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RESPONSE OF SPRING-MAIZE AND SOIL TO SALINE IRRIGATION IN NORTHWEST CHINA

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ABSTRACT Field experiments were conducted in three successive years (2007-2009) to study the effect of saline irrigation on spring-maize and soil in northwest China. Irrigation was applied with four salinity levels: 0.7 g·L^{-1}, 3 g·L^{-1}, 6 g·L^{-1} and 9 g·L^{-1}. Seasonal water application was established referring to average evapotranspiration (ET$_c$) of 510 mm from 1956 to 2005. Water level of 0.94 ET$_c$ and 0.56 ET$_c$ were applied in 2007, 1.0ET$_c$ in 2008 and 0.56ET$_c$ in 2009. Higher water salinity of 6 g·L^{-1} and 9 g·L^{-1} led to significant decline in leaf water potential compared to irrigation with fresh water, so photosynthesis rate and transpiration rate were markedly reduced, result in lower plant height and leaf area index. Reduction of all parameters in 3 g·L^{-1} treatment was not more than 30%. Yield of 9 g·L^{-1}, 6 g·L^{-1} and 3 g·L^{-1} treatment in 2009 was respectively 55%, 63% and 72% of fresh treatment (0.7 g·L^{-1}). Water deficit in a certain extent under saline irrigation also increased water use efficiency (WUE), and the higher salinity, the lower water use efficiency. Soil water depletion decreased with increasing water quantity and salinity. Total salt content of average 0-100 cm at the end of experiment of 0.7 g·L^{-1}, 3 g·L^{-1}, 6 g·L^{-1} and 9 g·L^{-1} was 0.69 g·kg^{-1}, 1.53 g·kg^{-1}, 2.14 g·kg^{-1} and 2.64 g·kg^{-1}, irrespective irrigation water quantity.

Keywords: Saline irrigation, spring-maize, salt

INTRODUCTION Shortage of good quality water is one figure problem for agriculture in the arid areas. For this reason, the availability of saline water for irrigation became an important consideration (Shalhevet, 1994; Beltran, 1999). But the use of saline water may cause salt accumulation in the root zone, ultimately reduce crop production through hindering water uptake. At the same time, declining in evaportranspiration may lead to change of water and salt movement in the soil.

Many researchers studied the salt distribution and accumulation when using saline water. Extra salt will accumulate in the soil when use saline water for irrigation without leaching in arid regions, where rainfall are less and water supply are also scarce (Lamsal et al., 1999). Pascale et al. (1995) found that soil salinity significantly increased with the higher salinity treatment at each soil depth and the same water salinity resulted in higher salt accumulation in the soil under higher frequency than low frequency irrigation. Ben-

Hur et al. (2001) studied water and salt distribution in a field irrigated with marginal water under high water table conditions, an accumulation of salt in the 0-1.2m soil layer in the upper part during irrigation. Ould Ahmed et al. (2007) studied the effect of two levels of irrigation input each at two frequencies on available soil water and soil salinity in due sand, the result showed that decreased water quantity may lead to soil salinity exceeded the threshold value. As the salt concentration increases above a threshold level, both the growth rate and the ultimate size of most plant species progressively decrease, and then will decrease yield (Tedeschi et al., 2002; Skaggs et al., 2006a, b; Ben-Asher et al., 2006a, b). Maize are moderately salt sensitive (Maas and Hoffman, 1977; Katerji et al, 2000), but sensitive to water deficit (Pandey et al., 2000; Cakir et al., 2004; Imma Farre et al., 2006). The yield response of corn did not differ under salinity and drought conditions (Stewart et al., 1977; Katerji et al., 1998; Katerji et al., 2004).

Many researches have been carried out to study the effect of saline irrigation on crop and soil. Here, we studied the effect of saline irrigation on spring maize and soil in an arid area. Both high and low irrigation quantity level was taken into account in the experiment. Not only crop growth and salt accumulation, but also soil water depletion under saline irrigation was investigated.

