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Full Length Article

Effect of Saline Water Irrigation on Soil Moisture and Salinity and Modeling Transpiration of Greenhouse-Grown Tomato in Response to Salt Stress

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Abstract

Fresh water shortage is a major limiting factor for the development of greenhouse agriculture in arid regions. Brackish or saline water irrigation is an important approach to address this issue. However, the salts from irrigation water are also brought into the soil. If the salts accumulate in the crop root zone, it may have a negative effect on crop growth. In this study, a greenhouse experiment was carried out to evaluate the influence of saline water irrigation on soil moisture and salinity and to examine the response of tomato transpiration to salt stress. The treatments comprised of three salinity levels (0.4 g L^{-1} (fresh water; control), 3.4 g L^{-1} and 6.4 g L^{-1}; denoted as T1, T2 and T3, respectively). Results showed that saline water irrigation significantly increased soil moisture and salinity, while no obvious difference was observed in root length density distribution among the treatments. Further, a method was developed to optimize the parameters in tomato transpiration model using the data from T3 treatment and the results were validated using the data from T2 treatment. We found that the optimized model could well simulate the effects of salt accumulation on tomato transpiration. Overall, our results would provide theoretical and technical support for soil salt regulation and sustainable saline water utilization for greenhouse agricultural production. © 2020 Friends Science Publishers

Keywords: Salt stress; Tomato; Saline water irrigation; Greenhouse; Transpiration model

Introduction

Greenhouse agriculture provides a suitable environment for crop growth using engineering and control technologies. Vegetable production in greenhouse breaks the natural temperature limitation observed in open field. Crops can be commercially produced year-round in greenhouse, thus, significantly improving land use efficiency. In recent years, greenhouse tomato cultivation has rapidly expanded in different regions of the world (Tüzel and Leonardi 2014; Soto *et al*. 2014; Jiang *et al*. 2015). Irrigation is the only water resource for crops growth in greenhouse. Water shortage is one of the major limiting factors on greenhouse agriculture development in arid areas. However, with the development of modern agriculture, the area of greenhouse establishment is projected to further increase. In this scenario, the problem of water shortage will become more serious.

Under saline water irrigation, crops are irrigated with saline or brackish water instead of fresh water, which opens new sources of irrigation water supply and is an important way to relieve the crisis of agricultural water shortage. Brackish water is widely distributed in arid and semi-arid regions worldwide, especially in Pakistan, North China and the Mediterranean (Naz *et al*. 2009; Qian *et al*. 2014; Gioia *et al*. 2018). Saline water irrigation can fully meet crop water requirements. Nevertheless, irrigation with saline water leads to the risk of salinization in surface soil. If the salt contents exceed crop tolerance, root absorption function will be inhibited, and the growth and yield will be restricted (Al-Maskri *et al*. 2010). The effects of saline water irrigation on soil environment and crop growth have been widely studied under open-field conditions. Wang *et al*. (2007) reported that there was no obvious salt accumulation in the root zone of field-grown tomato when electrical conductivity (EC) of irrigation water was less than 4.2 dS m^{-1}. Wan *et al*. (2008) found that the tomato water consumption decreased under irrigation water EC of 5 dS m^{-1}, but there was no effect on crop growth and yield.

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Zhang *et al.* (2016) also reported no evident influence on cotton water consumption when salt concentration of irrigation water was less than 7 g L^{-1}. In the greenhouse environment, plants are subject to high temperature and humidity. Rainfall leaching is blocked by the greenhouse covers (Hu *et al.* 2017). Therefore, compared with open fields, soil salinization in greenhouse environments seems to be more apparent. Zhai *et al.* (2016) found that the soil salts were accumulated in the root zone of greenhouse-grown tomato under saline water irrigation. In a pot experiment of tomato irrigated with saline water, Reina-Sánchez *et al.* (2005) found that the amount of water consumption decreased linearly with the increasing salt concentration in the irrigation water. The effects of irrigation with saline water on soil environment and crop water consumption are still needed to be explored under greenhouse conditions.

