://dx.doi.org/10.1016/j.agwat.2014.09.014.

14. Li C, Lei J, Zhao Y, Xu X, Li S. Effect of saline water irrigation on soil development and plant growth in the Taklimakan Desert Highway shelterbelt. Soil and Tillage Research. 2015; 146, Part A(0):99–107. http://dx.doi.org/10.1016/j.still.2014.03.013.

15. Kanzari S, Hachicha M, Boughila R, Battle-Sales J. Characterization and modeling of water movement and salts transfer in a semi-arid region of Tunisia (Bou Hajla, Kairouan)–Salinization risk of soils and aquifers. Computers and Electronics in Agriculture. 2012; 86(0):34–42. http://dx.doi.org/10.1016/j.compag.2011.09.010.

16. Yao R-j, Yang J-s, Zhang T-j, Hong L-z, Wang M-w, Yu S-p, et al. Studies on soil water and salt balances and scenarios simulation using SaltMod in a coastal reclaimed farming area of eastern China. Agricultural Water Management. 2014; 131(0):115–23. http://dx.doi.org/10.1016/j.agwat.2013.09.014.

17. Hou M, Shao X, Zhai Y. Effects of Different Regulatory Methods on Improvement of Greenhouse Saline Soils, Tomato Quality, and Yield. Scientific World Journal. 2014; Volume 2014:Article ID 953675.

18. Chen L-J, Feng Q, Li F-R, Li C-S. A bidirectional model for simulating soil water flow and salt transport under mulched drip irrigation with saline water. Agricultural Water Management. 2014; 146(0):24–33. http://dx.doi.org/10.1016/j.agwat.2014.07.021.

19. Wang D, Kang Y, Wan S. Effect of soil matric potential on tomato yield and water use under drip irrigation condition. Agricultural Water Management. 2007; 87(2):180–6. http://dx.doi.org/10.1016/j.agwat.2006.06.021.

20. Abdel Gawad G, Arslan A, Gaihbe A, Kadouri F. The effects of saline irrigation water management and salt tolerant tomato varieties on sustainable production of tomato in Syria (1999–2002). Agricultural Water Management. 2005; 78(1–2):39–53. http://dx.doi.org/10.1016/j.agwat.2005.04.024.

21. Incrocci L, Malorgio F, Della Bartola A, Pardossi A. The influence of drip irrigation or subirrigation on tomato grown in closed-loop substrate culture with saline water. Scientia Horticulturae. 2006; 107(4):365–72. http://dx.doi.org/10.1016/j.scienta.2005.12.001.

22. Malash N, Flowers TJ, Ragab R. Effect of irrigation systems and water management practices using saline and non-saline water on tomato production. Agricultural Water Management. 2005; 78(1–2):25–38. http://dx.doi.org/10.1016/j.agwat.2005.04.016.

23. Wan S, Kang Y, Wang D, Liu S-P, Feng L-P. Effect of drip irrigation with saline water on tomato (Lycopersicon esculentum Mill) yield and water use in semi-humid area. Agricultural Water Management. 2007; 90(1–2):63–74. http://dx.doi.org/10.1016/j.agwat.2007.02.011.

24. Cuartero J, Fernández-Muñoz R. Tomato and salinity. Scientia Horticulturae. 1998; 78(1–4):83–125. http://dx.doi.org/10.1016/S0304-4238(98)00191-5.

25. Dorais M, Papadopoulos A., Gosselin A. Greenhouse tomato fruit quality. Horticultural Reviews. 2001; 26:239–319.
Huang Z, He C-x, He Z-q, Zou Z-r, Zhang Z-b. The Effects of Arbuscular Mycorrhizal Fungi on Reactive Oxyradical Scavenging System of Tomato Under Salt Tolerance. Agricultural Sciences in China. 2010; 9(8):1150–9. http://dx.doi.org/10.1016/S1671-2927(09)60202-9.

Nebauer SG, Sánchez M, Martínez L, Liuch Y, Renau-Morata B, Molina RV. Differences in photosynthetic performance and its correlation with growth among tomato cultivars in response to different salts. Plant Physiology and Biochemistry. 2013; 63(0):61–9. http://dx.doi.org/10.1016/j.plaphy.2012.11.006.

Tuna AL, Kaya C, Ashraf M, Altunlu H, Yokas I, Yagmur B. The effects of calcium sulphate on growth, membrane stability and nutrient uptake of tomato plants grown under salt stress. Environmental and Experimental Botany. 2007; 59(2):173–8. http://dx.doi.org/10.1016/j.envexpbot.2005.12.007.

Shao X, Hou M, Chen J. Effects of EM-calcium spray on Ca uptake, blossom-end rot incidence and yield of greenhouse tomatoes (Lycopersicon esculentum). Research on Crops. 2013; 14(4):1159–66.

Adams P, Ho L.C. Effects of environment on the uptake and distribution of calcium in tomato and on the incidence of blossom-end rot. Plant Soil. 1993; 154:127–32.

Akhtar SS, Li G, Andersen MN, Liu F. Biochar enhances yield and quality of tomato under reduced irrigation. Agricultural Water Management. 2014; 133(0):92–103. http://dx.doi.org/10.1016/j.agwat.2013.11.008.