MATERIAL AND METHODS

Experimental site, soil and climate The field experiment was conducted in the Experimental Station for Water-saving in Agriculture and Ecology of China Agricultural University (ESWAE-CAU), located in the Shiyang River Basin, northwest China. The local climate is arid. Weather data for the crop growing period were obtained from a weather station in the experimental station. Rainfall in the maize growth period of 2007, 2008 and 2009 were 165, 64.8 and 110 mm, respectively. And most of them were not more than 5 mm per time. Eight non-weighing lysimeters with an area of 6.67 m^2 (2×3.33 m) splited around by concrete to avoid lateral leaking were used for experiment. Soil filled in the lysimeters was silt loam including sand of 33%, loam of 64%, and clay of 3%. Other soil characters at beginning of experiments were listed in Table 1.

Experimental design Irrigation quantity was based on calculation of maize actual average ET_C within period of 1956-2005 (Tong, 2007) which was about 510 mm. The irrigation quantity was 0.94 ET_c for high water level treatments and 0.56 ET_c for low water level treatments in 2007 when rainfall was more than average value, while only 1.00 ET_c in 2008 and 0.56 ET_c in 2009. The experiment was applied with four salinity levels: fresh water about 0.7 $g \cdot l^{-1}$ obtained from the well in the station, saline water of 3 $g \cdot l^{-1}$, 6$g \cdot l^{-1}$, 9 $g \cdot l^{-1}$ was obtained from a 2:2:1 mass mixture of NaCl, $MgSO_4$ and $CaSO_4$ to represent local groundwater chemical compositions. The irrigation time, irrigation water volume and water quality for each treatment was showed in Table2. Maize was respectively sown on Apr.17, Apr.20 and Apr.15 and harvested on Sep.24, Sep.18 and Sep.15 in 2007, 2008 and 2009. Plant density was 56 grains per lysimeter. Other agricultural practices followed traditional methods.

Sample measurement Photosynthesis and transpiration rate were measured at heading and grain-filling stage with an infrared gas analyzer (LI-6400 Portable Photosynthesis System, LI-COR, U.S.A.). Measurements were between 7:00-19:00 local time with an interval about two hours. The youngest leaves which fully expanded and exposed to direct solar radiation were selected, 2-3 replicates per treatment. The value which divided photosynthesis rate by transpiration rate was characterised as daily water use efficiency (DWUE). The pre-dawn leaf water potential (ψ) was measured with a pre-dawn water potential meter (WESCOR PSYPRO, USA). Three leaves per treatment were taken from the upper part of the canopy before dawn in fine days. SPAD in leaves of spring wheat was measured by SPAD-502 Chlorophyll Meter (Minolta CamemCo., Osaka, Japan), 5-10 replications per plot. Plant height, leaf area were measured in maize growth stages. 5-10 replicates per plot for height. The leaf area of 3-5 plants were obtained by length multiplies width then multiplies a coefficient of 0.75. Leaf area index (LAI) was calculated by leaf area divide ground area. After harvest, all grains per plot were collected as yield. SPAD, ψ, plant height and LAI were investigated throughout the growing season. Photosynthesis and transpiration rate, ψ and SPAD were not measured in 2007; all the other indexes were measured in three years.

Each treatment was equipped with a PVC tube of Diviner 2 000 for estimating volumetric soil water content. Soil moisture was determined every 5-10 days in each 10 cm layer down to 100 cm depth. Water consumption (ET) was calculated by water balance equation. Water consumption divided by yield educed water use efficiency (WUE). Deep percolation, upward flux and runoff were not taken into account. Soil samples were taken throughout the growing season to a depth of 100 cm in each plot to analyze for the electrical conductivity in the soil water extract of 1:5 ($EC_{1:5}$). $EC_{1:5}$ was then converted to total salt content (S) by an equation $S=0.0275EC_{1:5}+0.1366$ (Zhao, 2009).

Statistical analysis As the yield, soil moisture and salinity measurements and WUE were performed in one block, statistical analyses could not be performed for yield, water consumption and water productivity. Differences among treatment means were examined for statistical significance using the *t* test at 5% significance level. Analyses were performed on the SPSS16.0 software package (SPSS Inc., Chicago, IL, USA).