Accurate estimation of crop water consumption (transpiration) response to salinity stress is important to optimize the irrigation and soil salt regulation strategies. Crop transpiration is closely related to meteorology, crop varieties, soil moisture and salinity. Manual measurements of field-grown crop transpiration are cost, time and labor consuming. Based on the theories of heat balance or thermal pulse, in situ transpiration measurements were developed with the advantages of being non-destructive and having no effect on crop growth (Pausch *et al*. 2005; Wang *et al*. 2015). However, because of high cost of the equipment, the use of this method is not applicable in some cases. Recently, transpiration models developed based on the theories of energy balance have been widely used to calculate crop transpiration (Cohen *et al*. 1993; Smith and Allen 1996). Under saline stress, the crop water consumption can be simulated by combining the salt stress factor and potential transpiration model (Homaee *et al*. 2002; Shouse *et al*. 2011; Lekakis and Antonopoulos 2015). Previous work indicates that the parameters of salt stress factor varied with crop varieties and soil types. Thus, these parameters should be optimized using the data from practical conditions (Wang *et al*. 2012). However, few studies have been conducted to quantify vegetable crop transpiration in responses to salinity stress under greenhouse conditions. Tomato is one of the most important vegetable crops that provide vitamins, mineral and fiber for human beings (Flores *et al*. 2010). Particularly, under greenhouse cultivation, excessive fertilizer and water application leads to soil degradation because of increasing soil salinization (Shi *et al*. 2009). Characterizing the response of greenhouse tomato transpiration to salt salinity stress is necessary to regulate the soil salts and mitigate the impacts of soil salt accumulation on crop yield.

The objectives of this study were: (1) to evaluate the effects of salt concentration in irrigation water on root zone soil water, salt dynamics and transpiration of greenhouse-grown tomato; and (2) to develop a method for quantifying the influence of salt stress on tomato transpiration.

Materials and Methods

Experimental design

Experimental material: The experiment was conducted in a greenhouse located in Guangyang District, Langfang City, Hebei Province, China (39°32'N, 116°43'E). The annual mean temperature is 11.9°C and with 2,684 h of annual sunshine duration. The ground water table is below 25 m. The greenhouse is 30 m long by 6 m wide with a steel frame, covered with 0.2 mm thick polyethylene. The soil water retention curve and non-saturation water conductivity were characterized with the van Genuchten function (Genuchten 1980). The soil physical and hydraulic parameters are summarized in Table 1. The soil chemical parameters are illustrated in Table 2.

Tomato plants (*Lycopersicon esculentum* Mill., cultivar Jiali-14) were transplanted on March 21, 2016. Before transplanting, the planting beds were spaced 1.0 m apart and 0.4 m wide on the top. Plant seedlings were spaced 0.35 m apart within rows and the distance between two rows on each soil bed was 0.3 m. Dripline with wall thickness of 0.4 mm and 15 mm inside diameter was set up in each row and had emitters spaced at 10 cm intervals with a discharge of 1.38 L h^{-1}. The soil beds were covered with transparent polyethylene mulch (0.1 mm in thicknesses) to reduce soil surface evaporation.

Treatments: Three levels of irrigation water salinity were imposed: 0.4 g L^{-1} (tap water; control), 3.4 g L^{-1} and 6.4 g L^{-1}, (labeled as T1, T2 and T3, respectively). The salinity treatments were adjusted by adding NaCl and $CaCl_2$ to tap water in equal proportions. There were three replicates for each treatment. The seedlings were transplanted at 56 days after sowing. To increase the survival rate of the tomato seedlings, all the 3 treatments were irrigated with fresh water for the first 2 times of irrigation. Twenty seven days after transplanting (DAT), different salinity treatments were applied. Each plot was irrigated with 40 mm of water for 7 times at approximately 15 d interval or according to the requirement (1, 14, 27, 38, 55, 71 and 87 DAT). Water-soluble compound fertilizer (19:19:19, N: P_2O_5: K_2O) was applied at 1500 kg ha^{-1} using the drip fertigation system.

