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Effects of drip irrigation with saline water on waxy maize (*Zea mays* L. var. *ceratina* Kulesh) in North China Plain

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ABSTRACT

In order to study the effects of drip irrigation with saline water on waxy maize, three years of field experiments were carried out in 2007–2009 in North China Plain. Five treatments with average salinity of irrigation water, 1.7, 4.0, 6.3, 8.6, and 10.9 dS/m were designed. Results indicated that the irrigation water with salinity <10.9 dS/m did not affect the emergence of waxy maize. As salinity of irrigation water increased, seedling biomass decreased, and the plant height, fresh and dry weight of waxy maize in the thinning time decreased by 2% for every 1 dS/m increase in salinity of irrigated water. The decreasing rate of the fresh ear yield for every 1 dS/m increase in salinity of irrigation water was about 0.4–3.3%. Irrigation water use efficiency (IWUE) increased with the increase in salinity of irrigation water when salinity was <10.9 dS/m. Precipitation during the growing period significantly lightened the negative impacts of irrigation-water salinity on the growth and yield. Soil salinity in depth of 0–120 cm increased in the beginning of irrigation with saline water, while it was relatively stable in the subsequent year when salinity of irrigation water was not higher than 4.0 dS/m and the soil matric potential (SMP) at 0.2 m directly underneath the drip emitter was controlled above −20 kPa.

1. Introduction

Irrigation is an important practice in agriculture. Nowadays, the competition for fresh water in the development of urbanization, industry, leisure, and agriculture causes the decline of fresh water for irrigation (Bergez and Nolleau, 2003; Zwart and Bastiaanssen, 2004; Qadir and Oster, 2004), on the other hand, large amount of saline water resources in the world (Mantell et al., 1985; Ma et al., 2008) may be good alternative. Thus, it is necessary and feasible to use saline water for agricultural irrigation if appropriate crops, soil, and water managements are applied (Oster, 1994; Shalhevet, 1994).

Drip irrigation, with its characteristic of low rate and high frequent irrigation applications over a long period of time, can maintain high soil matric potential in the root zone thus compensate the decrease of osmotic potential introduced by the saline water irrigation, and the constant high total water potential can be maintained for the crop growth (Goldberg et al., 1976; Kang, 1998). Meanwhile, well-aerated condition can be maintained under drip irrigation (Keller and Bliesner, 1990). Therefore, drip irrigation has been regarded as the most advantageous method for applying saline water to crops (Shalhevet, 1994).

Knowledge of the effects of drip irrigation with saline water on various crops is one of the important factors for the application of proper irrigation strategy in North China Plain (semi-humid area). Wan et al. (2007) studied the effects of drip irrigation with saline water on tomato (*Lycopersicon esulentum* Mill) by controlling soil matric potential (SMP) at 0.2 m depth directly underneath the drip emitter higher than −20 kPa. The results showed that water with salinity levels (electrical conductivity of irrigation water, EC_{iw}) raging from 1.1 to 4.9 dS/m had little effects on the yield of tomato, but both irrigation water use efficiency (IWUE) and water use efficiency (WUE) increased with increase in salinity of water, and the soil salinity of 0–90 cm depth did not increase after three-year irrigation with saline water. Similar management was taken by Chen et al. (2009) to study the effects of drip irrigation with saline water (EC_{iw} was ranging from 1.6 to 10.9 dS/m) on oleic sunflower (*Helianthus annuus* L.). They found that the emergence rate decreased by 2.0% for every 1 dS/m increase of EC_{iw} when EC_{iw} was above 6.3 dS/m, the yield decreased by 1.8% for every 1 dS/m increase of EC_{iw} when EC_{iw} was above 1.6 dS/m, and soil salinity of 0–120 cm soil depth could be maintained in balance under drip irrigation with saline water.

Maize (*Zea mays* L.) classified as moderately sensitive of salinity (Mass and Grattan, 1999) is one of the major crops in the world

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Table 1
Soil properties in different soil layers.

Soil layers (cm)	Soil mechanical composition (%)			Soil texture	Soil bulk density (g/cm^3)	Saturated hydraulic conductivity (cm/day)	Field capacity (%)
	<0.002 mm	0.002–0.05 mm	0.05–1 mm				
0–30	9.13	82.91	7.96	Silt	1.22	67.67	27.55
30–45	9.44	88.53	2.03	Silt	1.45	21.95	28.31
45–65	10.39	89.19	0.42	Silt	1.36	25.61	32.21
65–75	9.32	89.99	0.69	Silt	1.32	32.07	32.69
75–160	9.99	89.64	0.37	Silt	1.35	27.04	36.32
160–240	9.01	90.22	0.77	Silt	1.27	39.04	38.51

(Panda et al., 2004). Some researchers have witnessed that irrigation can significantly affect dry matter production, growth, and yield of maize (Stockle and James, 1989; Oktem, 2008; Payero et al., 2008), thus it is also sensitive to drought (Farre' et al., 2000). Waxy maize (*Zea mays* L. var. *ceratina* Kulesh) was first found in China in 1909. Because of many excellent characteristics in terms of starch composition and economic value, waxy maize is becoming an important raw material for food industries, textiles, papermaking, and feedstuff (Tian et al., 2009; Fan et al., 2008), and the planting area of waxy maize is increasing quickly in China.

