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Effects of deficit irrigation with saline water on soil water-salt distribution and water use efficiency of maize for seed production in arid Northwest China

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ABSTRACT

In order to explore the utilization of groundwater resource, field experiments were conducted in 2012 and 2013 in the Shiyang River Basin of Northwest China. Altogether nine treatments included three water levels w1, w2 and w3 ($1ET_c$, $2/3ET_{c,}$ and $1/2ET_{c,}$ ET_c = 555 mm) in combination with three salinity levels s1, s2 and s3 (0.71 g/L, 3 g/L and 6 g/L).Soil water content, soil salt content and yield of maize for seed production were measured for studying the effects of deficit irrigation with saline water on water-salt distribution and water use efficiency of maize for seed production. The results showed that soil water content of saline water irrigation was higher than fresh water irrigation and soil salt content increased with increase of irrigation water salinity under the same irrigation water amount. Soil water content of deficit irrigation was lower than sufficient irrigation and soil salt content increased with decrease of irrigation water amount under the same irrigation water salinity. The soil salt accumulation increased gradually with increase of irrigation water salinity and decrease of irrigation water amount under the combined effect of irrigation water amount and irrigation water salinity. Irrigation with water salinity of 3 g/L and water amount of 370 mm will not cause a substantial yield reduction and could increase water use efficiency of maize for seed production. Irrigation schedule with irrigation water amount about 370 mm and irrigation water salinity below 3 g/L is recommended in this study area. The irrigation schedule of this study can be used in the practice of agricultural production and the results show a reasonably utilization of saline water, thereby supplying theoretical guidance for water-saving irrigation development.

1. Introduction

The Shiyang River Basin is an interior river basin that confronted excessive water explore and utilization, contradiction between water demand and water resources as well as environmental deterioration in Northwest China (Kang et al., 2004). For this arid area with surface water resources shortage, the groundwater is an important resource for social and economic development, maintaining the ecological environment and agricultural production. Due to excessive exploration of local water resources, the groundwater salinity increased year by year. The general groundwater salinity is 0.5–1.0 g/L in upstream region, 1.0–3.0 g/L in midstream region, 3.0–9.0 g/L in downstream region and up to 10.0 g/L in partial region of Shiyang River Basin (Huang et al., 2010; Feng et al., 2014). In order to make up the shortage of fresh water resources and ensure the steady development of agricultural production in arid area, saline water irrigation and deficit irrigation have been widely used in agricultural production(Ali et al., 2007; Chauhan et al., 2008; Geerts and Raes, 2009; Ahmed et al., 2010). The most important consideration in the utilization of saline water irrigation is crop yield (Malash et al., 2005). A large number of experiments have shown that the crops yield irrigated by saline water or brackish water can close or achieve to the yield irrigated by fresh water for some salt-tolerant crops (Niu et al., 2010; Wan et al., 2010; Malasha et al., 2012; Singh and Panda, 2012). However, the use of saline water may cause salt accumulation, change the way of soil water-salt movement and the soil environment of farmland, ultimately reducing crop productivity by hindering water uptake (Wan et al., 2010; Huang et al., 2010; Wang et al., 2015). The principle of using saline water irrigation is that the salt accumulation in the soil does not exceed the salt tolerance limit of the crop. Deficit irrigation provides a mean of increasing water use efficiency by reducing water consumption while minimizing adverse effects on yield (Mao et al., 2003; Panda et al., 2004; Zhang et al.,

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Table 1
Soil physical and chemical properties.

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Organic Matter ($g \cdot kg^{-1}$)	Soil bulk density ($g \cdot cm^{-3}$)	Field capacity ($cm \cdot cm^{-3}$)	Saturated water content ($cm \cdot cm^{-3}$)	Soil textural
0-20	59.46	28.58	11.96	11.76	1.48	0.27	0.36	Sandy loam
20-60	58.33	29.47	11.21	7.12	1.50	0.30	0.38	Sandy loam
60-100	43.35	42.63	14.02	5.48	1.52	0.32	0.40	Loam

Table 2
Irrigation schedule for different treatments.

Treatment	Salinity of irrigation water ($g \cdot L^{-1}$)	Irrigation water quota (mm)					Total irrigation water quota (mm)
		Jointing stage	Booting stage	Tasseling stage	Filling stage	Maturity stage	
w1s1	0.71	120	120	105	105	105	555
w1s2	3.00	120	120	105	105	105	555
w1s3	6.00	120	120	105	105	105	555
w2s1	0.71	80	80	70	70	70	370
w2s2	3.00	80	80	70	70	70	370
w2s3	6.00	80	80	70	70	70	370
w3s1	0.71	60	60	52.5	52.5	52.5	277.5
w3s2	3.00	60	60	52.5	52.5	52.5	277.5
w3s3	6.00	60	60	52.5	52.5	52.5	277.5

Table 3
Sowing date, irrigation date and harvest date for maize during each year.

Year	Sowing	Spring irrigation	1st irrigation	2nd irrigation	3rd irrigation	4th irrigation	5th irrigation	Harvest
2012	4/24	4/4	6/6	6/30	7/21	8/13	8/31	9/23
2013	4/20	4/1	6/5	6/30	7/20	8/10	8/29	9/13

Table 4
The VG soil hydraulic parameters.