Root samples were taken 4 times (30, 53, 71 and 96 DAT) using an auger (8 cm in diameter) at 0–10, 10–20, 20–30, 30–40, 40–50 cm soil depth. Soil cores were taken in three locations around the tomato plant, that is, the edge of the soil bed, clinging to the plant and the center of soil bed. The roots were washed using tap water on a mesh with grids of 0.5 mm. Roots were scanned with a scanner (EsponV700, Seiko Epson Corp, Japan) and analyzed with a commercial software (WinRHIZO, Regent Instruments Inc., Canada) for root length density. The three root samples at the same depth were used to obtain average root length density.

After root sampling, soil was sampled at 0–10, 10–20, 20–30, 30–50, 50–70 cm depth adjacent to the root sampling points. Soil cores were collected using an auger (2 cm in diameter). Sampling was conducted before and after irrigation for 10 times. Each soil sample was divided into two parts. One was used for the soil moisture measurement using gravimetric method, and the other was used to determine the EC of soil water 1:5 extracts (w/v) with an electrical conductivity meter (DDS-307, Shanghai Precision & Scientific Instrument Inc., China). Without consideration of iron toxicity, the effect of salinity stress on crops is closely related to osmotic potential (Somma *et al.* 1998; Babazadeh *et al.* 2017). The soil osmotic potential was calculated by (Setia *et al.* 2011):

$$\varphi_o = -3.6A\frac{EC\rho}{\theta} \tag{1}$$

Where, φ_o is the soil osmotic potential (cm); A is the ratio of water to soil (V/W); *EC* is the electrical conductivity of soil extracts (dS cm^{-1}); ρ is soil bulk density (g cm^{-3}); θ is soil volume water content (cm^3 cm^{-3}).

Simulating greenhouse tomato transpiration rate response salinity stress

About 99% of water taken up by plant roots is used for transpiration (Ouyang *et al.* 2016), which means that the rate of root water uptake of the whole plant is almost the same as the rate of transpiration. Therefore, the transpiration rate T_a (cm d^{-1}) can be expressed as:

$$T_a = \int_0^{Lr} S\left(\mathrm{z,t}\right) dz \tag{2}$$

Where *S(z,t)* is root water absorption rate (cm^3 cm^{-3} d^{-1}). Under saline water irrigation; crop would suffer from water and salinity stress simultaneously. Under combined water and salt stress, the root water uptake rate was estimated as follows (Skaggs *et al.* 2006):

$$S(z,t) = K_s\left(\varphi_o\right) K_w\left(\theta\right) S_{\max}\left(z,t\right) \tag{3}$$

Where $K_s(\varphi_o)$ and $K_w(\theta)$ are salt and water stress factors, which are used to describe the influences of salt and water stress on crop water uptake respectively, ranging from 0 to 1.

Substituting Eq. (3) into Eq. (2) yields:

$$T_a = \int_0^{Lr} k_s\left(\varphi_o\right) K_w\left(\theta\right) S_{\max}\left(z,t\right) dz \approx k_s\left(\overline{\varphi_o}\right) k_w\left(\bar{\theta}\right) \int_0^{Lr} S_{\max}\left(z,t\right) dz = k_s\left(\overline{\varphi_o}\right) k_w\left(\bar{\theta}\right) T_p \tag{4}$$

Where $\overline{\varphi_o}$ is the average soil osmotic potential in the crop rootzone (cm); $\bar{\theta}$ is the average soil moisture in the crop root zone (cm^3 cm^{-3}); and T_p is the potential transpiration rate (cm d^{-1}), which represents the maximum transpiration under optimal conditions.

The water stress reduction factor $K_w(\theta)$ can be calculated by Allen *et al.* (1998) and Raes *et al.* (2006):

$$k_w\left(\bar{\theta}\right) = \begin{cases} 1 & \theta_j \le \bar{\theta} \le \theta_f \\ \dfrac{\bar{\theta} - \theta_p}{\theta_j - \theta_p} & \theta_p < \bar{\theta} < \theta_j \\ 0 & \bar{\theta} \le \theta_p \end{cases} \tag{5}$$

Where θ_f is field water capacity (cm^3 cm^{-3}); θ_j is the threshold of root zone soil moisture below which crop transpiration will be affected by water stress and K_w would be smaller than 1 (cm^3 cm^{-3}); and θ_p is wilting point (cm^3 cm^{-3}).

