Effects of irrigation regimes on soil NO_3^--N, electrical conductivity and crop yield in plastic greenhouse

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Abstract: Developing water-saving irrigation regimes has important practical significance not only in alleviating the crucial water shortage, but also in controlling soil salinization for the protected cultivation in eastern China. A field study with six treatments was conducted to evaluate the effects of different irrigation regimes with subdrainage systems on the soil nitrate nitrogen, salinity and moisture, also evaluate the effects on tomato growth, fruit yield and irrigation water use efficiency (IWUE). The treatments were distinguished by three different irrigation amounts of 310 mm, 360 mm and 410 mm, and two irrigation frequencies of 7 and 11 times. Results showed that the irrigation amount had significant effects on the soil NO_3^--N and electric conductivity (EC). A positive correlation was detected between soil NO_3^--N (x) and EC (y) at 0-20 m depth after harvest, with a linear equation of $y=0.063x-0.670$. Soil volumetric moisture at 0.10 m and 0.20 m depth was increased as the irrigation amount increased. Moreover, a higher amount of irrigation increased the fruit yield but reduced the IWUE of tomato. It was also found that smaller irrigation amounts combined with frequent intervals could increase fruit yield and IWUE. However, the fruit quality of tomato had a significant ($p<0.05$) negative correlation with irrigation amount. Therefore, the parameters of irrigation regime including the irrigation amount and intervals should be considered comprehensively in order to find a compromise between salinity control and irrigation water use efficiency improvement.

Keywords: irrigation regimes, greenhouse, tomato, soil nitrate nitrogen, soil electric conductivity, soil salinity, water use efficiency

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1 Introduction

Greenhouse cultivation has become one of the world's most important agricultural productions due to its high economic benefit[1,2]. At present, agricultural facilities have been in rapid development in both developed and developing countries, and various types of greenhouses are used in the vegetable production which not only saved the resources of cultivated farmlands but also increased farmers' incomes[3-5]. In China, the area of greenhouse cultivation has accounted for 11.6% of the national agricultural acreage[6].

Among vegetables that cultivated in greenhouse, tomato is a major product because of its high water productivity and profitability. Xia et al.[7] reported that soil salinity and nitrate nitrogen of arable layer (0-25 cm) in plastic greenhouse was 4 times and 5.9 times, respectively, higher than that in open field after 2 to 3 years of cultivation. Chang et al.[8] and Zhang et al.[9] showed that an obvious reduction of soil productivity and crop yield was caused by greenhouse soil secondary salinization. In the aspect of the composition of soluble soil salt, there was significant difference between greenhouse saline soil and coastal saline soil. The salt in coastal saline soil was mainly composed of 8 ions, including K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, Cl^- and SO_4^{2-}, and greenhouse saline soil was mainly composed of K^+, Ca^{2+}, Mg^{2+}, NO_3^-, PO_4^{3-} and SO_4^{2-}. Han et al.[10] and Liu et al.[11] showed that nitrate accumulation was demonstrated to be one of the main causes for soil secondary salinization. Gao et al.[12] and Hao et al.[13] reported that soil nitrate increased with the process of soil secondary salinization in greenhouse, and found positive correlation between soil nitrate and salt content.

Irrigation had a significant effect on soil salinity, it can reduce soil nitrate and salts[14,15]. The traditional irrigation by local farmers was excessive in greenhouse cultivation, but it caused water resources shortage and groundwater pollution[16-18]. With

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the increasing shortage of irrigation water resources and the requirement of simultaneous salt controlling and water saving, optimized irrigation systems for crops, such as irrigation quota and irrigation frequency, was the key problem to be studied in controlling greenhouse soil secondary salinization.

Drip irrigation was an efficient and water-saving localized irrigation technology[19] To improve crop water use efficiency. Yang and Ren[20] reported that compared with farmers' traditional way of border irrigation, greenhouse cultivation using drip irrigation can save water by more than 50%. Chai et al.[21] showed that drip irrigation could effectively control surface greenhouse soil salt. Liu et al.[22] reported that drip irrigation and infiltrating irrigation could slow the speed of greenhouse secondary salinization. Current studies showed that drip irrigation had a significant role in saving water and reducing soil salinity. However, the influence of drip irrigation on soil water, salt and nitrate under the condition of subsurface drainage has not been studied in details. In view of the importance of sustainable development of facilities cultivation, this study was performed with six irrigation regimes as compared to different amount and internals under subsurface drainage. The aim of this study was to evaluate the soil desalination, irrigation water use efficiency and crop yield.