Soil depth	Residual water content	Saturated water content	Saturated hydraulic conductivity	Water content shape factor	Water content shape factor	Water content shape factor
(cm)	θ_r ($cm^3 \cdot cm^{-3}$)	θ_s ($cm^3 \cdot cm^{-3}$)	K_s ($cm \cdot d^{-1}$)	α	n	γ
0-20	0.044	0.36	32.57	0.024	1.434	0.5
20-60	0.043	0.38	29.85	0.024	1.417	0.5
60-100	0.049	0.4	13.71	0.011	1.48	0.5

2004). The crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season in this method. The expectation is that any yield reduction (especially in water-limiting situations) will be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation (Ali et al., 2007). Many investigations have been carried out worldwide regarding the effects of deficit irrigation on crop yield and water use efficiency (Mansourifar et al., 2010; Salemi et al., 2011; Ahmadi et al., 2015). They reported that regulated deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on the yield (Webber et al., 2006; Geerts and Raes, 2009; Du et al., 2010; Kifle and Gebretsadikan, 2016. Soil water-salt distribution, crop yield and water use efficiency under combined deficit and saline water irrigation are different to those under separate deficit or saline irrigation. Shani and Dudley (2001) stressed that the maximum yield and the corresponding irrigation water quantity for poor quality water are less than those for good quality water. Jiang et al. (2013) reported that spring wheat is sensitive to deficit irrigation, especially at the booting to grain-filling stages, but was not significantly affect by saline irrigation and the combination of deficit irrigation and saline water irrigation. Maize is one of the most important crops in the world and is sensitive to salt content (Panda et al., 2004; Leogrande et al., 2016). Mohammadi et al. (2011) reported that the water deficit and salinity stress had a significant effect on grain yield of hybrid maize. The maize for seed production is one of the main economic crops and the planting area of maize is rapidly increasing in arid Northwest China. However, soil water-salt distribution, yield and water use efficiency of maize for seed production under deficit irrigation with saline water have been reported rarely.

This study has an important theoretical significance for deficit irrigation and saline water irrigation theory and also guides agricultural production practice. The objectives of this study were: (1) to study the effects of deficit irrigation with saline water on soil water-salt distribution (2) to study the effects of deficit irrigation with saline water on yield and yield components of maize for seed production; (3) to study the effects of deficit irrigation with saline water on water use efficiency of maize for seed production.

2. Materials and methods

2.1. General description of the study area

Field experiments were conducted from 2012 to 2013 at the Shiyang River Experimental Station of China Agriculture University (102°52′E,

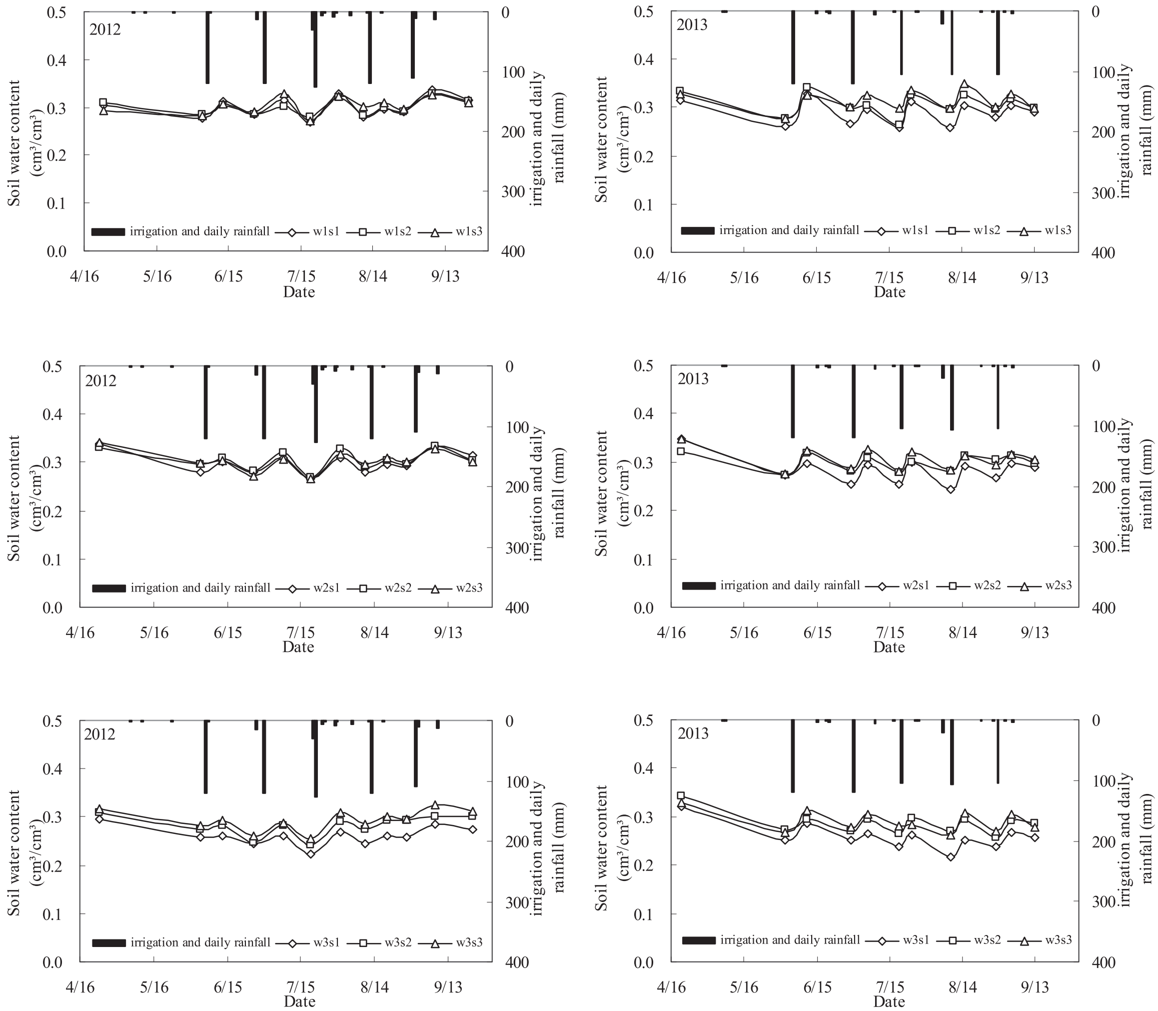

Fig. 1. Soil water distribution under different irrigation water salinity with the same amount (0–100 cm).