Akhter SS, Li G, Andersen MN, Liu F. Biochar enhances yield and quality of tomato under reduced irrigation. Agricultural Water Management. 2014; 138(0):37–44. http://dx.doi.org/10.1016/j.agwat.2014.02.016.

Suarez MC. Blossom-end rot of tomato (Lycopersicon esculentum Mill.)—a calcium- or a stress-related disorder? Scientia Horticulturae. 2001; 90(3–4):193–208. http://dx.doi.org/10.1016/S0304-4238(01)00227-8.

Kuşçu H, Turhan A, Demir AO. The response of processing tomato to deficit irrigation at various physiological stages in a sub-humid environment. Agricultural Water Management. 2014; 130(0):92–103. http://dx.doi.org/10.1016/j.agwat.2013.11.008.

Ouyang L, Li G, Dong L. The effects of salt stress on tomato growth and fruit quality. Acta Agronomica Sinica. 2002; 28(4):709–15. http://dx.doi.org/10.1371/journal.pone.0142204 PMID: 26540394

Taylor MD, Locascio SJ, Alligood MR. Blossom-end rot incidence of tomato as affected by irrigation quantity, calcium source, and reduced potassium. HortScience. 2004; 39(5):1110–5.

Hou M, Zhu L, Jin Q. Surface Drainage and Mulching Drip-Irrigated Tomatoes Reduces Soil Salinity and Improves Fruit Yield. PLoS ONE. 2016; 11(5):e0154799. doi: 10.1371/journal.pone.0154799

Maggio A, De Pascale S, Angelino G, Ruggiero C, Barbieri G. Physiological response of tomato to saline irrigation in long-term salinized soils. European Journal of Agronomy. 2004; 21(2):149–59. http://dx.doi.org/10.1016/S1161-0301(03)00092-3.

Postharvest Biology and Technology. 2014; 93(0):114–21. http://dx.doi.org/10.1016/j.postharvbio.2014.02.014.

Sánchez-Rodríguez E, Rubio-Wilhelmi MdM, Blasco B, Leyva R, Romero L, Ruiz JM. Antioxidant response resides in the shoot in reciprocal grafts of drought-tolerant and drought-sensitive cultivars in tomato under water stress. Plant Science. 2012; 188–189(0):89–96. http://dx.doi.org/10.1016/j.plantsci.2011.12.019.

Subramanian KS, Santhanakrishnan P, Balasubramanian P. Responses of field grown tomato plants to arbuscular mycorrhizal fungal colonization under varying intensities of drought stress. Scientia Horticulturae. 2006; 107(3):245–53. http://dx.doi.org/10.1016/j.scienta.2005.07.006.

Patané C, Tringali S, Sortino O. Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions. Scientia Horticulturae. 2011; 129(4):590–6. http://dx.doi.org/10.1016/j.scienta.2011.04.030.

Taylor MD, Locascio SJ, Alligood MR. Blossom-end rot incidence of tomato as affected by irrigation quantity, calcium source, and reduced potassium. HortScience. 2004; 39(5):1110–5.

Hou M, Zhu L, Jin Q. Surface Drainage and Mulching Drip-Irrigated Tomatoes Reduces Soil Salinity and Improves Fruit Yield. PLoS ONE. 2016; 11(5):e0154799. doi: 10.1371/journal.pone.0154799

PMID: 27153110

Wang W, Shao X, Chen J. Principal component analysis of effects of irrigation water quality and quantity on tomato quality. Journal of Hohai university (Natural Science). 2014; 42(4):372–6.

Zhai Y, Yang Q, Hou M. The Effects of Saline Water Drip Irrigation on Tomato Yield, Quality, and Blossom-End Rot Incidence—A 3a Case Study in the South of China. PLoS ONE. 2015; 10(11):e0142204. doi: 10.1371/journal.pone.0142204

PMID: 26540394
46. Zotarelli L, Scholberg JM, Dukes MD, Muñoz-Carpena R, Icerman J. Tomato yield, biomass accumulation, root distribution and irrigation water use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling. Agricultural Water Management. 2009; 96(1):23–34. http://dx.doi.org/10.1016/j.agwat.2008.06.007.

47. Hou M, Shao X, Jin Q, Gao X. A 15N tracing technique-based analysis of the fate of fertilizer N: a 4-year case study in eastern China. Archives of Agronomy and Soil Science. 2017; 1:1–10. doi: 10.1080/03650340.2016.1182159

48. Shao GC, Wang MH, Liu N, Yuan M, Kumar P, She DL. Growth and Comprehensive Quality Index of Tomato under Rain Shelters in Response to Different Irrigation and Drainage Treatments. scientific world journal. 2014. 457937 doi: 10.1155/2014/457937. WOS:000343475500001. PMID: 25054180

49. Shao XH, Hou MM, Chen LH, Chang TT, Wang WN. Evaluation of Subsurface Drainage Design Based on Projection Pursuit. Energy Procedia. 2012; 16, Part B:747–52. http://dx.doi.org/10.1016/j.egypro.2012.01.120.

