Agricultural Water Management 104 (2012) 210–220

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

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

Drip irrigation of waxy corn (*Zea mays* L. var. *ceratina* Kulesh) for production in highly saline conditions

Shuqin Wan[a], Yanping Jiao[b], Yaohu Kang[a,*], Wei Hu[a], Shufang Jiang[a], Junli Tan[c], Wei Liu[d]

[a] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] Hebei Provincial Academy of Water Resources, Shijiazhuang 050051, China
[c] College of Civil Engineer and Water Conservancy, Ningxia University, Yinchuan 750021, China
[d] Ningxia Agriculture Comprehensive Development Office, Yinchuan 750021, China

ARTICLE INFO

Article history:
Received 22 January 2011
Accepted 13 December 2011

Keywords:
Drip irrigation
Soil matric potential
Waxy corn
Saline soil
Water and salt management

ABSTRACT

A 4-year trial was set up to test the feasibility of growing waxy corn (*Zea mays* L. var. *ceratina* Kulesh) in a highly saline wasteland with drip irrigation in the Ningxia plain, northwest China. The original soil salinity expressed as electrical conductivity of the saturation paste extract (EC_e) averaged 28 dS/m in the 0–120 cm depth. The experiment included five soil matric potential (SMP) treatments in which the SMP at 20 cm depth below the drip emitters was controlled higher than −5, −10, −15, −20 and −25 kPa after waxy corn establishment. The results showed that drip irrigation created a favorable soil condition for waxy corn growth through forming and maintaining a high moisture and low salinity region in the root zone when the SMP was maintained higher than −25 kPa. Waxy corn growth and yield parameters increased with the increase of SMP from −25 kPa to −5 kPa, but their responses to SMP decreased with the prolonged period of cultivation. Irrigation frequency and irrigation amount decreased significantly as SMP decreased from −5 kPa to −25 kPa, and the highest irrigation water use efficiency (IWUE) was available when the SMP was around −15 kPa in 2005, and was between −20 kPa and −25 kPa in successive years. After years of cultivation and drip leaching, the highly saline soil gradually changed to a moderately saline soil. This research suggests that drip irrigation can be successfully used in growing waxy corn in dry and highly saline conditions after appropriate management strategies are adopted.

1. Introduction

Ningxia Plain is one of the largest irrigation areas and the most important food production bases in northwest China. However, soil salinity has plagued its agriculture for a long time due to its dry climate, flat terrain and inadequate drainage systems (Xiong et al., 1996), and salt-affected soils covered 67.4% of its land area in 1962 (Zhou et al., 2010). Many strategies were devised and taken to prevent the increasing trend of soil salinization and reclaim the salt-affected soils. The strategies that proved effective in practice, include washing away the accumulated salts by flushing, ponding fresh water on the soil surface and removing salts by leaching, building surface and subsurface drainage systems, decreasing the area of paddy fields, planting green manure crops, trees and salt-tolerant plants, and applying organic and mineral fertilizer (Yao, 1996; Yu and Rui, 2006). The persistent endeavor resulted in remarkable achievements in developing and reclaiming the salt-affected soils. The proportion of the salinized soils was reduced from 67.4% in 1962 to 33.5% in 2007 (Zhou et al., 2010).

However, these measures were found to be ineffective and difficult to meliorate some leftover salt-affected soils due to their special salt contents, soil textures and low-lying locations. For example, cohesive soils in brown and red, locally known as red sticky salty soils, are widely distributed over the Ningxia Plain. The soils suffer from high salinity and shallow ground water, and their infiltration capacity tends to decrease greatly accompanied by the corruption of soil structure as soils are saturated. Past practices indicated that the soils cannot be reclaimed by flushing, ponding water, or other similar traditional methods. Moreover, leaching salts out of soil with excessive valuable water resource becomes unsuitable and expensive when the competition for water is growing due to fast industrialization and urbanization. Therefore, it is urgent to find new strategies to utilize and reclaim these salt-affected soils with the aim to meet the increasing demand of food production in China.

Drip irrigation, with its characteristics of applying irrigation water and nutrients precisely and uniformly at high frequencies,

* Corresponding author. Tel.: +86 1064856516; fax: +86 1064856516.
E-mail address: kangyh@igsnrr.ac.cn (Y. Kang).

0378-3774/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2011.12.020

can result in low soil salinity, adequate soil water content, nutrients and aeration in the root zone. It has a higher salt leaching efficiency than other irrigation techniques (Goldberg et al., 1976; Keller and Bliesner, 1990; Burt and Isbell, 2005). Drip irrigation has been evaluated to be highly profitable for growing processing tomatoes in salt-affected, shallow groundwater conditions in the San Joaquin Valley (Hanson and Bendixen, 1995; Hanson and May, 2003, 2004; Hanson et al., 2006, 2009).

The key issue related to the utilization and reclamation of salt-affected soils using drip irrigation is to make a reasonable and convenient irrigation schedule to ensure adequate irrigation for both crop growth and reduction in soil salinity. In recent years, our research showed that soil matric potential (SMP) measured by tensiometer is an ideal indicator of soil water content, and can be easily used to help farmers schedule field irrigations (Kang and Wan, 2005; Wang et al., 2007a,b). Our research on drip irrigation with saline water indicated that good soil moisture and salinity condition can be maintained in the root zone throughout the crop growing season when the SMP at 20 cm depth immediately under the emitters is kept higher than −20 kPa (Wan et al., 2007, 2010; Chen et al., 2009; Kang et al., 2009, 2010).