The salt stress factor was calculated using the method described by Homaee *et al.* (2002) and Shouse *et al.* (2011):

$$k_s\left(\overline{\varphi_o}\right) = 1 + \frac{\alpha}{360}\left(\overline{\varphi_o} - \varphi_o^*\right) \tag{6}$$

Where α is the fitting parameters; φ_o^* is the threshold of root zone osmotic potential below which the crop transpiration will be influenced by salinity stress and k_s would be smaller than 1 (cm). The parameters of α and φ_o^* are related to crop varieties and soil types. Therefore, obtaining the parameters of the salt stress factor under actual conditions is the key to accurately estimate actual crop transpiration rate under salt stress.

The transpiration salt stress factor can be calculated by Eq. (4):

$$k_s\left(\overline{\varphi_o}\right) = \frac{T_a}{k_w\left(\bar{\theta}\right) T_p} \tag{7}$$

The parameters in the transpiration salt stress factor can be optimized by combining Eqs. (6) and (7) with the least squares method. In Eq. 7, the actual transpiration rate can be calculated using Eq. 2 on the premise that the actual root water uptake rate distribution is determined. $k_w\left(\bar{\theta}\right)$ can be calculated with Eq. (5). In addition to using the Penman-Monteith equation, the potential crop transpiration rate can also be calculated as follows: For the fresh water irrigation treatment T1, the effect of salinity stress on tomato transpiration rate was neglected because of the low EC values of soil extracts, that is, (φ_o) was equal to 1. Based on Eq. 3, the maximum root water uptake rate S_{max} can be expressed as:

$$S_{\max}(z,t) = \frac{S\left(z,t\right)}{K_w\left(\bar{\theta}\right)} \tag{8}$$

Similar to Eq. (2), the potential transpiration T_p can be calculated by:

$$T_{\mathrm{p}} = \int_0^{Lr} S_{\max}\left(\mathrm{z}\right) dz \approx \frac{1}{K_w\left(\bar{\theta}\right)} \int_0^{Lr} S\left(z,t\right) dz \tag{9}$$

Determination of the actual root water uptake rate profiles is important to optimize the parameter of salt stress factor (Eq. 6). An inverse method provided a reference for estimating the root water uptake rate (Zuo and Zhang 2002). This method was developed based on a one-dimensional model of soil water flow. The drip irrigation was chosen in this study. Although the distance between the two drip lines and the two emitters was small in each soil bed (20 cm and 10 cm, respectively), the wetting patterns overlapped. The validity of this inverse method to estimate the actual transpiration rate should be further investigated.

In addition, plant transpiration can be estimated using the water balance method (Yuan *et al*. 2001; Qiu *et al*. 2011; Chen *et al*. 2015):

$$P + I = R + D + ET - \Delta S \tag{10}$$

$$T_a = \frac{ET - E}{N} \tag{11}$$

In Eq. (10), P is rainfall (cm); I is irrigation (cm); R is runoff (cm); D is deep drainage (cm); ET is evapotranspiration (cm); ΔS is the change of soil water storage over a period of N days (cm). In Eq. (11), E is soil surface evaporation (cm). In the greenhouse, the rainfall was blocked by the plastic film, that is, P=0. The runoff and deep drainage can be ignored under drip irrigation conditions (Yuan *et al*. 2001; Qiu *et al*. 2011). The applicability of the inverse method to calculate the crop transpiration rate was investigated by comparing the two methods of calculating the actual transpiration.

Model performance criteria

Statistical indices were employed to evaluate the performance of simulating transpiration response to salinity stress as follows:

(1) Relative error (*RE*)

$$RE = \frac{\sum_{i=1}^{n}\left|EV_i - SV_i\right|}{\sum_{i=1}^{n} EV_i} \times 100\% \tag{12}$$

(2) Root mean square error (*RMSE*)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(EV_i - SV_i\right)^2}{n}} \tag{13}$$

(3) Normalized root mean square error (*nRMSE*)

$$nRMSE = \frac{RMSE}{\overline{EV}} \times 100\% \tag{14}$$

Table 1: Soil physical and hydraulic parameters

Soil texture	ρ	FC	*Ks*	*θs*	*θr*	*α*	n
	g cm^{-3}	cm^3 cm^{-3}	cm d^{-1}	cm^3 cm^{-3}	cm^3 cm^{-3}	cm^{-1}	
Silt loam	1.42	0.21	13.6	0.45	0.07	0.032	1.75