2 Materials and methods

2.1 Research site

The study was conducted in a plastic greenhouse at the Nanjing Research Institute of Vegetables (latitude 31°45′N, longitude 118°49′E), Jiangsu province, eastern China, for one growing season (2014). The mean annual rainfall is 1106.5 mm, average annual temperature and relative humidity are 15.7℃ and 81%. The essential soil (Alfisoils according to FAO classification) physic-chemical properties of soil are presented in Table 1.

Table 1 Soil properties of the experimental area

Soil depth	pH	Volume density /g cm^{-3}	Electrical conductivity /ms cm^{-1}	Nitrate nitrogen mg kg^{-1}	Organic matter /%
0-20 cm	5.42	1.38	4.59	92.2	1.442
20-40 cm	5.61	1.40	2.75	59.3	1.062

2.2 Experimental design and field measurements

The experiment was conducted in a plastic greenhouse with the subdrainage system by the corrugated plastic pipe drains (drain spacing of 8 m and drain depth of 0.7 m). Seeds of tomato (*Solanum lycopersicum* L. cv. Fanqiedahong) were sown in seedling packs on March 2, 2014 in a plastic greenhouse. Fifty days later, young seedlings were transplanted into the fields (April 20). Fruits in the first truss matured on July 5. The space between plants was 0.3 m and was 0.5 m between rows. The top and branches of the plant were pruned in growth duration with only fruit on the first three trusses. 10 t/hm^2 (N, 5.2, P, 30, K, 20 g/kg) organic fertilizer that fermented with oil mill sludge, rice bran and fish meal was applied uniformly to each treatment along with the plowed soil. Plant management and pest control were performed according to the local practices. Different irrigation treatments were started after the seedlings were transplanted. Each treatment plot occupied an area of 8 m×3 m, including 7 rows. Each treatment was replicated three times. Tomato plants were mulched with black plastic film and irrigated by drip irrigation.

The irrigation regimes including irrigation amount and times were designed based on the routine irrigation system (irrigation amount 360 mm and 7 times during one growing season of tomato) from local farmers. Irrigation amount contained 3 rates of 410 mm (high), 360 mm (average) and 310 mm (low). The irrigation frequency was 7 and 11 times during the whole growth stage of tomato. Experimental design of irrigation regimes was shown in Table 2. At the same time, another plastic greenhouse with the same soil physical and chemical properties was used for the control without subdrainage systems.

Table 2 Experimental design of irrigation regimes

Tomato growth stages		Treatments						
		CK	T1	T_2	T_3	T_4	T_5	T_6
Transplanting stage (April 20)	Irrigation amount per time /mm	30	30	30	30	30	30	30
	Irrigation time	1	1	1	1	1	1	1
Transplant recovering stage (April 25)	Irrigation amount per time /mm	30	30	30	30	30	30	30
	Irrigation time	1	1	1	1	1	1	1
Flowering stage (May 4)	Irrigation amount per time /mm	40	30	30	40	40	50	50
	Irrigation time	1	1	1	1	1	1	1
The first cluster fruit expanding stage (May 16)	Irrigation amount per time /mm	70	60	30	70	35	80	40
	Irrigation time	1	1	2	1	2	1	2
The second cluster fruit expanding stage (June 2)	Irrigation amount per time /mm	70	60	30	70	35	80	40
	Irrigation time	1	1	2	1	2	1	2
The first cluster fruit mature stage (June 14)	Irrigation amount per time /mm	60	50	25	60	30	80	40
	Irrigation time	1	1	2	1	2	1	2
The third cluster fruit expanding stage (June 24)	Irrigation amount per time /mm	60	50	25	60	30	60	30
	Irrigation time	1	1	2	1	2	1	2
Total irrigation amount/mm		360	310	310	360	360	410	410
Total irrigation frequency		7	7	11	7	11	7	11

At stages of transplanting, flowering, fruit ripening at the first truss and the final harvest, soil samples were collected from soil layers of 0-20, 20-40 and 40-60 cm, with three replicates on each layer. Meanwhile, the soil electrical conductivity (EC) and NO_3^--N were measured[23]. Soil volumetric moisture was measured by a profile probe (produced by Delta-T company) each time after irrigation.