37°52′N) in the middle reaches of Shiyang River Basin, located in Gansu Province of Northwest China. The area is characterized as a typical arid climate zone with an altitude of 1581 m. The average annual rainfall and potential evaporation of this area is 164.4 mm and 2000 mm, respectively. The groundwater depth in the experimental area is about 48 m. The experiments were conducted in non-weighing lysimeter containing 18 test pits with an area of 6.66 square meters (3.33 m × 2 m) and depth of 3 m. Each test pits was separated by cement concrete and the bottom was a cement floor. The physical and chemical properties of the test soil before experiments are presented in Table 1.

2.2. Experimental design

Irrigation was performed with three water amount levels of 1ET$_c$ (w1), 2/3ET$_c$ (w2) and 1/2ET$_c$ (w3), ET$_c$ was the average evapotranspiration of maize for seed production. The sufficient irrigation water requirement for maize during each growth stage was decided by the reference crop water requirements and *Kc*.

$$ET_c = K_c ET_0 \tag{1}$$

The ET_0 was calculated by Penman-Menteith method, the *Kc* of maize for each specific growth stage was referred to former study results Tong (2007). The total crop water requirement of maize was 555 mm calculated by Eq. (1). The maize was irrigated 5 times according to the local experience at different growth stage. The total irrigation quota was the total water amount during the whole growth period. The irrigation was performed with three salinity levels of 0.71 g/L (s1), 3 g/L (s2), 6 g/L (s3), which represented groundwater salinity of the upstream, midstream and downstream of Shiyang River. There were 9 treatments with two replicates, 18 test pits were laid out by split plot arrangement. The irrigation schedule is decided as Table 2.The sowing, irrigation and harvest times are shown in Table 3. Spring irrigation was a special irritation in this area that performed once at the volume of about 120 mm half a month before sowing every year for the purpose of salt leaching and soil water conservation. Fresh water with a salinity of 0.71 g/L was obtained from a local well. According to composition of the local groundwater, saline water of 3 g/L and 6 g/L were prepared artificially by dissolving NaCl, $MgSO_4$ and $CaSO_4$ in fresh water at a mass ratio of 2:2:1, respectively. The pH of different irrigation water was about 7. Maize for seed production of the variety of "Golden northwest No. 22" was sowed in one-line male plant and seven-line female plant with 56 plants in each test pits. Before sowing, the whole plots were fertilized with 375 kg/hm^2 of N, 225 kg/hm^2 of P_2O_5 and 300 kg/hm^2 of K_2O as a basal fertilizer. Cultural practices were executed following local experience.

2.3. Meteorological data and sampling methods

An automatic meteorological station (Weather Hark, Campbell Scientific, USA) was installed at the experimental station. Temperature, relative humidity, precipitation, wind speed and solar radiation were measured and the data was recorded every hour. Total precipitation during the maize growth stage in 2012 and 2013 was 130 mm and