RESULTS

Spring maize growth The difference of photosynthesis and transpiration rate, ψ and SPAD between T1 and T2, T3 and T4, T5 and T6, T7 and T8 was not significant in 2008 and 2009. Therefore, only the difference among salinity levels in 2008 was presented here. The difference of photosynthesis rate was obvious at 11:00 to 16:00 when luminous intensity was higher (Fig.1). Photosynthesis rate decreased with increasing water salinity. Photosynthetic midday-depress at heading stage was found in T3 and T1 treatments. Transpiration rate increased with decreasing water salinity in most cases. Daily water use efficiency of 6 $g \cdot L^{-1}$ and 9 $g \cdot L^{-1}$ treatments at 11:00 to 16:00 declined markedly at two stages (Fig.1). But that of 3 $g \cdot L^{-1}$ at grain-filling stage was higher than fresh treatment. Plant adapt to salt stress by decreasing their potential to exact more water from the soil. Thereby, pre-dawn leaf water potential can be used to characterize the effect of saline irrigation. Pre-dawn leaf potential showed a typical trend of an increase after irrigation and a decrease during intervals between two successive irrigations (Fig.3). The higher the salinity, the lower the pre-dawn leaf potential. That of 6 $g \cdot L^{-1}$ and 9 $g \cdot L^{-1}$ were reduced significantly, and with the values less than -0.8 MPa in most cases. The difference between 3 $g \cdot L^{-1}$ and fresh treatment was obvious only in the period 50-80 days after sowing. In our study, a pre-dawn leaf potential of less than -0.8 MPa was detrimental to spring-maize growth. The result was similar to other field surveys.