50. Yu Wang, Zheng Wei. Evaluation of water-saving irrigation mode for flue-cured tobacco based on projection pursuit classification model. Water-saving irrigation. 2012; 18:2060–2.

51. Hou MM, Shao XH, Chen LH, Chang TT, Wang WN, Wang YF. Study on fertilizer N leaching, accumulation, and balance in tobacco fields with N-15 tracing technique. J Food Agric Environ. 2012; 10(2):1284–9. WOS:000305310800076.

52. de Marsily G. An overview of the world’s water resources problems in 2050. Ecohydrology & Hydrobiology. 2007; 7(2):147–55. http://dx.doi.org/10.1016/S1642-3593(07)70180-5.

53. Shao G-C, Deng S, Liu N, Yu S-E, Wang M-H, She D-L. Effects of controlled irrigation and drainage on growth, grain yield and water use in paddy rice. European Journal of Agronomy. 2014; 53:1–9. doi: 10.1016/j.eja.2013.10.005. WOS:000330150300001.

54. Jensen CR, Battilani A, Plauborg F, Psarras G, Chartzoulakis K, Janowicz F, et al. Deficit irrigation based on drought tolerance and root signalling in potatoes and tomatoes. Agricultural Water Management. 2010; 98(3):403–13. http://dx.doi.org/10.1016/j.agwat.2010.10.018.

55. Lu S. Effects of salt stress on sugar content and sucrose metabolism in tomato fruit. China Vegetable. 2012; 20(2):56–61.

56. Beckles DM. Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit. Postharvest Biology and Technology. 2012; 63(1):129–40. http://dx.doi.org/10.1016/j.postharvbio.2011.05.016.

57. Chalmers DJ. Productivity of peach trees Factors affecting dry weight distribution during tree growth. AnnBot. 1975; 239:423–32.

58. Li YL, Stanghellini C, Challa H. Response of tomato plants to a step-change in root-zone salinity under two different transpiration regimes. Scientia Horticulturae. 2002; 93(3–4):267–79. http://dx.doi.org/10.1016/S0304-4238(01)00329-6.

59. Katerji N, van Hoorn JW, Hamdy A, Mastrorilli M. Response of tomatoes, a crop of indeterminate growth, to soil salinity. Agricultural Water Management. 1998; 38(1):59–68. http://dx.doi.org/10.1016/S0378-3774(98)00051-1.

60. Nonami H. Blossom end rot of tomato plants may not be caused by calcium deficiency. Acta Hort. 1995; 396:107–14.

61. Selby. Investigations of plant diseases in forcing house and garden. Ohio Agri Exp Sta Bull. 1896; 73:146–221(from Spurr 1959).

62. Mohamed AA. Effect of soil water regime and calcium level on growth, yield and blossom-end rot incidence of tomato plant. Mesopotamia J Agric. 1989; 21:65–78.

63. Speery WJ. Soil moisture and cultivar influence cracking, blossom-end rot, zippers, and yield of staked fresh-market tomatoes. HortTechnol. 1996; 6:21–4.

64. DeKork PC. The effect of water stress and form of nitrogen on the incidence of blossom-end rot in tomatoes. JSci Food Agric. 1982; 33:509–15.

65. Reina-Sánchez A, Romero-Aranda R, Cuartero J. Plant water uptake and water use efficiency of greenhouse tomato cultivars irrigated with saline water. Agricultural Water Management. 2005; 78(1–2):54–66. http://dx.doi.org/10.1016/j.agwat.2005.04.021.

66. Ehret. Translocation of calcium in relation to tomato fruit growth. Ann Bot. 1986; 58:679–88.

67. Yang J. Effect of irrigation with brackish water on soil salinity and spring maize growth. Acta Agriculturae Zhejiangensis. 2010; 22(6):813–7.

68. Wang R, Wan S, Kang Y, Dou C. Assessment of secondary soil salinity prevention and economic benefits under different drip line placement and irrigation regime in northwest China. Agricultural Water Management. 2014; 131(0):41–9. http://dx.doi.org/10.1016/j.agwat.2013.09.011.
69. Abd El-Mageed TA, Semida WM, Abd El-Wahed MH. Effect of mulching on plant water status, soil salinity and yield of squash under summer-fall deficit irrigation in salt affected soil. Agricultural Water Management. 2016; 173:1–12. http://dx.doi.org/10.1016/j.agwat.2016.04.025.

70. Hou M, Shao X. Optimization of irrigation-drainage scheme for tomato crop based on multi-index analysis and projection pursuit model. ZeMdirbyste-Agriculture. 2016; 103(2):221–8.

71. Shao G-c, Wang M-h, Liu N, Yuan M, Kumar P, She D-L. Growth and Comprehensive Quality Index of Tomato under Rain Shelters in Response to Different Irrigation and Drainage Treatments. Scientific World Journal. 2014. 457937 doi: 10.1155/2014/457937 WOS:000343475500001.

72. Wu Y, Jin X, Xu Y. Effects of Saline Water Irrigation on Tomato Growth, Quality and Yield Under Straw Mulching. Water-saving irrigation. 2015; 7(1):21–4.