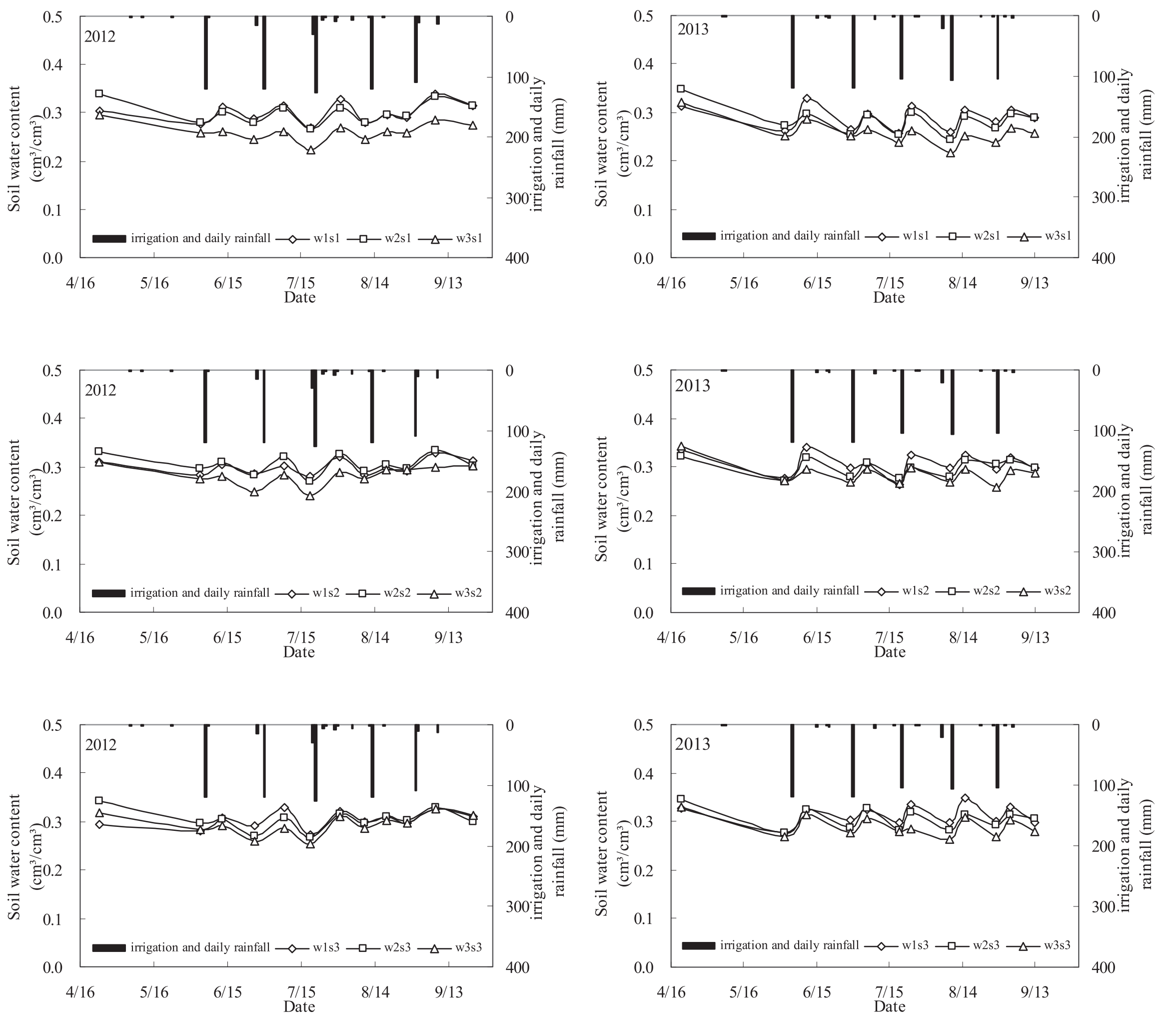

Fig. 2. Soil water distribution under different irrigation water amount with the same salinity (0–100 cm).

64.6 mm, respectively.

The soil samples were taken before seeding, after harvest and before or after irrigation using soil auger during the growth period of maize at the depth of 0–10, 10–20, 20–40, 40–60, 60–80, and 80–100 cm in 2012 and 2013. The soil moisture was measured using gravimetric method. The reserved soil samples were air-dried, ground and passed through 1 mm sieve. Soil leachates were prepared at soil-to-water ratio of 1:5. Electrical conductivity, EC1:5 was measured using SG-3 conductivity meter (SG3-ELK742, Mettler-Toledo International Inc., Switzerland) and translated into soil salinity by using the equation, S = 0.0275EC1:5 + 0.1366 (Wang et al., 2016). After harvest, maize yield components, such as ear length, ear diameter and aboveground dry matter were determined by taking average of 6 plants per plot. The weight of 100 grains for each plot was determined in triplicates. The maize for seed production from each plot were threshed and dried after harvest. The maize yield of 10 plants in each test pits was measured to determine yield per hectare. The saturated hydraulic conductivity was measured by soil permeability meter (TST-55, China) using constant head permeameter. The soil water retention curve was determined using a high-speed refrigerated centrifuge. The VG soil hydraulic parameters analyzed by the RECT program are presented in Table 4. The data obtained from experiments was analyzed using double-factor analysis of variance (ANOVA) by SPSS 17.0 software package (SPSS Inc., Chicago, IL, USA).

2.4. Calculation water use efficiency of maize for seed production

Water use efficiency of maize for seed production was calculated by the following equation.

$$ET = P_0 + I - \Delta W - \text{R-L} + D \tag{2}$$

$$\Delta W = 10 \times rH(W_1 - W_0) \tag{3}$$

where ET is water consumption during the whole crop growth period (mm); P_0 is the total effective rainfall (≥2.5 mm); I is the irrigation amount (mm); ΔW is the soil water depletion in the measured soil depth during the growing stage (mm), and it was positive when soil water was recharged and negative when consumed; W_0 is soil moisture before sowing maize (cm^3/cm^3); W_1 is soil moisture after harvest of maize (cm^3/cm^3); R is surface runoff and it is assumed to be zero (mm); L is soil water side penetration (mm) and it is assumed to be zero; r is soil bulk density (g/cm^3); and D is the bottom water flux of 0–100 (mm). The bottom water flux of 100 cm was estimated according to Darcy's equation, and was negative when downwards and positive when upwards. According to Darcy's law, soil water exchange at the bottom of 100 cm can be estimated using equation:

$$q = -K(\bar{\theta})gradH \tag{4}$$

where q is the vertical water flux (mm/d); $\bar{\theta}$ is the average soil moisture at 100 cm (cm^3/cm^3); grad$H$ is the hydraulic head gradient between 80–100 and 100–120 cm; and $K(\bar{\theta})$ is unsaturated hydraulic conductivity, which is given by:

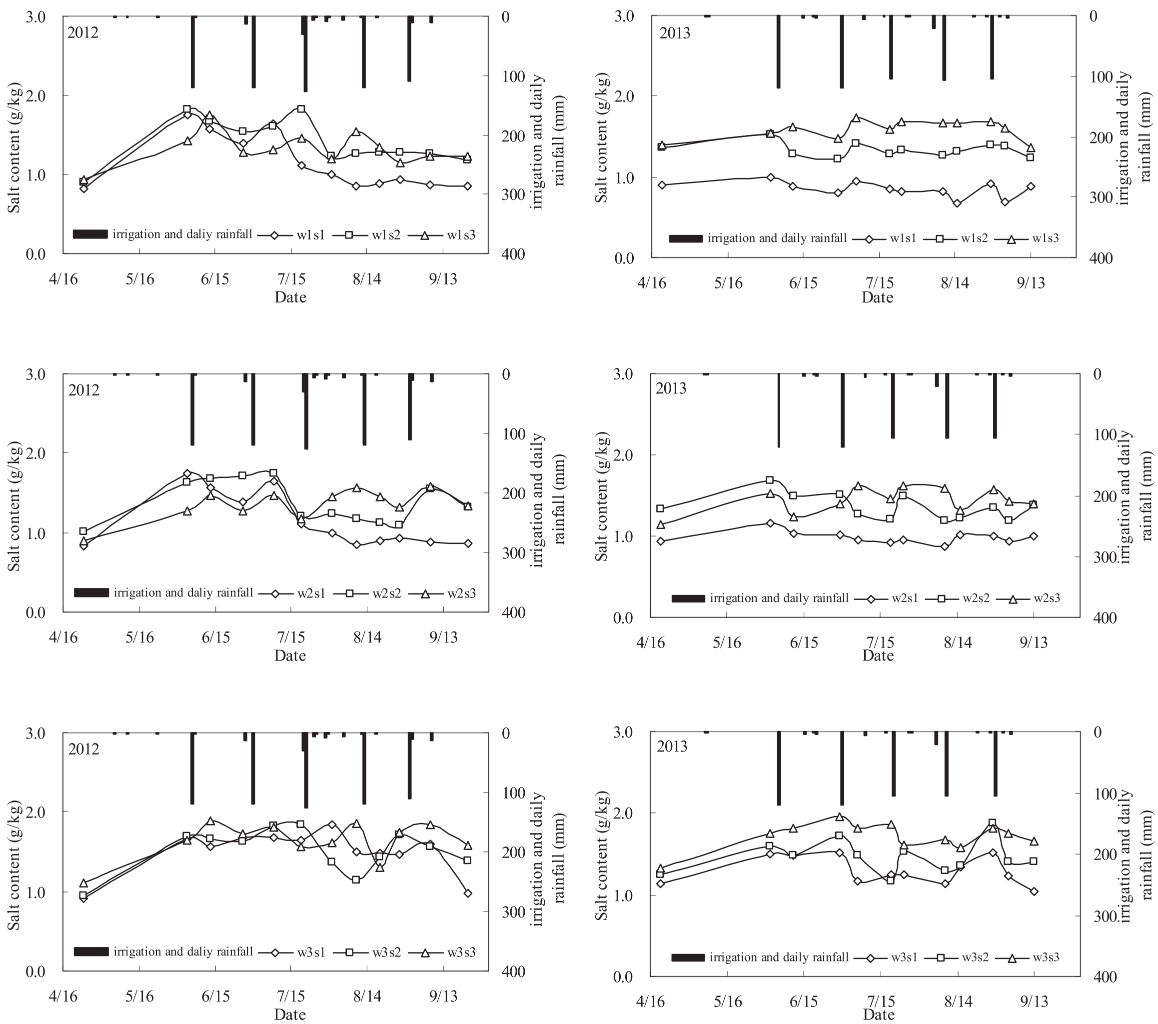

Fig. 3. Soil salt distribution under different irrigation water salinity with the same amount (0–100 cm).

$$K(\theta) = C(\theta)D(\theta) \tag{5}$$

where θ is soil volumetric moisture (cm^3/cm^3); and $C(\theta)$ is specific soil water capacity (/cm). The result can be obtained through the soil water retention curve, which is given by:

$$S = 5.39468 \times 10^5 e^{-26.886\theta} \tag{6}$$

$$C(\theta) = 6.895 \times 10^{-8} e^{26.886\theta} \tag{7}$$

where S is soil water suction (cm); $D(\theta)$ is soil water diffusion (cm^2/min) and is determined by horizontal soil column method

$$D(\theta) = 0.0008 e^{21.275\theta} \tag{8}$$

Water use efficiency (WUE) is calculated as mentioned below:

$$WUE = \frac{Y}{ET} \tag{9}$$

Where Y is the maize yield (kg/hm^2).

3. Results and discussion

3.1. Soil water distribution

Soil water distribution was mainly affected by irrigation water amount and irrigation water salinity under saline water irrigation. Soil water distribution at the same irrigation water amount but different irrigation water salinity is shown in Fig. 1. It can be seen from Fig. 1 that soil water content gradually increased with increase of irrigation water salinity under the same irrigation water amount except sufficient irrigation (w1) and mild deficit irrigation (w2) in 2012, which mean that soil water content of the saline water irrigation was higher than fresh water irrigation, and this phenomenon became more obvious with time increase of saline water irrigation. It can be explained that the salt brought into the soil by saline water irrigation would lower the soil water potential, which then caused salt stress on crops and affected the root water uptake. The results are in accordance with research of Ben-Asher et al. (2006) and Jiang et al. (2016). There was no obvious difference of soil water distribution among three irrigation water salinity through w1 and w2 treatment in 2012. The year of 2012 was a normal flow year. The rainfall was larger than 2013 with a rainfall amount up to 130 mm during the whole maize growing period, which weaken the effects of deficit irrigation on soil water distribution to some extent. Soil water distribution of each treatment was basically the same under the same irrigation salinity (Fig. 2). The soil water content of w1 and w2 treatment was significantly higher than w3 treatment and the soil water content of w2 treatment was slight lower than w1 treatment, but no significant difference. It was evident that the soil water content decreased slightly when adopting deficit irrigation of 2/3 ET_c than sufficient irrigation.

3.2. Soil salt distribution

After saline water irrigation, soil salt content was mainly affected by irrigation water amount and irrigation water salinity. Fig. 3 presents