In order to test the effectiveness of drip irrigation to meliorate salt-affected soils, an open-field research was conducted for waxy corn production in a very strong saline wasteland by controlling different SMPs at 20 cm depth immediately under the emitters in the Ningxia Plain. The objectives of the study were: (1) to determine the effect of different SMPs on waxy corn growth, yield, and irrigation water use efficiency under drip irrigation; and (2) to optimize water and salt management strategies to maintain crop productivity in highly saline soils.

2. Materials and methods

2.1. Experimental site

A 4-year (2004–2008) field experiment was conducted at Qingtongxia Agricultural Experimental Station, which is about 1000 m away from the main course of the Yellow River. The station (latitude: 37°36′N; longitude: 105°39′E; 1156 m above sea level) is located in the middle of the Ningxia Plain. It is a typical temperate continental arid climate, with a mean annual temperature of 8.5 °C. Average annual precipitation is 185 mm, most of which (about 70%) falls between July and September. Annual potential evaporation is about 2085 mm, ten times more than annual rainfall.

Crops are usually irrigated with water pumped from the Yellow River. Average water table is about 1.4 m deep through the year and rises to 0.8 m deep during the crop growing seasons in the experimental site. The ionic composition for irrigation water and ground water is given in Table 1. Soil at the experimental site is silt loam and its bulk density varies 1.47–1.78 g/cm^3. Original soil nutrients such as total N, available N and P, and organic matter are in the low level for grain corn (Dahnke et al., 1992; Brown et al., 2010). The soil suffers from strong salinization, and belongs to the chloride-sulfate type saline-sodic soil. Some physical and chemical properties of the initial soil are shown in Tables 2–4.

2.2. Experimental design

Five treatments in terms of soil matric potential (SMP) were designed, with SMP value at 20 cm depth immediately under the emitters higher than −5, −10, −15, −20 and −25 kPa after waxy corn establishment. The five treatments were replicated three times in 15 plots and laid out in a completely randomized block design.

Each of the 15 plots consisted of four raised beds, 0.8 m wide between bed centers. The beds were 0.4 m wide, 15 m long and 0.15 m high. The area of each plot was 48 m^2.

Each treatment was equipped with an independent drip irrigation system. The irrigation system consisted of valves, pressure gauges, a water flow meter, a screen filter, a fertilizer tank and twelve drip tapes (four tapes in one plot). Thin-wall drip tapes (Beijing Lvyuan Co.) with 0.2 m emitter spacing and a flow rate of 0.75 L/(m h) at the operating pressure of 0.03 MPa were placed on the center of each raised bed, and then white polyethylene films (about 0.038 mm thick) were spread over the bed.

2.3. Agronomic practices

Waxy corn (*Zea mays* L. sinesis Kulesh) is one of the widely cultivated crops in Ningxia Plain. As a starch variant of normal corn, kernels containing 100% amylopectin starch, it is an important raw material for food industries, textiles, papermaking and feedstuff.

One row of waxy corn (variety Zhongnuo No. 1) was planted in each bed about 0.05 m away from the drip line. By artificially rupturing the films, 2–3 seeds were sown with 0.2 m interval in May. At the fourth leaf growth stage, seedlings were thinned to leave only one seedling at each location maintaining a plant density of 62,500 per ha. Waxy corns were harvested in August and the growth period was about 95 days. The cultural, diseases and pest management practices were the same as local commercial crop production.

2.4. Irrigation and fertilization

In order to leach accumulated salts in the upper soil and form a favorable soil moisture condition for corn germination and emergence, about 40 mm (four times of the maximum waxy corn water use occurring during tasseling and silking) water was applied immediately after sowing. Thereafter the soil around the seeds or seedling's roots was checked every day to ensure that it was moist, if not, about 3 mm water was applied for all treatments each time until the fourth leaf growth stage. After waxy corn establishment, irrigation based on different SMP thresholds was initiated. The applied water for each irrigation event for all treatments was 5 mm from the fifth leaf to the beginning of tasseling growth stage, and rose up to 10 mm from the tasseling growth stage to harvest.

Considering the original soils suffered from nutrient deficiency, basal-dressing and top-dressing were applied during the experiment. Before field was plowed, 225 kg/ha compound fertilizer (monoammonium phosphate: 18% N, 46% P_2O_5, 1.5% SO_4^{2-}) was uniformly applied to all plots as base fertilizer. After the treatments started, water-soluble urea (46% N) and potassium sulfate (50% K_2O) were put into fertilizer tanks for each irrigation event until the last week. For the whole growth periods of waxy corn, application of urea and potassium sulfate by fertigation was 165 to 250 kg/ha and 90 to 115 kg/ha, respectively.

2.5. Observation and equipment

2.5.1. Rainfall and evaporation

Meteorological data, including rainfall and evaporation, were obtained from a weather station, which is 150 m away from the experimental site. Daily evaporation (E_p) was measured by a 20-cm diameter pan installed 0.7 m above the soil surface.

2.5.2. Soil matric potential

Three vacuum gauge tensiometers were installed at 20 cm, 35 cm and 50 cm depth immediately under the emitters for SMP monitoring in one plot for each treatment. The tensiometers were observed three times each day at 8:00, 11:00, and 15:00 for the