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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, paper-making, 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 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.

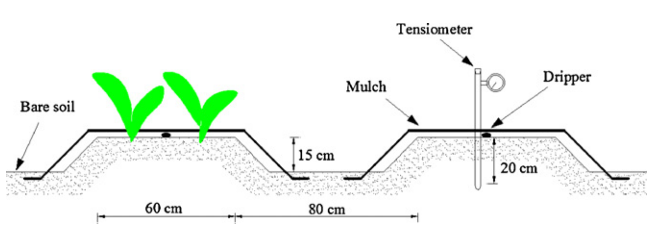

Fig. 1. Dimensions of beds and the position of tensiometer.

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

2009. The horizontal distance to drip emitters for sampling were 0, 14, 28, 42, 56, 70 cm, and sample depths were 0–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100 and 100–120 cm depth. The three replications of soil samples were mixed into one sample per treatment for analyzing soil salinity. All soil samples were air-dried and sieved through a 1 mm sieve, and the electrical conductivity of extracts of 1:5 soil–water ratio by weight ($EC_{1:5}$) was determined using a conductivity meter (DDS-11A). In order to convert $EC_{1:5}$ to electrical conductivity of saturated-soil extract (EC_e) for all soil samples, the relationships between EC_e and $EC_{1:5}$ were determined. EC_e was measured using the methods of Robbins and Wiegand (1990). The relationships for different depths with different soil particle composition are as following:

At 0–30 cm depths:

$$EC_e = 11.49 EC_{1:5} \quad (R^2 = 0.95) \tag{1}$$

At 30–40 cm depths:

$$EC_e = 11.10 EC_{1:5} \quad (R^2 = 0.98) \tag{2}$$

At 40–80 cm depths:

$$EC_e = 10.46 EC_{1:5} \quad (R^2 = 0.93) \tag{3}$$

At 80–120 cm depths:

$$EC_e = 9.06 EC_{1:5} \quad (R^2 = 0.92) \tag{4}$$

Most (about 75%) of the root system of maize was located in the top 0.4 m soil layer (Tardieu, 1988; Phene et al., 1991) as was also found under drip irrigation (Kang and Wan, 2005; Wan and Kang, 2006; Wang et al., 2007), so the average value of EC_e in 0–40 cm soil layer was taken to estimate the relationship between yield and soil salinity under drip irrigation with saline water in 2007–2009, respectively.

The data obtained from experiments were analyzed using a single-factor analysis of variance (ANOVA) and the means of different treatments were compared using least significant different test (LSD) by SPSS Version 13.0. Significant differences were determined at $\alpha = 0.05$ level of significance. The relationship equations that related the growth and yield parameter to the salinity level of water were calculated.

3. Results and discussion

3.1. Precipitation

Total precipitation during the growing period of waxy maize was 261.4 mm in 2007, 220.9 mm in 2008, and 311.7 mm in 2009 (Fig. 2), accounting for about 54.3%, 43.8%, and 60.8%, respectively, of the annual precipitation in these three years. There were eight effective precipitation events (≥10 mm a day) in 2007, which contributed 232.3 mm, the corresponding numeric values were 8 and 198.0 mm in 2008, and 13 and 277.1 mm in 2009. In general, the precipitation was mainly contrasted in the seedling emergence stage and elongation stage in 2007 and 2008, while the most of the rain came late in the silk and ripening stage in 2009.

3.2. Irrigation and soil matric potential

Total number of irrigation and irrigation depth are shown in Table 2. It showed that the higher the water salinity, the fewer the number of irrigation times and the shallower the irrigation-water depth. This implies that drip irrigation with saline water not only save fresh water, but also save saline water by controlling SMP at 0.2 m depth directly underneath the drip emitter above −20 kPa. Similar results were also found by Wan et al. (2007) and Chen et al. (2009). Relatively, much more amount of water was applied in 2009 than that in 2007 and 2008 because of less rain in the elongation stage of maize in 2009 than that in 2007 and 2008. It was found that the SMP at 0.2 m depth directly underneath the drip emitter for treatments of different salinities of irrigation water was controlled well above −20 kPa in the three-year experiment.

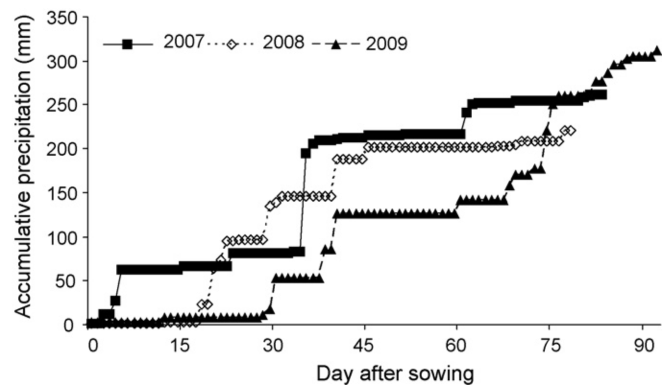

Fig. 2. Precipitation during the growing period of waxy maize in 2007–2009.