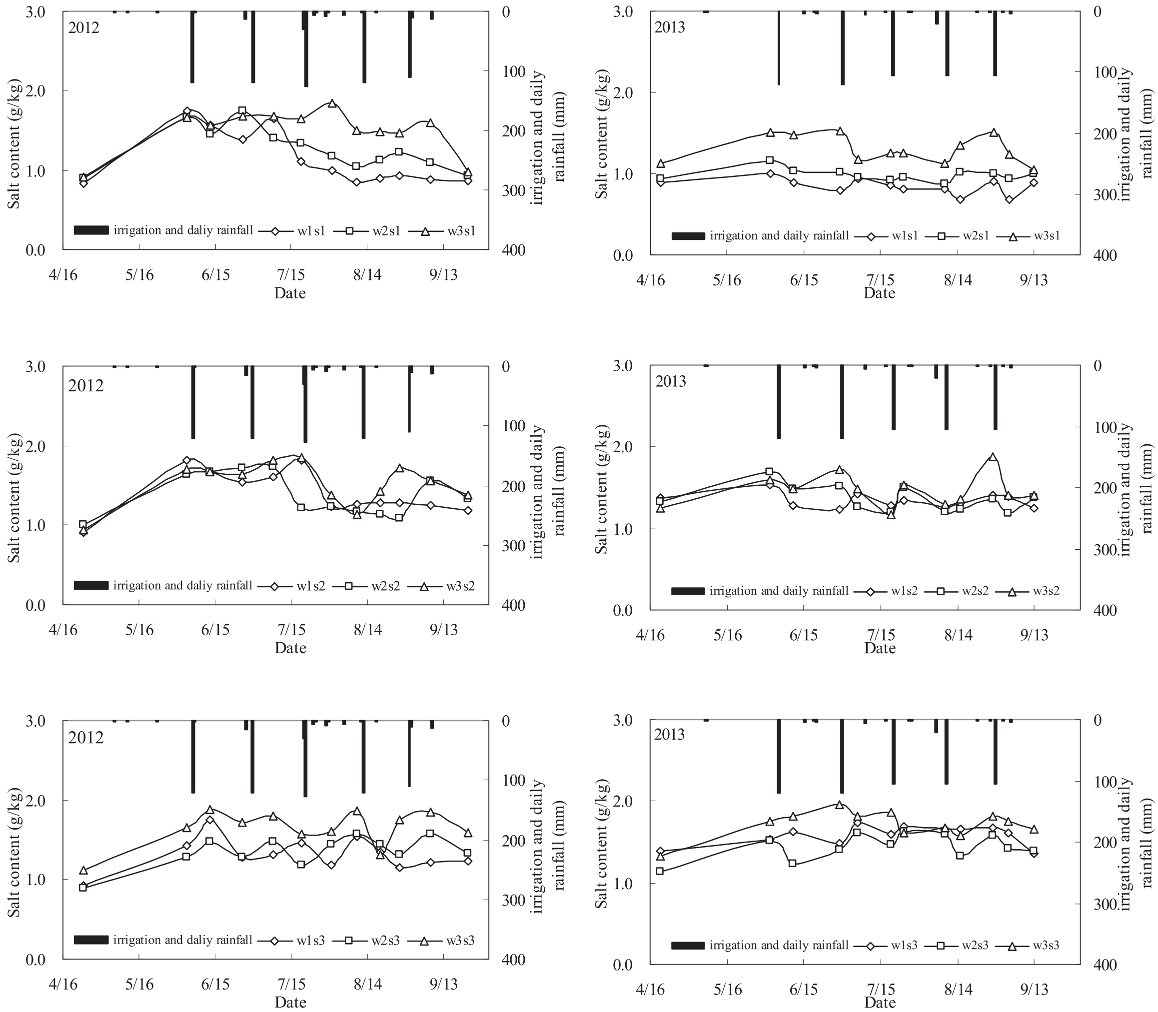

Fig. 4. Soil salt distribution under different irrigation water amount with the same salinity (0–100 cm).

Table 5
Soil salt accumulation in the 0–100 cm soil under different treatments.

Treatment	Salt content before the experiment (g/kg)	2012			2013		
		Salt content after harvest (g/kg)	Salt accumulation (g/kg)	Salt accumulation rate (%)	Salt content after harvest (g/kg)	Salt accumulation (g/kg)	Salt accumulation rate (%)
w1s1	0.826	0.859	0.033	3.99	0.890	0.064	7.76
w1s2	0.910	1.185	0.276	30.29	1.240	0.331	36.33
w1s3	0.931	1.231	0.301	32.33	1.365	0.434	46.66
w2s1	0.892	0.936	0.044	4.91	1.004	0.111	12.48
w2s2	1.007	1.326	0.319	31.70	1.377	0.371	36.83
w2s3	0.895	1.331	0.436	48.68	1.393	0.498	55.67
w3s1	0.921	0.970	0.049	5.34	1.047	0.126	13.68
w3s2	0.941	1.379	0.438	46.61	1.399	0.458	48.73
w3s3	1.114	1.584	0.471	42.29	1.655	0.542	48.67

soil salt distribution under different irrigation water salinity with the same amount. It can be seen from Fig. 3 that soil salt content increased with increase of irrigation water salinity under the same irrigation amount except for w1 and w2 treatment in 2012. The change rule of soil salt distribution was not clear at the early stage of maize for seed production under w1 and w2 treatment in 2012. This was mainly that the little salt was brought into soil at the early growth period and the change rule was not noticeable until the middle and late stage of maize growth period with the accumulation of saline water irrigation. Fig. 4 presents soil salt distribution under different irrigation water amount with the same salinity. It showed that soil salt content increased with decreased of irrigation amount under the same irrigation salinity except for s2 and s3 treatment in 2013. The main reason was that the soil salt content was mainly accumulated in the crop root soil layer and it could not be fully leached with a smaller irrigation amount. Inversely, soil salt content could be leached down to 100 cm soil layer with the large irrigation amount. Therefore, the continuous use of saline water irrigation would make soil salt content increase rapidly. The smaller the irrigation water amount, the greater the irrigation water salinity and the more soil salt accumulation. However, soil salt content could not be

Table 6
Yield and its components.