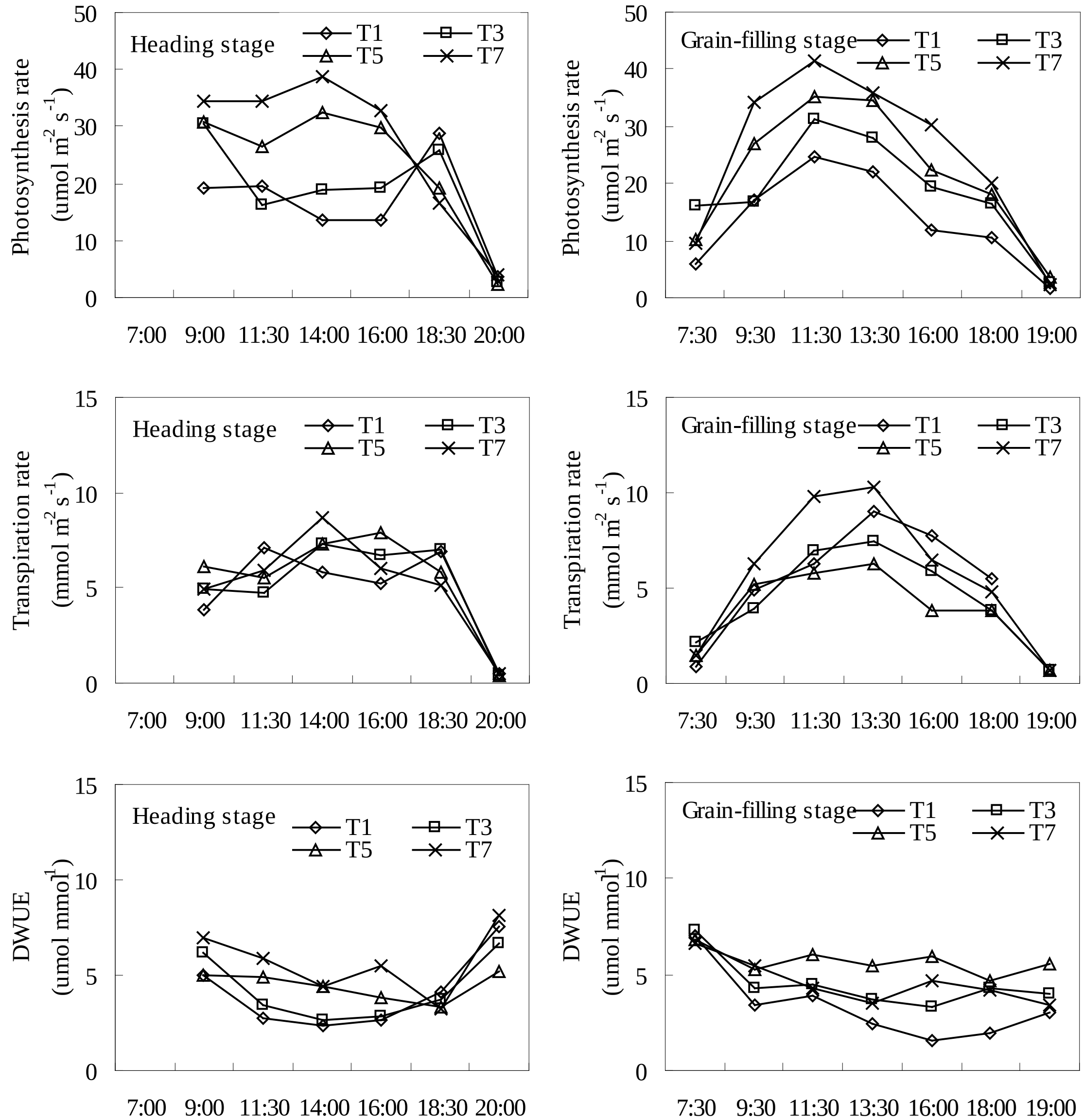

Fig.1. Effect of water salinity on photosynthesis rate, transpiration rate and DWUE on spring maize: comparisons among four salinity treatments.

Relative chlorophyll can be used as an index of plant sensitivity to various stresses. The difference in SPAD was obvious in the period 75-100 days after sowing (Fig.4). That of saline treatments were lower than fresh treatment, but the difference among three saline treatments was not significant.

The difference in plant height and leaf area index appeared from about 60 days after sowing in 2007, 50 days in 2008 and 30 days in 2009. The two parameters at grain-filling stage (when they reached the maximum of the whole grown period) of each treatment were presented in Table 3. Compared to fresh water treatment, plant height and LAI of 9 $g \cdot L^{-1}$, 6 $g \cdot L^{-1}$, 3 $g \cdot L^{-1}$ in 2009 was reduced by about 30%, 20% and 10%, respectively.

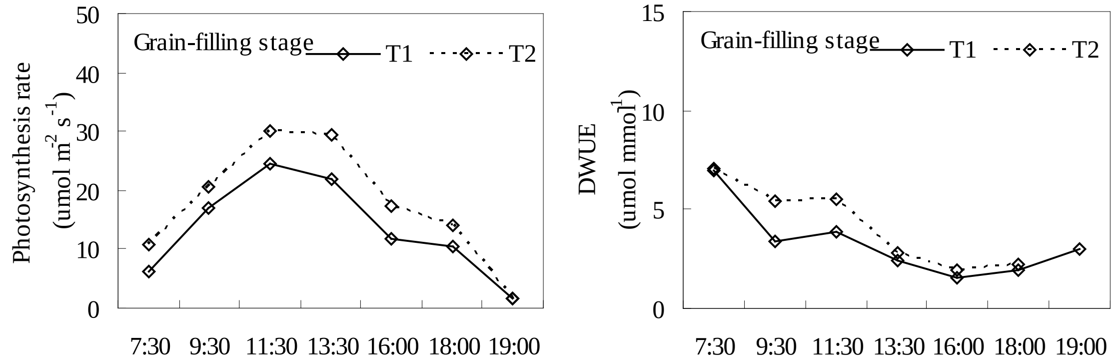

Fig.2. Effect of water quantity on photosynthesis rate and DWUE on spring maize: comparisons between T1 and T2.