ρ: bulk density; FC field capacity; *Ks*: saturated hydraulic conductivity; *θs* and *θr*: saturated and residual water contents, respectively; *α* and *n*: fitted coefficients in Genuchten (1980) equation

Table 2: Soil chemical parameters

TN	AP	AK	OM	PH
g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	
1.02	55.7	137.7	11.3	7.54

TN: total nitrogen; AP: available phosphorus; AK: available potassium; OM: organic matter

Where EV_i is the estimated tomato transpiration rate using the inverse method (cm d^{-1}); SV_i is the simulated tomato transpiration rate (cm d^{-1}); $\overline{EV}$ is the mean of the estimated data (cm d^{-1}). *RE* was used to characterize the difference between the estimated and simulated transpiration and ranged from 0 to 1. With the *RE* value closer the to 0, the model become more accurate. ***nRMSE*** represents the relative size of the mean difference between the estimated and simulated values without units in a range of 0 to 100%.

Results

Effects of saline water irrigation on soil moisture and soil salinity

The average soil moisture among the treatments is shown in Fig. 1a–c. In the topsoil layer, the average soil moisture after irrigation (31, 39, 56, 72 and 88 DAT) was significantly higher ($P < 0.05$) than before the next irrigation (37, 53, 71, 86 and 101 DAT). In general, the soil moisture order was as follows: T3>T2>T1 before each irrigation (37, 53, 71, 86 and 101 DAT). During the periods of 31–37, 39–53, 56–71, 72–86 and 88–101 DAT, the average soil moisture within the tomato root zone was 0.152, 0.177, 0.170, 0.167 and 0.160 cm^3 cm^{-3} in T1 treatment (Fig. 1a); 0.178, 0.201, 0.191, 0.176 and 0.178 cm^3 cm^{-3} in T2 treatment (Fig. 1b); and 0.204, 0.204, 0.201, 0.215 and 0.201 cm^3 cm^{-3} in T3 treatment (Fig. 1c). For treatments T2 and T3, the average soil moisture in five observations was 75% higher than field water capacity. For T1 treatment, the tomato was influenced by water stress only during the period of 31–37 DAT.

Changes in the average soil water extracts EC ($EC_{1:5}$) across treatments are shown in Fig. 2a–c. There were significant differences in $EC_{1:5}$ ($P < 0.05$) among the three treatments, especially during the later period of the experiment (57–101 DAP). The $EC_{1:5}$ increased with the increasing irrigation water salinity at each sampling period. When compared with T1, for treatments T2 and T3 the average $EC_{1:5}$ increased by 85.66% and 191.49%, respectively.

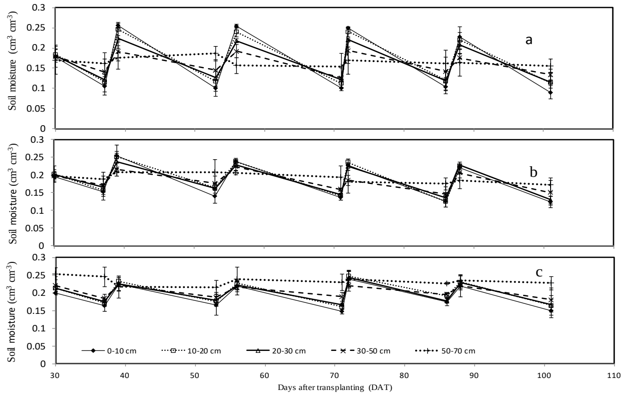

Fig. 1: Measured soil moisture at different soil layers during the experimental periods for treatments: (**a**) T1: 0.4 g L^{-1}, (**b**) T2: 3.4 g L^{-1}, (**c**) T3: 6.4 g L^{-1} (DAT: days after transplanting). Vertical error bars indicate±1 mean errors