Yield index	Year	w1			w2			w3		
		s1	s2	s3	s1	s2	s3	s1	s2	s3
Ear length (cm)	2012	146.5	139.2	136.6	133.0	135.8	133.7	130.4	130.9	128.6
	2013	142.5	134.9	129.4	131.7	129.5	121.9	120.3	119.5	114.5
Ear diameter (cm)	2012	43.3	44.2	42.6	42.3	42.1	41.2	40.4	40.0	41.5
	2013	41.1	43.2	40.4	38.6	36.5	35.0	35.5	36.6	36.7
Hundred-grain weight (g)	2012	45.7	45.2	44.0	44.2	43.9	44.2	42.2	42.4	40.6
	2013	40.5	39.7	37.9	38.7	38.2	37.8	37.5	37.7	36.8
Dry matter weight (g)	2012	267.3	264.8	253.5	244.6	231.1	237.1	214.4	200.7	216.3
	2013	242.0	240.1	237.9	235.2	227.8	218.9	203.8	176.3	174.6
Yield	2012	6767.8	6507.7	6440.1	6487.5	6341.0	5741.0	4885.9	4659.5	4436.1
(kg·hm^{-2})	2013	6425.0	6050.4	5962.9	5846.6	5765.3	5082.4	4600.7	4269.2	3915.8

Table 7
The results of ANOVA of yield and its components.

Yield index		2012		2013	
		F-Value	*P*-Value	F-Value	*P*-Value
Ear length (cm)	w	4.01	0.04	4.27	0.03
	s	0.47	0.64	4.71	0.02
	w × s	0.44	0.78	5.35	0.00
Ear diameter (cm)	w	8.23	0.00	1.27	0.30
	s	0.11	0.89	7.46	0.00
	w × s	1.13	0.38	2.38	0.08
Hundred-grain weight (g)	w	120.64	0.00	0.96	0.40
	s	13.85	0.00	2.41	0.12
	w × s	5.33	0.01	1.76	0.18
Dry matter weight (g)	w	5.64	0.01	1.78	0.19
	s	0.27	0.77	19.9	0.00
	w × s	0.14	0.97	1.56	0.21
Yield	w	76.65	0.00	1.24	0.31
(kg·hm^{-2})	s	4.52	0.04	37.06	0.00
	w × s	0.46	0.76	8.52	0.00

Note: The difference is significant at $p<0.05$. w is irrigation water quantity, s is irrigation water salinity.

fully leached by a small amount of irrigation water because it was mainly accumulated in the crop root soil layer and caused salt stress so as to affect the normal growth of crop (Malash et al., 2005; Feng et al., 2017). In practice, we need to consider the influence of irrigation water amount and irrigation water salinity when formulating irrigation schedule of crop in soil salinization area.

Table 5 shows the soil salt accumulation of different treatments in 0–100 cm after the harvest of maize for seed production during 2012 and 2013 in comparison to before the experiments. Through the analysis of Table 5, the soil salt accumulation of each treatment increased with the increase in the use of saline water irrigation. The soil salt accumulation of all treatments in 2013 were higher than those in 2012, even if under the sufficient irrigation of fresh water, soil salt accumulation increased slightly. The soil salt accumulation increased by 0.031 g/kg in 2013 compared with in 2012. Therefore, soil salt accumulation would increase by adopting saline water irrigation for a long time and soil salt accumulation would intensify with increase of irrigation water salinity. In terms of soil salt accumulation rate, it was the highest under saline water irrigation with 6 g/L with the same irrigation amount but different soil salinity. During the 2-year experiments, the salt accumulation rate of w2s3 treatment was 48.68% and 55.67% in 2012 and 2013, respectively. The salt accumulation rate of fresh water irrigation was the smallest and it was 3.99% and 7.76% of w1s1 treatment in 2012 and 2013, respectively. The salt accumulation rate under saline water irrigation with 3 g/L was between 30% and 50% and it increased gradually with decrease of irrigation water amount under the same irrigation water salinity. Taking s2 treatment as an example, the salt accumulation rate of w1s2、w2s2 and w3s2 was 30.29%, 31.70%, 46.61% and 36.33%, 36.83%, 48.73% in 2012 and 2013, respectively. Therefore, comprehensively considered the effect of irrigation water amount and salinity, the soil salt accumulation increased gradually with increase of irrigation water salinity and decrease of irrigation water amount.

3.3. The yield and its components of maize for seed production

Table 6 presents the yield of maize for seed production during the 2-year irrigation experiments. The results showed that the maize for seed production had experienced different degrees of yield reduction along with the increase of irrigation water salinity under the same irrigation water amount. The reduction rate was 2.2%–11.5% and 2.0%–14.8% in 2012 and 2013, respectively. Taking w2 treatment as an example, compared to w2s1 treatment, the yield of w2s2 and w2s3 treatments were reduced by 2.2%, 11.5% and 2.0%, 13.0% in 2012 and 2013, respectively. The yield of maize for seed production under w1 and w3 treatments showed a similar rule. It was clear that the maize for seed production yield of appropriate saline water irrigation came close to the

Table 8
The water use efficiency of maize for seed production.