Fruit quality including nitrate, vitamin C (VC), soluble protein and soluble sugars were analyzed[23]. Irrigation water use efficiency (IWUE) was calculated as the ratio of crop yield to irrigation water and expressed in kg/m. The elution rate of soil NO_3^--N (N_r) was calculated as:

$$N_r = (SN_1 - SN_2)/SN_1$$

where, SN_1 was soil nitrate nitrogen before crop transplanted (mg/kg) and SN_2 was soil nitrate nitrogen after crop harvested (mg/kg). The elution rate of soil electrical conductivity was calculated as follows:

$$EC = (EC_1 - EC_2)/EC_1,$$

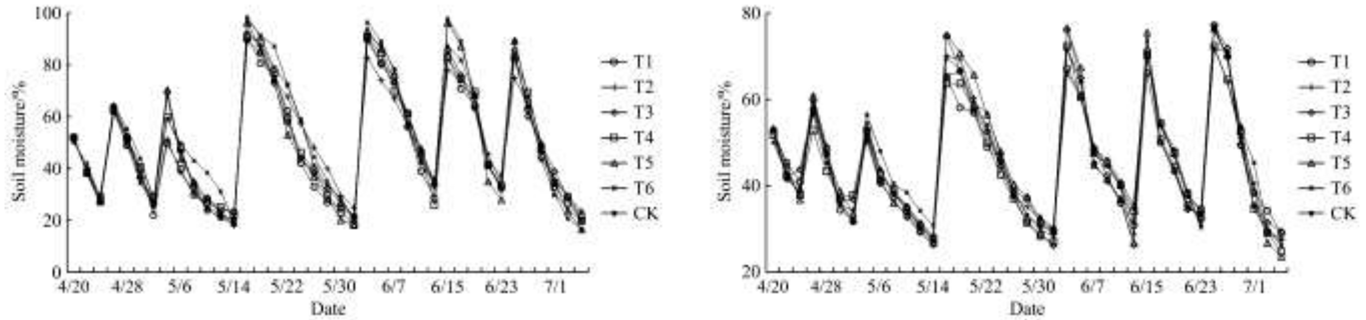
where, EC_1 was soil electrical conductivity before crop transplanted (ms/cm) and EC_2 was soil electrical conductivity after crop harvested (ms/cm).

The data were analyzed at p<0.05 according to Duncan's multiple range test using the SPSS17.0 Software.

3 Results

3.1 Soil moisture

Figure 1 shows the dynamic of soil volumetric moisture in 0.10 m and 0.20 m layers from April 20 to July 5. The trend of soil volumetric moisture at 0.10 m was similar to that at the 0.20 m depth. Each time after irrigation, the soil moisture reached the maximum and then decreased to the minimum 7-10 d later. During the whole tomato growth period, soil moisture varied between 16.38% and 97.19% at 0.10 m depth and between 23.65% and 76.5% at 0.20 m depth. Soil moisture tended to increase as the irrigation amount increased on the same date except CK. Soil moisture of treatments with subsurface drainage was lower than that of field without subsurface drainage, indicating the fact that drainage can contribute to water flow in soil.



a. Dynamic of soil moisture(volumetric) at 0.10 m depth for various irrigation b. Dynamic of soil moisture(volumetric) at 0.20 m depth for various irrigation

Note: T1: total irrigation amount 310 mm, irrigation 7 times, with subdrainage systems; T2: total irrigation amount 310 mm, irrigation 11 times, with subdrainage systems; T3: total irrigation amount 360 mm, irrigation 7 times, with subdrainage systems; T4: total irrigation amount 360 mm, irrigation 11 times, with subdrainage systems; T5: total irrigation amount 410 mm, irrigation 7 times, with subdrainage systems; T6: total irrigation amount 410 mm, irrigation 11 times, with subdrainage systems; CK: total irrigation amount 360 mm, irrigation 7 times, without subdrainage system.