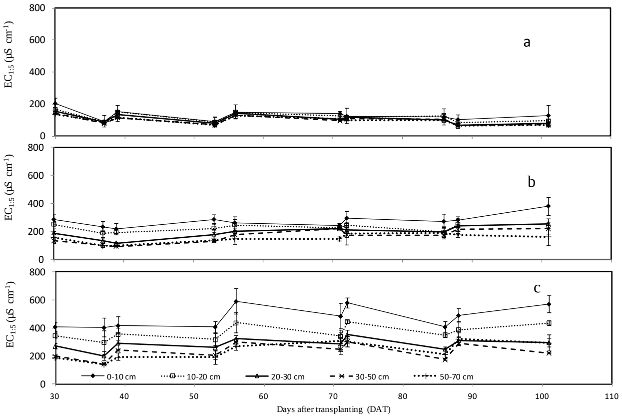

Fig. 2: Measured EC of soil extracts ($EC_{1:5}$) at different soil layers during the experimental periods for treatments: (**a**) T1: 0.4 g L^{-1}, (**b**) T2: 3.4 g L^{-1}, (**c**) T3: 6.4 g L^{-1} (DAT: days after transplanting). Vertical error bars indicate±1 mean errors

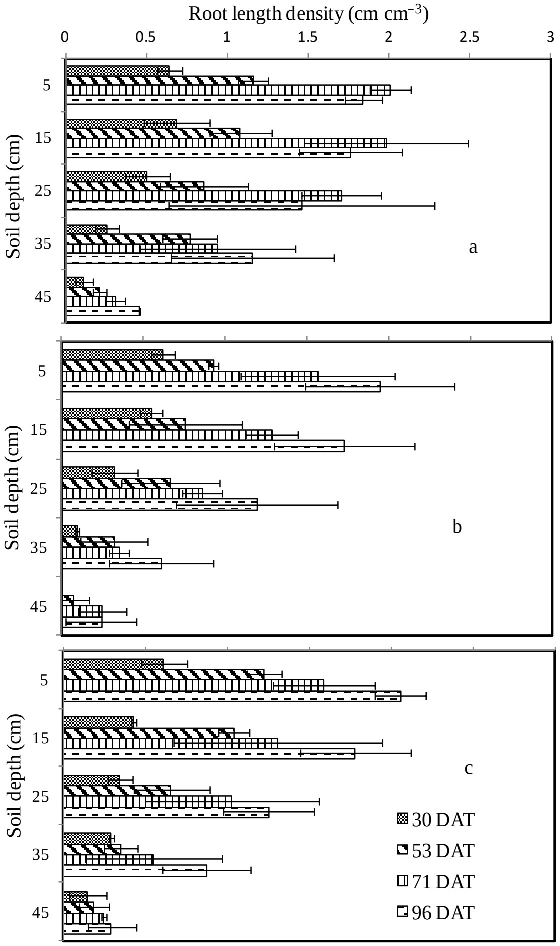

Fig. 3: Measured root length density during the experimental periods for treatments: (**a**) T1: 0.4 g L^{-1}, (**b**) T2: 3.4 g L^{-1}, (**c**) T3: 6.4 g L^{-1} (DAT: days after transplanting). Horizontal error bars indicate±1 mean errors

Effect of saline water irrigation on tomato root length density distributions

The root length density distributions for treatments T1, T2 and T3 are shown in Fig. 3a–c. The root length density decreased with increasing soil depth and more than 80% of the root length density was found within the 0–40 cm of soil layer. In general, no significant differences were observed in the distributions of root length density among treatments. For T1 treatment, the root length density increased until 71 DAT, and then tends to decrease. For treatments T2 and T3, the root length density continued to increase during the whole experimental period.

Simulation of tomato transpiration under salinity stress

Optimizing the parameters of tomato transpiration model under salinity stress [Eq. (6)] is the key for simulating the influences of soil salinity on tomato transpiration. In Eq. 6, the soil osmotic potential can be obtained using the soil water extracts $EC_{1:5}$ (Fig. 2) based on Eq. (1). The actual and potential transpiration rates can be calculated using Eqs. (2) and (9), if the actual root water uptake rate distributions are obtained. The estimated root water uptake rate using two measured soil moisture profiles with the inverse method are shown in Fig. 4a–c. The methods of calculating tomato transpiration rate through integrating the inversed root water uptake distribution [Eq. (2)] and the water balance method [Eqs. (10) and (11)] were compared in Fig. 5. The actual tomato transpiration rate obtained via the two methods matched well, which indicated that the inverse method can be employed to estimate the actual tomato transpiration in this study. Using the data from T3, the parameters in Eq. (6) were optimized using the least squares method as: α=0.032 and $\varphi_o^* = -816.25$ cm.