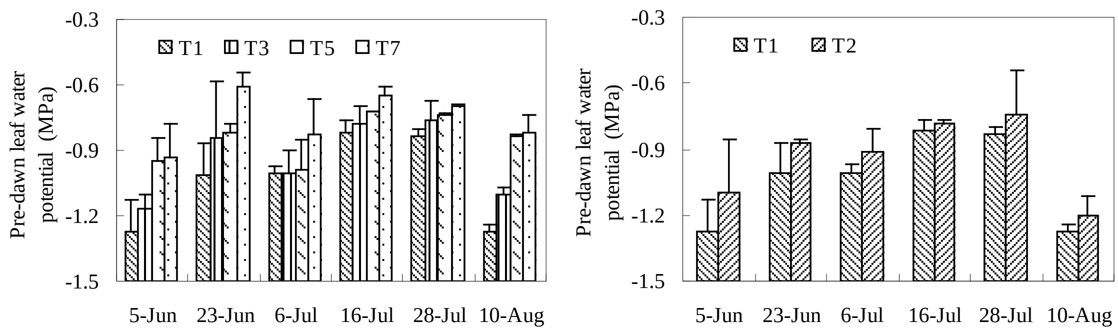

Fig.3. Effect of water salinity on pre-dawn leaf water potential: comparisons among four salinity treatments T1, T2, T3, T4. Effect of water quantity: comparisons between T1 and T2. Vertical bars represent the standard deviation of the mean.

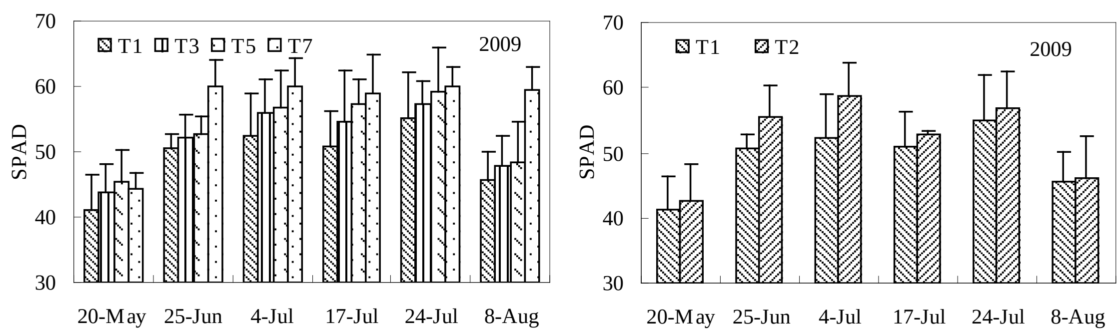

Fig.4. Effect of water salinity on SPAD: comparisons among four salinity treatments T1, T3, T5, T7. Effect of water quantity: comparisons between T1 and T2. Vertical bars represent the standard deviation of the mean.

Although irrigation water quantity was same in 2008 and 2009, deficit irrigation in 2007 still made obvious effect on spring-maize growth and physiological characters in the last two years. The photosynthesis rate, DWUE, pre-dawn leaf potential, SPAD of T1 was lower than T2 as showed in Fig.2, Fig.3 and Fig.4. More salt accumulated in T1 than T2 led to this phenomenon. Similar results also can be found in other saline treatments, but unnecessary details were not given here.

Yield, water consumption and WUE As presented in Table 4, saline and deficit irrigation both reduced yield insignificantly in 2007. The effect of saline irrigation enhanced with time of utilization and salt concentration. Yield was reduced by 50% under 9 $g \cdot L^{-1}$ treatment, but not more than 30% under 3 $g \cdot L^{-1}$ treatment in 2009. Yield and water consumption decreased with increasing salt concentration at the same water quantity. In 2007, compared to $0.94ET_c$ treatment at the same water quality, $0.56ET_c$ treatment reduced water consumption by 19%-27% and yield by 3%-18%. Water use efficiency of 3 $g \cdot L^{-1}$ treatment in 2009 was still higher than 2.0 $kg \cdot m^{-3}$. Even water consumption of each treatment in 2009 was lower than 2008 due to deficit irrigation, yield was not reduced markedly. Thereby, WUE of each treatment in 2009 was not significantly reduced or even increased.