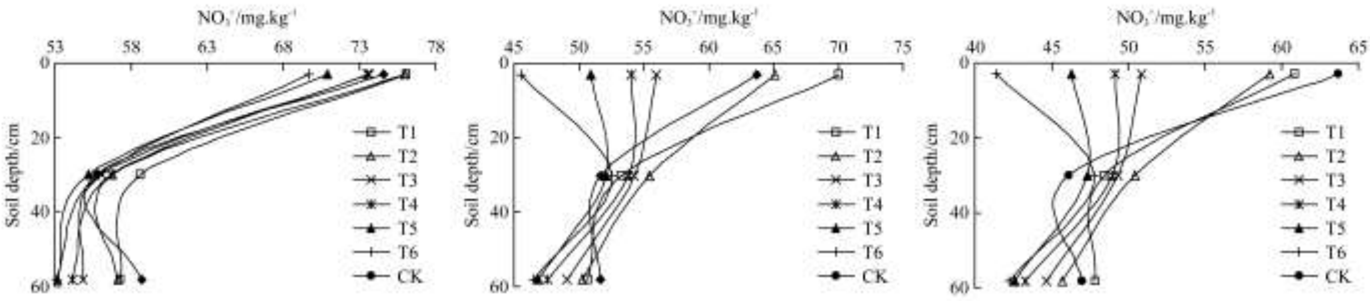
Figure 1 Dynamic of soil moisture(volumetric) at 0.10 m (a) and 0.20 m (b) depths for various irrigation regimes from April 20 to July 5

From the results of dynamic of the soil moisture tension at 0.10 and 0.20 m, it was discovered that irrigation regime affected the dynamic of soil moisture. Tomato in different treatments tolerated soil water stress for different length of time and when irrigation water was less, the time of drought stress was earlier as previously reported[24].

3.2 Soil nitrate nitrogen (soil NO_3^--N)

Soil NO_3^--N distribution in the soil profile at 0.6 m depth under different treatments during the crop growing period is presented in Figure 2. At flowering stage, the elution rate of soil NO_3^--N (N_r) in 0-20 cm soil under low irrigation level (310 mm; T_1 and T_2), average irrigation level (360 mm; T_3 and T_4) and high irrigation level (410 mm; T_5 and T_6) was 17.5%, 20.2% and 23.7%, respectively (Figure 2a). The N_r in 0-20 cm soil of the plastic greenhouse without subdrainage systems (CK) was 19.1%. N_r of 0-20 cm was found to have some relationships with the irrigation amount. However, these differences were not significant at the 5% level. The NO_3^--N in the soil at 20-60 cm depth under different treatments did not change significantly.

At the fruit ripening stage on the first truss, N_r in the soil profile at 60 cm depth were 14.1%, 15.7%, 21.5%, 24.3%, 26.0%, 28.2% and 17.6% with treatments of T_1, T_2, T_3, T_4, T_5, T_6 and CK, respectively (Figure 2b, Table 3). Soil N_r increased as the irrigation amount increased. Particularly, the soil N_r of T_6 was significantly higher than that of T_4.



a. Flowering time b. The first cluster fruit mature stage c. Harvesting time

Note: T1: total irrigation amount 310 mm, irrigation 7 times, with subdrainage systems; T2: total irrigation amount 310 mm, irrigation 11 times, with subdrainage systems; T3: total irrigation amount 360 mm, irrigation 7 times, with subdrainage systems; T4: total irrigation amount 360 mm, irrigation 11 times, with subdrainage systems; T5: total irrigation amount 410 mm, irrigation 7 times, with subdrainage systems; T6: total irrigation amount 410 mm, irrigation 11 times, with subdrainage systems; CK: total irrigation amount 360 mm, irrigation 7 times, without subdrainage system.