The objectives of this study were (1) to investigate the effects of drip irrigation with saline water of different salinity levels on seedling emergence, growth, yield, and IWUE of waxy maize, and (2) to assess the soil salinity under drip irrigation with saline water of different salinity levels.

2. Materials and methods

2.1. Experimental site and natural conditions

Field experiments were conducted at Jinghai Experimental Station for Efficient Water Use of Agriculture in the Coast Zone, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. The station is located in Jinghai county, Tianjin Municipality, China (38°53′ N, 116°47′ E, 5 m above sea level). It has a temperate semi-humid monsoon climate, with mean annual precipitation of 570 mm, which is received mainly from June to August. The soil texture is silt (Table 1). Soil bulk density and saturated hydraulic conductivity differed with soil depth ranging from 1.22 (0–30 cm) to 1.45 g/cm^3 (30–45 cm), and from 21.95 (30–45 cm) to 67.67 cm/day (0–30 cm), respectively (Table 1).

2.2. Experimental design and arrangement

In the year of 2007–2009, five treatments, with electrical conductivity of irrigation water (EC_{iw}) of 1.7, 4.0, 6.3, 8.6, and 10.9 dS/m were designed. Irrigation water with different salinities was obtained by mixing the water with various ratios from two wells with EC_{iw} of 1.7 and 11.9 dS/m in the station.

Five treatments were replicated three times with the experimental plots arranged in a completely randomized block design. Each plot was 4.2 by 4.4 m in area, consisting of three raised (15 cm in height) beds with 1.4 m between bed centers. The width and length of each bed was 0.6 and 4.4 m, respectively (Fig. 1), and the

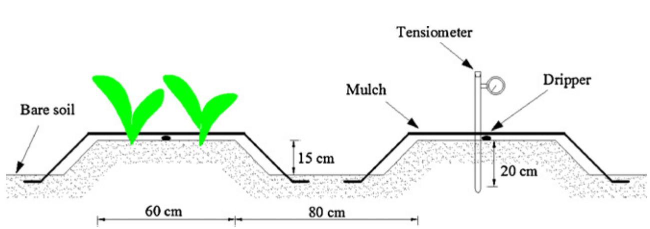

Fig. 1. Dimensions of beds and the position of tensiometer.

position and location of beds was the same during the three years of the experiments. Each treatment was an independent unit of gravity drip irrigation system. The system consisted of a tank (390 l) and nine drip tubes (three tubes in one plot). The tank was installed at 1.2 m above the ground to contain irrigation water. The drip tube with 0.2 m emitter intervals were placed at the center of each raised bed.

Seeds of the waxy maize (*Zea mays* L. var. *ceratina* Kulesh) hybrid "Zhongnuo No. 1" were sown on 26 June 2007, 5 June 2008, and 10 May 2009 in double rows in a zigzag pattern. The rows were 0.3 m apart; within a row, the seeds were sown 23 cm apart. The thinning occurred on the 10th day in 2007–2009. In 2007, the beds were mulched with black polyethylene sheets after thinning; in 2008 and 2009, the black polyethylene mulch was in place before sowing.

Observations were made three times daily (at 8:00, 14:00, and 17:00 h) to determine the appropriate time for water application. Irrigation water was applied when the soil matric potential (SMP) measured with vacuum gauge tensiometer placed at 0.2 m depth directly underneath the drip emitters was higher than −20 kPa. The amount of water for each irrigation event of all treatments was 7 mm, which was the maximum daily evapotranspiration of crops in the local area. In order to ensure the emergence, 28 mm water which was the same salinities as designed for each treatment was applied after sowing.

Basal dose of 300 kg/ha of a compound fertilizer (monoammonium phosphate: 18% N, 46% P_2O_5, 1.5% SO_4^{2-}) was applied uniformly to the plots when the beds were raised in 2007–2009. The dressing was supplemented with urea (46% N), applied by mixing it with irrigation water at a concentration of 30% (w/w). Over the entire growth period, a top dressing of urea approximately 89 kg/ha was given mixed with irrigation water in 2007, 73 kg/ha in 2008, and 81 kg/ha in 2009, respectively.

2.3. Observation and measurements

The number of seedlings was counted daily from sowing to thinning (10 days) for calculating the seedling emergence rate in 2007–2009. The emergence rate was calculated based on the amount of sown. The height and total biomass (fresh weight and dry weight) of young seedlings (10 plants per replicate) were measured at thinning time in 2008 and 2009.

Ten plants in every plot were chosen to determine plant height in 2007–2009. Ten plants in each plot were chosen to determine leaf area index (LAI) in 2008 and 2009. The leaf length and width of waxy maize were measured in the experiment, and LAI was defined as total leaf area per plant ground surface area.

Total yield of fresh ear for all plants on the plots was measured during the harvest. Ten plants in every plot were chosen to determine the following parameters: mean weight of 100 seeds, mean number of row per ear and mean number of kernel per row.

Soil samples were obtained from each plot with an auger (2.0 cm in diameter and 15 cm in height) on 13 April and 21 September in 2007, 30 April and 28 August in 2008, and 4 May and 13 August in