Agricultural Water Management 212 (2019) 424–432

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

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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ARTICLE INFO

Keywords:
Saline water irrigation
Deficit irrigation
Soil water-salt distribution
Maize for seed production
Yield
Water use efficiency

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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https://doi.org/10.1016/j.agwat.2018.09.019
Received 28 May 2018; Received in revised form 7 September 2018; Accepted 9 September 2018
0378-3774/

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,