Figure 2 Effects of different irrigation systems (a, b and c) on NO_3^--N in soil profile

Table 3 The elution rates of soil nitrate nitrogen (Nr) and EC

Treatments	Soil Nr /%		The elution rates of soil EC /%
	First cluster fruit mature stage	Harvesting time	Harvesting time
T1	14.1[c,d]	22.42[e]	18.94[e]
T2	15.7[c,d]	23.36[e]	23.57[c,d]
T3	21.5[b,c]	28.53[d]	32.02[b]
T4	24.3[b]	30.22[c]	33.65[b]
T5	26.0[a,b]	32.75[b]	43.05[a]
T6	28.2[a]	35.18[a]	44.14[a]
CK	17.6[c]	22.61[e]	28.20[c]

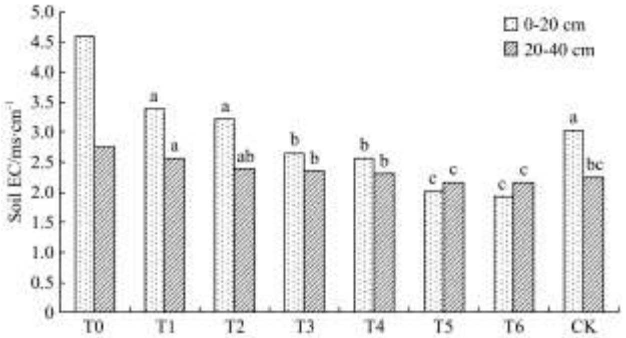
At the final harvest time, the soil NO_3^--N decreased in response to any given quantity of applied water as compared to the initial soil NO_3^--N for all the treatments. For example, soil NO_3^--N with T_1 treatment in 0-20 cm, 20-40 cm and 40-60 cm decreased from 92.2 mg/kg, 59.3 mg/kg and 51.1 mg/kg (at transplanting time) to 70.0 mg/kg, 53.3 mg/kg and 50.7 mg/kg (at harvesting time) in soils irrigated with 310 mm and 7 times (Figure 2c). N_r was 22.42%, 23.36%, 28.53%, 30.22%, 32.75%, 35.18% and 22.61% for T_1, T_2, T_3, T_4, T_5, T_6 and CK, respectively. N_r of T_5 and T_6 higher than that of the other treatments and the difference was significant at the 0.05 level (Table 3). Therefore, increasing the irrigation amount would increase the soil N_r. On the other hand, soil N_r also increased with increases of irrigation frequency. Particularly, the N_r of T_3 was significantly higher than that of T_4. In addition, subsurface drainage system had positive influence on the elution of soil NO_3^--N. The irrigation regimes of T3 and CK were the same, while the N_r of CK was significantly lower than that of T_3 after the harvest of tomato. This was possibly because that the soil NO_3^--N dissolved easily in water and moved to deeper soil or underground with irrigation water, and subdrainage systems accelerated this migration of water and NO_3^--N.

3.3 Electrical conductivity of soil

Soil electrical conductivity (EC) with different treatments at crop transplanting time and harvesting time are shown in Figure 3. The irrigation regime significantly affected soil EC during the crop growth period. Soil EC at 0-40 cm depth decreased with the applied irrigation water from 310 to 410 mm during the experiment. The irrigation amounts of T5 and T6 were higher than those of T3 and T4, but soil EC of T3 and T4 were significantly higher than those of T5 and T6 in 0-20 cm soil depth (p<0.05), indicating that the irrigation amounts significantly affected soil EC. The irrigation amounts and times of T3 (with subdrainage) and CK (without subdrainage) were the same, but soil EC of CK was significantly higher than T3. This result indicated that field with subdrainage can accelerate the migration of salinity.

The elution rates of soil EC with different treatments in 0-40 cm soil layer were 18.94%, 23.57%, 32.02%, 33.65%, 43.05%, 44.14% and 28.20% under T1, T2, T3, T4, T5, T6 and CK, respectively (Table 3). There was significant difference among T2, T4 and T6 (p<0.05). Therefore, soil EC decreased as the irrigation amount increased when irrigation frequency was the same. Similarly, under the same irrigation amount, the soil EC decreased with the increase of irrigation frequency.