Treatment	Irrigation amount (mm)	Precipitation (mm)		Soil water depletion (mm)		Bottom water flux of 0-100 cm (mm)		Water consumption (mm)		Yield (kg·hm^{-2})		WUE (kg·m^{-3})	
		2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
w1s1	555	130	64.6	14.50	−28.89	−63.45	−52.46	607.05	596.03	6767.8	6425.0	1.11	1.08
w1s2	555	130	64.6	12.81	−29.74	−66.37	−56.54	605.82	592.80	6507.7	6050.4	1.07	1.02
w1s3	555	130	64.6	18.12	−35.08	−74.63	−63.41	592.25	591.27	6440.1	5962.9	1.09	1.01
w2s1	370	130	64.6	−28.99	−61.09	−22.36	−17.13	506.63	478.56	6487.5	5846.6	1.28	1.22
w2s2	370	130	64.6	−34.43	−59.11	−49.87	−41.83	484.56	451.88	6341.0	5765.3	1.31	1.28
w2s3	370	130	64.6	−38.92	−43.84	−36.34	−32.23	502.58	446.21	5741.0	5082.4	1.14	1.14
w3s1	277.5	130	64.6	−25.37	−78.30	−2.36	−3.00	430.51	417.40	4885.9	4600.7	1.13	1.10
w3s2	277.5	130	64.6	−17.25	−65.73	−8.32	−5.56	416.43	402.27	4659.5	4269.2	1.12	1.06
w3s3	277.5	130	64.6	−10.87	−61.26	−10.26	−12.12	408.11	391.24	4436.1	3915.8	1.09	1.00

yield of fresh water irrigation. However, much high irrigation water salinity would greatly reduce the yield of maize for seed production. The yield of maize for seed production gradually decreased with decrease of irrigation water amount under the same irrigation water salinity. The reduction rate was 2.6%–31.1% and 4.7%–34.3% in 2012 and 2013, respectively. Taking s2 treatment as an example, compared to w1s2 treatment, the yield of w2s2 and w3s2 treatments were reduced by 2.6%, 28.4% and 4.7%, 29.4% in 2012 and 2013, respectively. The yield of maize for seed production of s1 and s3 treatments showed a similar rule. It can be seen that moderate deficit irrigation had slight effect on maize yield, but excessive deficit irrigation would result in a great reduction in maize yield. Under both soil water-salt stress, compare to w1s1 treatment, the maize yield of w2s2, w2s3, w3s2, w3s3 treatments were reduced by 6.3%, 15.2%, 31.2%, 34.4% and 10.9%, 20.8%, 33.5%, 39.0% in 2012 and 2013, respectively. Thus it can be seen that the irrigation with water salinity of 3 g/L and the water amount of 2/3 ET_c will not cause a substantial yield reduction of maize for seed production in this study area.

Table 7 is the variance analysis result of maize for yield and its component factors in two years irrigation experiments. The significant difference among treatment is analyzed by double-factor analysis of variance. The different irrigation treatments were subjected to Tukey's test ($p < 0.05$). Results indicated that the irrigation water amount had significant influence on ear length, ear diameter, hundred-grain weight, dry matter weight and yield and the irrigation water salinity had significant influence on hundred-grain weight and yield in 2012. The interaction between irrigation water amount and irrigation water salinity had only significant influence on hundred-grain weight in 2012. The irrigation water amount had significant influence on ear length, and the irrigation water salinity had significant influence on ear length, ear diameter, dry matter weight and yield in 2013. The interaction between irrigation water amount and irrigation water salinity had significant influence on ear length and yield in 2013.

3.4. The water use efficiency of maize for seed production

Table 8 shows the water use efficiency of maize for seed production in different treatments. The water use efficiency of maize was mainly affected by water consumption and yield. From Table 8 analysis, we can see that the water use efficiency of deficit irrigation treatment was generally grater than sufficient irrigation treatment. Taking 2012 as an example, the minimum water use efficiency of maize was w1 treatment and the value was 1.11 kg/m^3. The water use efficiency of w2 and w3 treatment increased by 15.32% and 1.80% under fresh water irrigation, by 22.43% and4.67% under irrigation water salinity with 3 g/L in comparison of w1 treatment, respectively. The water use efficiency of maize, which was adopted deficit irrigation with irrigation water amount of 2/3 ET_c, was the largest under the same irrigation water salinity. The use efficiency of maize for seed production had the similar rule in 2013. The results showed that a certain degree of deficit irrigation was beneficial to improve the water use efficiency of crop, but excessive deficit irrigation would also reduce the water use efficiency of maize for seed production. The use efficiency of maize was also affected by irrigation water salinity. The water use efficiency of maize of w1 and w3 treatment decreased with increase in irrigation water salinity in two years experiments. Taking w1 treatment in 2013 as an example, the water use efficiency of w1s2 and w1s3 treatment decreased by 5.32% and 6.44% in comparison of w1s1 treatment, respectively. The water use efficiency of maize decreased more obvious under the greater irrigation water salinity except for w2 treatment. The use efficiency of maize had the similar rule in 2012. The maximum water use efficiency of maize was w2s2 treatment and the maximum value was 1.31 kg/m^3 and 1.28 kg/m^3, respectively in 2012 and 2013. The results showed that the water use efficiency of maize could be increased with irrigation water amount of 2/3 ET_c and irrigation water salinity of below 3 g/L under soil water-salt stress.

4. Conclusions

We performed deficit irrigation with saline water experiments for 2 consecutive years to study the effects of deficit irrigation with saline water on soil water-salt distribution and water use efficiency of maize for seed production in arid Northwest China. The main conclusions of this study were that soil water-salt distribution was affected by both irrigation water amount and irrigation water salinity under deficit irrigation with saline water. The soil water content of saline water irrigation was higher than fresh water irrigation and soil salt content increased with increase of irrigation water salinity under the same irrigation water amount. The soil water content of deficit irrigation was lower than sufficient irrigation and soil salt content increased with decrease of irrigation water amount under the same irrigation water salinity. The soil salt accumulation increased gradually with increase of irrigation water salinity and decrease of irrigation water amount under the combined effect of irrigation water amount and irrigation water salinity. Irrigation with water salinity of 3 g/L and water amount of 370 mm will not cause a substantial yield reduction and could increase water use efficiency of maize for seed production. Irrigation schedule with irrigation water amount about 370 mm and irrigation water salinity below 3 g/L is recommended in this study area. Therefore, it can realize the reasonable utilization of saline water and water-saving irritation and this irrigation schedule can be promoted in the practice of agricultural production.

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