The method of optimizing the parameters of the tomato transpiration salt stress factor was validated using the data from another independent treatment T2. The

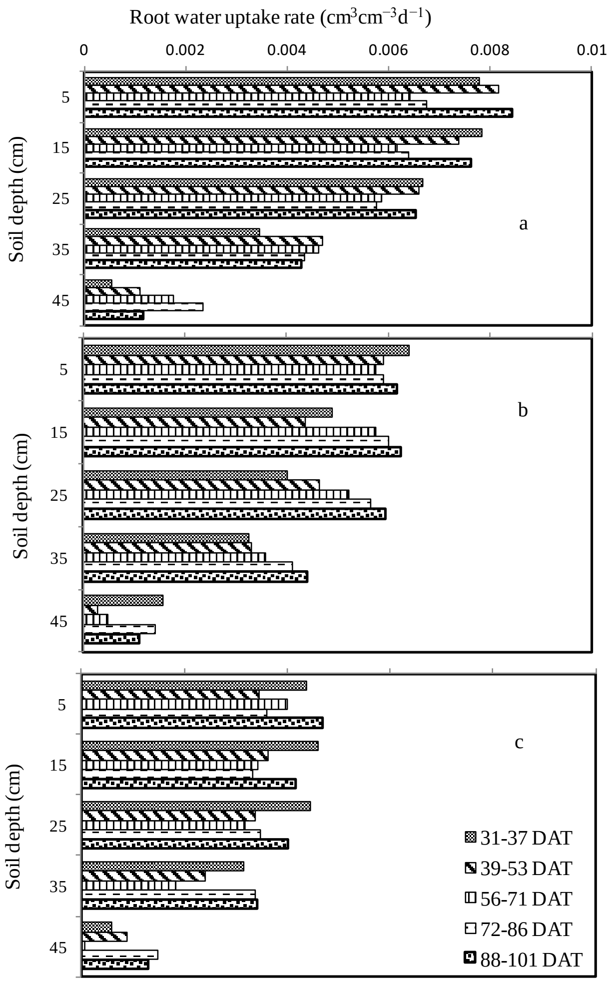

Fig. 4: The estimated average root water uptake rate distributions during the experimental periods for treatments: (**a**) T1: 0.4 g L^{-1}, (**b**) T2: 3.4 g L^{-1}, (**c**) T3: 6.4 g L^{-1} (DAT: days after transplanting)

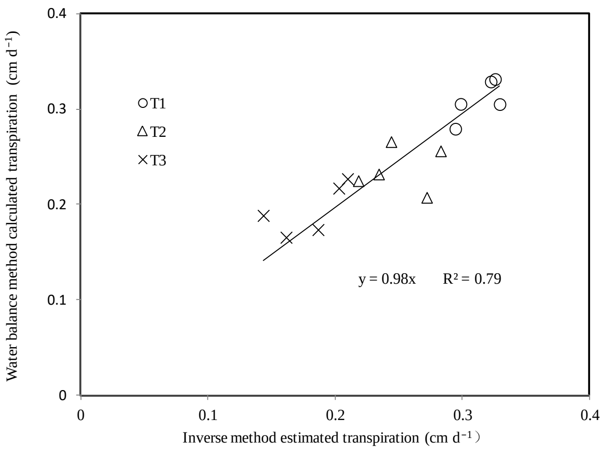

Fig. 5: The comparison of tomato transpiration rate between inverse estimated and water balance calculated values during the experimental period for various treatments (T1:0.4 g L^{-1}, T2: 3.4 g L^{-1}, T3: 6.4 g L^{-1})