There was positive correlation between NO_3^--N and EC in 0-20 cm soil depth at the end of the experiment (Figure 4, Table 4). Nitrate nitrogen–EC equations were obtained for all treatments using regression analysis. The linear equation was: $y=0.063x-0.670$; the logarithmic equation was: $y=3.327\ln(x)-10.497$; the quadratic equation was: $y=0.002x^2-0.278x-6.237$; the exponential equation was: $y=0.714e^{0.025x}$, where, y was soil EC (ms/cm) and x was soil NO_3^--N (mg/kg). Therefore, soil EC can be estimated if the soil NO_3^--N after crop harvest was known.



Note: T0: soil before the crop transplanting time; T1: total irrigation amount 310 mm, irrigation 7 times, with subdrainage systems; T2: total irrigation amount 310 mm, irrigation 11 times, with subdrainage systems; T3: total irrigation amount 360 mm, irrigation 7 times, with subdrainage systems; T4: total irrigation amount 360 mm, irrigation 11 times, with subdrainage systems; T5: total irrigation amount 410 mm, irrigation 7 times, with subdrainage systems; T6: total irrigation amount 410 mm, irrigation 11 times, with subdrainage systems; CK: total irrigation amount 360 mm, irrigation 7 times, without subdrainage system.

Figure 3 Effects of different irrigation systems on salinity in soil profile

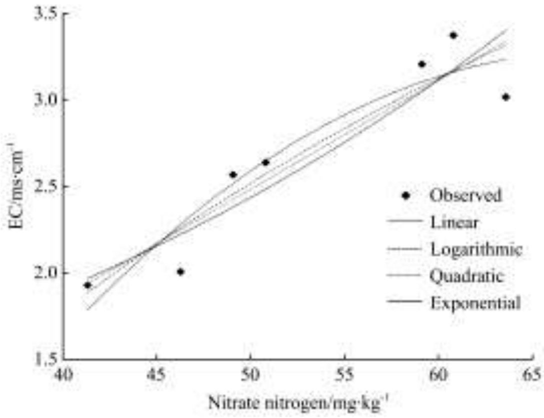


Figure 4 The relationship between soil nitrate nitrogen (soil NO_3^-) and EC

Table 4 Summary of models and Estimate value of statistical parameter

Models	Summary of models					Estimate value of statistical parameter		
	R^2	F	df1	df2	Sig.	Regression constant	b1	b2
Linear	0.864	31.684	1	5	0.002	–0.670	0.063	
Logarithmic	0.878	35.877	1	5	0.002	–10.497	3.327	
Quadratic	0.895	16.993	2	4	0.011	–6.237	0.278	–0.002
Exponential	0.860	30.705	1	5	0.003	0.714	0.025	

Dependent variable: soil EC; independent variable: soil nitrate nitrogen.
See Table 3 for the statistic explanations.

3.4 Fruit yield and quality

Irrigation regimes had significant effects on fruit size and total yield (Table 5). T6 obtained highest yield of 51154 kg/hm^2. The increment in tomato yield in the treatment of T6 compared to the other treatments can be mainly explained by the mean fruit weight per plant and the fruit size. The total tomato fruit yield was increased as the irrigation water amount increased. The irrigation amount mainly affected the fruit size. Mean fruit size was influenced positively by an increasing amount of irrigation water[25]. Otherwise, the irrigation frequency had influences on tomato yield. Significant difference in fruit yield was detected between T3 and T4. The yield increased with increases of irrigation frequency under the same irrigation amount. The fruit yield of T6 was also significantly higher than that of T5, and it should be noticed that the irrigation amount of T5 and T6 were the same. In conclusion, smaller amount of irrigation water applied at more frequent intervals increase fruit yield.