Faci et al (1980) reported that WUE can be increased under moderate water deficit; Katerji et al (1996) found that salinity not clearly affected water use efficiency of maize. Result in our study indicated that water deficit at a certain extent under saline irrigation also increased water use efficiency (WUE), and the higher salinity, the lower water use efficiency. Salinity significantly reduced WUE when irrigated with water of high salt concentration; the effect will be enhanced with time.

Soil water distribution and depletion Soil water temporal variety depended on the irrigation input, water quality and the crop stage. In three years' experiment, the peak values of soil water content of all treatments appeared at irrigation periods, and then sharply decreased because of high evapotranspiration. Different irrigation water quantity and salt concentration also varied water distribution in depth. Soil water content of 60-100cm was almost not affected by water input under low irrigation level ($0.56ET_c$). Also, soil water distribution under 9 $g \cdot L^{-1}$ and 6 $g \cdot L^{-1}$ treatment was different to fresh water treatments in 2008 and 2009. Take soil water of T1 and T7 in 2008 for example (Fig.5). Soil water dynamics in the up layer 0-20cm of two treatments behaved the similar trend, increasing in irrigation period and then decreasing because of intensively water uptake. But the soil water content of 20-100cm kept at high value all the time, average soil moisture of 20-100cm layer of T1 was about 33.01%. The results proved that when maize were irrigated with higher saline water, osmotic stress inhibits water uptake from the soil, and more water was leaved in the soil. In our study, treatments which irrigated with salinity water of 6 $g\ L^{-1}$ and 9 $g\ L^{-1}$ inhibits water uptake markedly, but the impact in treatments with saline water of 3 $g\ L^{-1}$ was not detected.

Soil water depletion increased with decreasing irrigation water quantity and salt concentration (Fig.6). In 2007 and 2009, soil water depletion showed positive under deficit irrigation. The result showed that deficit irrigation treatments made use of soil moisture sufficiently. Soil water depletion of 9 $g \cdot L^{-1}$ and 6 $g \cdot L^{-1}$ treatment in 2008 showed negative as presented in Fig.7. It demonstrated that severe salt stress induced by higher salt concentration hindered water extraction significantly. Sufficient irrigation brought more salt into soil than deficit treatment at the same water quality, and the remained salt will hinder water uptake more intensively in root zone. Thereby, when using high concentration saline water, sufficient irrigation may be not helpful.

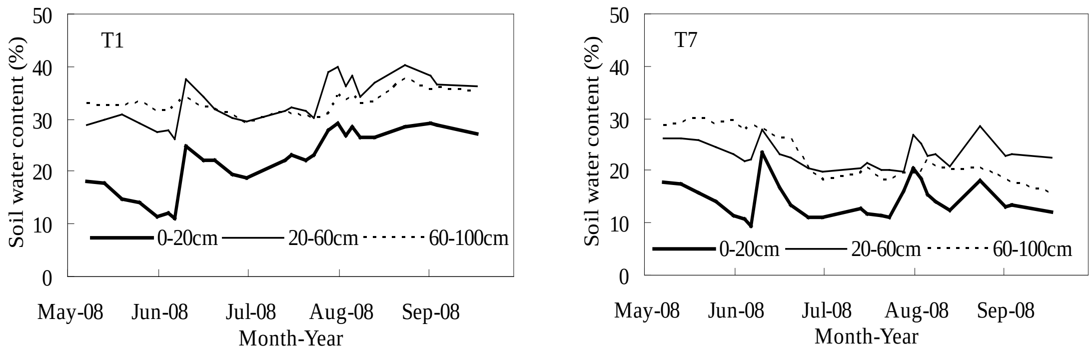

Fig.5. Soil water distribution of 0-100 cm in maize growth period of T1 and T7 in 2008