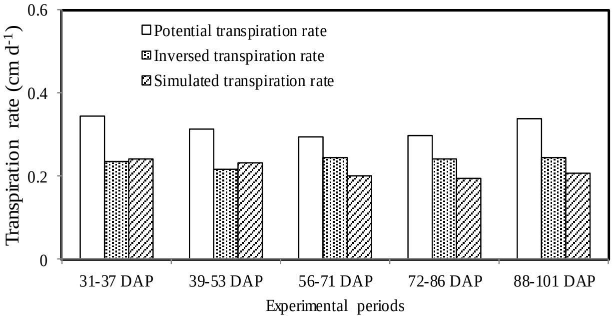

Fig. 6: The comparison of simulated and estimated tomato transpiration rate for T2 treatment during the experimental period

comparison between the predicted and inversed tomato transpiration is shown in Fig. 6. Evaluation indices for the performance of tomato transpiration rate simulation model under salt stress showed that the response of tomato transpiration to salt stress was captured with *RE* of 12.77%, *RMSE* of 0.035 cm d^{-1} and *nRMSE* of 14.88%.

Discussion

Accurate estimation of the crop transpiration is essential for improving water use efficiency and effective irrigation management (Liu *et al.* 2013; Soufi *et al.* 2019). Soil salinity is one of the major factors limiting crop yield under greenhouse conditions (Rameshwaran *et al.* 2016). The main problem caused by soil salinity is the reduction of soil osmotic potential which will decrease the ability of plant water uptake (Yousif *et al.* 2010; Deinlein *et al.* 2014). In this study, the soil salinity in the root zone increased with salt concentrations in irrigation water (Fig. 2–3). Therefore, the tomato root water uptake (transpiration) was negative affected by the salt accumulation in the root zone (Fig. 4), which led to higher soil moisture in the saline water irrigation treatments (Fig 1). Similar results were reported by Wang *et al.* (2012) and Jiang *et al.* (2016). The change of soil moisture was more obvious in the soil layers where the tomato root well developed (Fig. 3). As the soil surface covered with plastic film to reduce soil evaporation, the difference in soil moisture in the upper soil layers reflected the influence of soil salinity on tomato transpiration. As the tomato roots were exposed to low osmotic potential environment, the root water uptake ability was inhibited. In such a case, more photosynthates would be allocated to belowground fraction for root growth to absorb more water. Therefore, there were little effects of salinity on root growth (Fig. 3). Similar results were reported by Shalhevet *et al.* (1995) and Snapp and Shennan (2010).

The influence of soil salinity on crop water consumption needs to be explored for designing irrigation schedule. It is difficult to measure transpiration rate directly on a whole plant in response to field conditions (Droogers

2000). The modeling method provides a useful tool for describing the influences of salt stress on the crop transpiration rate (Wang *et al*. 2012). However, the parameters in the crop transpiration model differed with different conditions and need to be optimized for a given environment. In this study, a method was developed to optimize the parameters of salinity stress reduction factor in crop transpiration model through the estimated transpiration rate, measured soil moisture and soil osmotic potential as α=0.032 and $\varphi_o^* = -816.25$ cm. The model was verified independently by comparing the simulated transpiration rate with the inverse estimated values. Results showed that the established model performed well (Fig. 6). Previous model studies suggested that the *nRMSE* ≤15% shows "good" agreement; 15%–30% shows "moderate" agreement; and ≥30% shows "poor" agreement (Yang *et al.* 2014). Because the RE was 12.77%, RMSE was 0.035 cm d^{-1} and nRMSE was 14.88% in our study, the optimized model was effective to simulate the tomato transpiration influenced by root zone soil salt accumulation. Thus, the method of optimizing the parameters of salinity stress reduction factor in transpiration model can be used to describe the pattern of crop transpiration rate under salt stress conditions.

Conclusion

The soil moisture and soil salinity increased with increasing salt concentration in irrigation water. The tomato transpiration rate was restricted by the soil salt accumulation in 0–40 cm soil layers. While, there was no obvious effects of saline water on root length density. The response model of tomato transpiration to salinity stress was established through optimizing the parameters of the salt stress factor using the inversed transpiration rate, measured soil moisture and soil osmotic potential. We found that the established model could effectively simulate tomato transpiration rate under saline water irrigation, which provides a theoretical basis for soil salt regulation and sustainable saline water use in greenhouse agriculture.

Acknowledgments

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