Table 5 Tomato yield, per fruit weight and fruit quality

Treatments	Fruit quality					Per fruit weight /g	Total yield /kg·hm^{-2}
	NO_3^--N/mg·kg^{-1}	VC/mg·kg^{-1}	Total acid/g·kg^{-1}	Soluble sugar/g·kg^{-1}	Sugar/acid		
T1	29.40^{a}	9.59^{a}	4.55^{a}	49.94^{a}	10.98^{a}	106^{d}	34337^{d}
T2	25.19^{b}	10.74^{a}	4.65^{a}	52.53^{a}	11.30^{a}	127^{c,d}	36157^{d}
T3	24.36^{b}	8.48^{b}	4.73^{a}	45.29^{a,b}	9.58^{a,b}	137^{c}	42267^{c}
T4	22.57^{b,c}	9.43^{a,b}	4.55^{a}	49.19^{a}	10.81^{a}	143^{b}	46089^{b}
T5	21.80^{b,c}	7.58^{c}	4.71^{a}	37.67^{c}	8.00^{b}	155^{a,b}	48577^{b}
T6	18.41^{c}	7.33^{c}	4.67^{a}	39.17^{b,c}	8.39^{a,b}	161^{a}	51154^{a}
CK	27.83^{a,b}	8.08^{b,c}	4.56^{a}	44.01^{a,b}	9.65^{a,b}	125^{c,d}	36546^{d}

See Table 3 for the statistic explanations.

T1: total irrigation amount 310 mm, irrigation 7 times, with subdrainage systems; T2: total irrigation amount 310 mm, irrigation 11 times, with subdrainage systems; T3: total irrigation amount 360 mm, irrigation 7 times, with subdrainage systems; T4: total irrigation amount 360 mm, irrigation 11 times, with subdrainage systems; T5: total irrigation amount 410 mm, irrigation 7 times, with subdrainage systems; T6: total irrigation amount 410 mm, irrigation 11 times, with subdrainage systems; CK: total irrigation amount 360 mm, irrigation 7 times, without subdrainage system.

3.5 Irrigation water use efficiency

Figure 5 shows irrigation water use efficiency (IWUE) of tomato with different treatments. The IWUE of tomato was affected by irrigation amounts and frequency. The IWUE related to the irrigation treatments were 4.9, 7.8, 11.7, 13.6, 11.8 and 13.2 kg/m^3 under T1 (310 mm, 7 times), T2 (310 mm, 11 times), T3 (360 mm, 7 times), T4 (360 mm, 11 times), T5 (360 mm, 7 times) and T6 (360 mm, 11 times). In general, IWUE values tended to be higher with a higher irrigation amount and frequency. However, it should be noticed that the highest yield was not obtained with highest IWUE. This means that increasing irrigation water can increase fruit yield, but it may reduce IWUE when exceeded certain value.

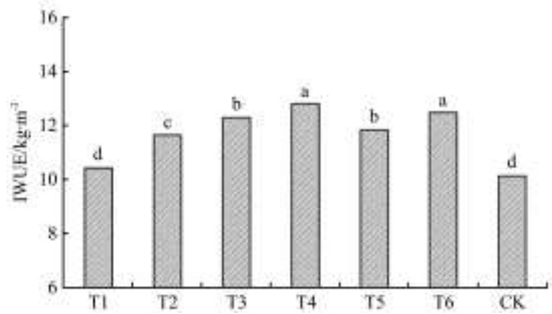


Figure 5 Effects of irrigation regimes on irrigation water use efficiency

See Table 3 for the statistic explanations.

T1: total irrigation amount 310mm, irrigation 7 times, with subdrainage systems; T2: total irrigation amount 310 mm, irrigation 11 times, with subdrainage systems; T3: total irrigation amount 360 mm, irrigation 7 times, with subdrainage systems; T4: total irrigation amount 360 mm, irrigation 11 times, with subdrainage systems; T5: total irrigation amount 410 mm, irrigation 7 times, with subdrainage systems; T6: total irrigation amount 410 mm, irrigation 11 times, with subdrainage systems; CK: total irrigation amount 360 mm, irrigation 7 times, without subdrainage system.

4 Discussion

Soil nitrate and EC decreased with increasing irrigation from 310 mm to 360 mm. Besides, soil NO_3^--N was also decreased by increasing irrigation frequency. A positive correlation between soil NO_3^--N(x) and EC(y) in 0-0.20 m layer after the final harvest was detected and could be simulated by a linear curve as $y = 0.063x - 0.670$ (R^2=0.864). This result suggested that the decrease of EC in this study was possibly not only due to the desalinization effect of irrigation, but also due to the fact that irrigation water promoted the soil NO_3^--N moving to the deeper soil layers. Early study has demonstrated that irrigation, particularly the excessive irrigation, usually causes large quantities of soil N loss[26].