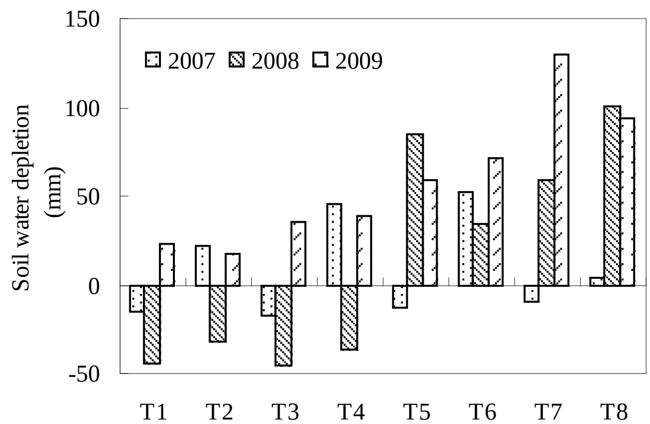

Fig.6. Soil water depletion of 0-100 cm in maize growth period of three years

Salt accumulation Average total salt content of 0-100 cm increased with salt concentration obviously in three years' study (Fig.7). In 2007, soil salinity of 0.56ET_c treatment was lower than 0.94 ET_c at the same salt concentration. Compared to sowing in 2008, average soil salinity at harvesting of 9$g·L^{-1}$, 6$g·L^{-1}$ and 3$g·L^{-1}$ increased 2.05, 2.24 and 2.38 times respectively, while that in 2009 were just 1.53, 1.19 and 1.32 times. Under saline irrigation, especially high salt concentration, reducing water input properly was better for decreasing salt accumulation rate. Irrespective irrigation water quantity, average total salt content at the end of experiment of 0.7 $g·L^{-1}$, 3 $g·L^{-1}$, 6 $g·L^{-1}$ and 9 $g·L^{-1}$ were 0.69 $g·kg^{-1}$, 1.53 $g·kg^{-1}$, 2.14 $g·kg^{-1}$ and 2.64 $g·kg^{-1}$, respectively, which were 0.56, 1.83, 5.36 and 3.78 times more than beginning of experiment.

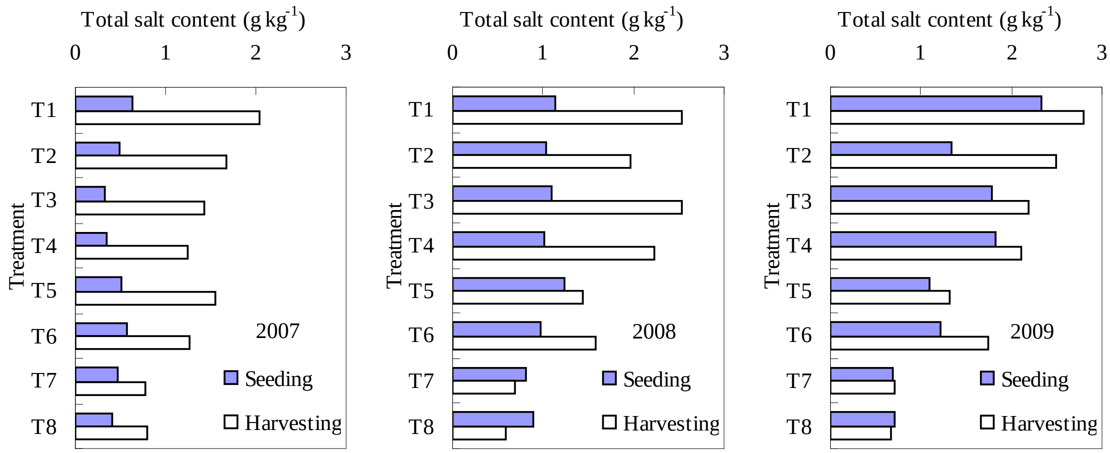

Fig.7. Average total salt content of 0-100 cm at seeding and harvesting stage of three years

CONCLUSION The results indicated that high irrigation water salinity of 6 g·L^{-1}and 9 g·L^{-1} led to significantly declining in photosynthesis rate, leaf water potential, chlorophyll, plant height and LAI compared to irrigation with fresh water. Photosynthetic midday-depress was found in heading stage of 9 g·L^{-1} and 6 g·L^{-1} treatments. A pre-dawn leaf potential of -0.8 MPa was critical to spring-maize growth. The difference of physiological and growth index between 3 g·L^{-1} and fresh treatment was not obvious. Yield of 3 g·L^{-1} was reduced not more than 30%. After three years experiments, all treatments got salt accumulation in soil, the amount and the depth increased with elevating water salinity and reducing water quantity. Low irrigation level under low salt concentration proved to be better than high irrigation level under high salt concentration. Under saline irrigation, on one hand, low water input can make good use of soil moisture; on the other hand, salt accumulation rate can be decreased in a certain extent. Salt concentration that exceeds 6 g·L^{-1} is not suitable for irrigation, especially in this arid area. When considering soil salinization and crop yield at the same time, salt concentration of 3g L^{-1} may be available to a few years utilization. When use saline water, properly reducing irrigation water input may decrease soil salinity and increase water use efficiency according to our study.

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APPENDIX A

Table 1. Soil physical properties and classification (0-100cm)

Soil Texture	Salinity ($g\cdot kg^{-1}$)	$EC_{1:5}$ ($mS\cdot m^{-1}$)	Total nitrogen ($g\cdot kg^{-1}$)	Organic ($g\cdot kg^{-1}$)	CEC ($mmol\cdot kg^{-1}$)
Silt Loam	0.34-0.63	8.13-13.90	0.34-0.54	5.67-7.80	118.06-138.60

Table 2. Experimental design for spring maize

T	S ($g\cdot l^{-1}$)	Elongation-Booting			Booting-Tasseling			Tasseling-Grounting			Grounting-Maturity		
		1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
T1	9	120	120	60	120	135	75	120	135	60	120	120	90
T2		60	120	60	75	135	75	60	135	60	90	120	90
T3	6	120	120	60	120	135	75	120	135	60	120	120	90
T4		60	120	60	75	135	75	60	135	60	90	120	90
T5	3	120	120	60	120	135	75	120	135	60	120	120	90
T6		60	120	60	75	135	75	60	135	60	90	120	90
T7	0.7	120	120	60	120	135	75	120	135	60	120	120	90
T8		60	120	60	75	135	75	60	135	60	90	120	90

T: treatments; S: salt concentration; 1st, 2nd, 3rd: first, second and third year of the experiment.

Table 3. Plant height and LAI of each treatment at grain-filling stage

Treatment	Plant height (cm)			LAI(cm^2cm^{-2})		
	2007	2008	2009	2007	2008	2009
T1	260.00	198.63	169.00	5.31	5.69	3.99
T2	249.30	239.25	213.00	6.83	6.26	4.80
T3	271.00	244.88	224.33	7.20	6.49	5.00
T4	253.00	242.63	220.00	7.07	6.48	4.78
T5	276.00	254.38	252.67	7.35	7.00	5.93
T6	258.70	249.50	250.33	7.26	6.97	5.82
T7	285.30	274.88	283.83	7.73	7.75	6.31
T8	260.00	269.13	271.00	7.48	7.63	6.15

Table 4. Yield, water consumption and water use efficiency

Treatment	ET (mm)			Yield ($kg\ m^{-2}$)			WUE ($kg\ m^{-3}$)		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
T1	629	530	419	1.32	0.75	0.77	2.09	1.42	1.84
T2	462	543	413	1.27	1.08	0.93	2.76	1.99	2.26
T3	627	530	431	1.37	1.31	0.89	2.19	2.48	2.07
T4	495	538	433	1.28	1.37	1.06	2.59	2.54	2.44
T5	632	635	454	1.38	1.21	1.13	2.19	1.90	2.49
T6	512	630	467	1.34	1.44	1.10	2.63	2.29	2.35
T7	645	633	524	1.54	1.73	1.60	2.39	2.74	3.06
T8	475	675	489	1.27	1.79	1.48	2.67	2.65	3.03