Soil volumetric moisture was increased with increases of irrigation amount at 0.10 m and 0.20 m depth. Increasing irrigation water amount can increase tomato fruit yield, and irrigation of 410 mm showed the best yield. This confirmed the previous finding by Hanson and May[27] under drip systems. In addition, compared to traditional irrigation regimes of local farmers, crop yield can be significantly increased by subdrainage system without increasing irrigation amount. Possibly, the subdrainage system promoted the desalinization effects produced by the irrigation. However, the tomato fruit quality had significant negative correlation with irrigation amount. This negative correlation might be explained from two aspects: (1) irrigation itself decreased the overall fruit quality. Similar results have been obtained by Zhai et al.[28], and the mechanism was that lowering the irrigation quota decreased the amount of water that used for the osmotic regulation of seedcase, thus increased the vitmin C content. Meanwhile, the concentration of sugar that entered into the fruit through the phloem was increased, which was helpful to increase the sugar content[29]; (2) the irrigation decreased the soil salinity, while slight salt stress could enhance the fruit quality. Early study by Zushi et al.[30] showed that salt enhanced tomato sensory attributes as a result of increases in sugar, organic acid, and amino acid contents.

Irrigation water use efficiency correlates fruit yield and the quantity of water consumed, which is a key indicator for the selection of an optimum irrigation program[31]. In this study, irrigation water use efficiency is increased as irrigation frequency increased at the same irrigation amount. However, the highest fruit yield was not in correspondence with the highest irrigation water use efficiency. Increasing irrigation water amount can increase fruit yield, but it may reduce irrigation water use efficiency, while smaller amounts of irrigation applied at frequent intervals increase fruit yield and irrigation water use efficiency. Therefore, in practical, a smaller quota for each irrigation time combined with more frequent intervals was recommended by this study.

Developing irrigation regimes for greenhouse saline soils should consider many indicators such as desalinization rate, nutrient loss, fruit quality, yield and so on. To find the compromise among these indexes are extremely important. In this study, after comprehensively considering effects of different irrigation regimes on soil nitrate nitrogen, electric conductivity and the irrigation water productivity, it is concluded that T4 (irrigation amount of 310 mm, irrigation frequency for 11 times) was the best irrigation regime.

However, the influences from climate, soil, and irrigation water quality will need to be taken into account when applying our conclusions to the other locations.

5 Conclusions

(1) The irrigation amount had significant effects on the soil NO_3^--N and electric conductivity (EC). A positive correlation was detected between soil NO_3^--N (x) and EC(y) at 0-20 m depth after harvest, with a linear equation of $y=0.063x-0.670$.

(2) Higher amount of irrigation water increased the fruit yield but reduced the irrigation water use efficiency of tomato. Smaller irrigation amounts combined with frequent intervals could increase fruit yield and the water use efficiency.

(3) The fruit quality of tomato showed a significant (p<0.05) negative correlation with irrigation amount.

(4) The parameters of irrigation regime including irrigation amount and intervals should be considered comprehensively in order to find a compromise between salinity control and irrigation water use efficiency improvement.

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Abbreviations

Term	Unit	Description
SN_1	mg kg^{-1}	soil nitrate nitrogen before crop transplanted
SN_2	mg kg^{-1}	soil nitrate nitrogen after crop harvested
N_r		soil NO_3^-N
EC_1	ms cm^{-1}	soil electrical conductivity before crop transplanted
EC_2	ms cm^{-1}	soil electrical conductivity after crop harvested
T0		soil before the crop transplanting time
T1		total irrigation amount 310 mm, irrigation 7 times, with subdrainage systems
T2		total irrigation amount 310 mm, irrigation 11 times, with subdrainage systems
T3		total irrigation amount 360 mm, irrigation 7 times, with subdrainage systems
T4		total irrigation amount 360 mm, irrigation 11 times, with subdrainage systems
T5		total irrigation amount 410 mm, irrigation 7 times, with subdrainage systems
T6		total irrigation amount 410 mm, irrigation 11 times, with subdrainage systems
CK		total irrigation amount 360 mm, irrigation 7 times, without subdrainage system

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