3.3. Seedling emergence and biomass

In the three-year experiment, there were no significant effects of salinity treatment on seedling emergence on and after five days. Most of the plants had emerged by five days with only slightly (about 5%) greater additional emerge up to 10 days when the thinning occurred. The results were similar to the report of Mass et al. (1983) who observed that maize germinated well in salinity conditions.

In 2007, there were three effective precipitation events, and with precipitation of 12, 14.8, and 34.5 mm which were received on third, fifth, and sixth day after sowing, respectively, while there was only 1.9 and 2.4 mm rain in whole emergence period in 2008 and 2009. However, the emergence rates on the fifth day after sowing in 2008 and 2009 were higher than that on the fifth day after sowing in 2007. Part of reasons may be attributed to the application of mulch. The black polyethylene mulch was not in place during the emergence period in 2007, while the black mulch had been in place before sowing in 2008 and 2009, and the temperature under the mulch would be higher than that without mulch. It indicated that the mulch could be a good choice to promote the emergence rate under drip irrigation with saline water.

The plant height, fresh weight, and dry weight of waxy maize seedling were significantly different ($P < 0.05$) among the treatments, the higher the water salinity, the lower the plant height and the seedling biomass production. This was similar to that reported by Katerji et al. (1994). The relationship between biomass of seedling and water salinity was shown in Fig. 3. It can be found

Table 2
Number of irrigations and irrigation depths for each treatment in 2007–2009.

EC_{iw} (dS/m)	Number of irrigations			Irrigation-water depths (mm)		
	2007	2008	2009	2007	2008	2009
1.7	16	17	24	112	119	168
4.0	12	14	24	84	98	168
6.3	12	12	19	84	84	133
8.6	10	9	18	70	63	126
10.9	10	9	18	70	63	126

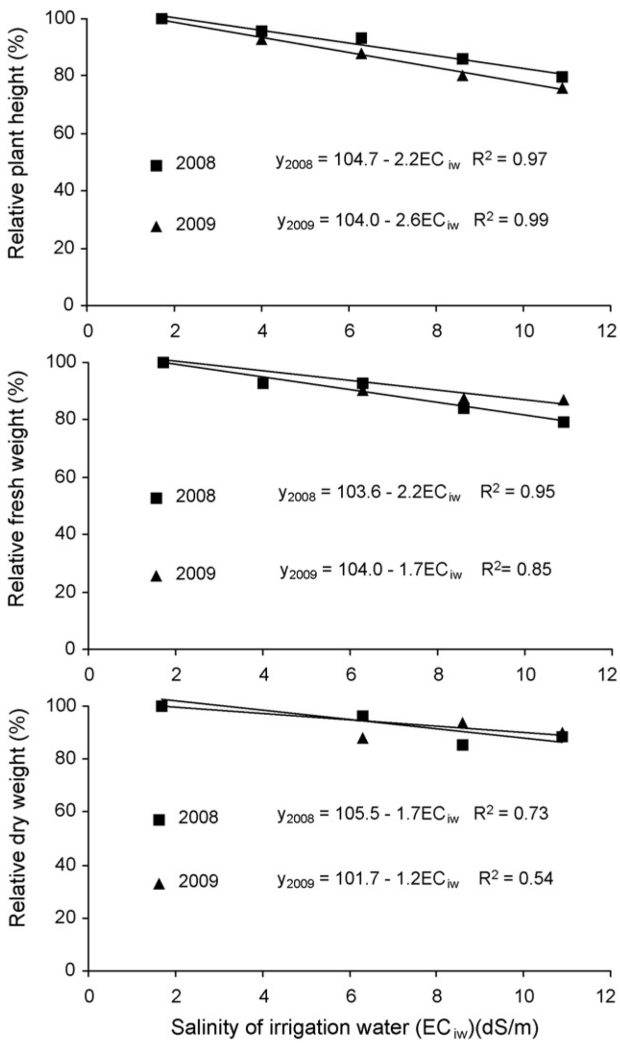

Fig. 3. Relationship between relative seedling biomass of waxy maize and salinity of irrigation water (EC_{iw}) at the thinning time in 2008 and 2009.

that the plant height, fresh weight, and dry weight of waxy maize seedling decreased with the increase of water salinity linearly. In general, the plant height and the biomass production of seedling decreased by 2% for every 1 dS/m increase in EC_{iw}.

Therefore, drip irrigation with saline water for EC_{iw} below 10.9 dS/m did not affect the seedling emergence rate while it affected the seedling biomass.

3.4. Plant height and leaf area index (LAI)

In 2007, the plant height of different treatments had no significant differences on 19th day after sowing, but the magnitude of gain in plant height began to differ significantly across the treatments: the higher the salinity level of irrigation water, the shorter magnitude of gain in plant height. The shortest plants were on average 96.6% as tall as the tallest plants on the harvesting day. In 2008 and 2009, the plant height differed significantly among the treatments of different salinities of irrigation water throughout the growing season, i.e., plants irrigated with saline water for $EC_{iw} \leq 4.0$ dS/m were the tallest and those irrigated with 10.9 dS/m were the shortest. The shortest plants were on average 96.3% and 87.5% as tall as the tallest plants on the harvesting day in 2008 and 2009, respectively.

The differences of plant height among five treatments appeared from the 19th day after sowing in 2007, while in 2008 and 2009,

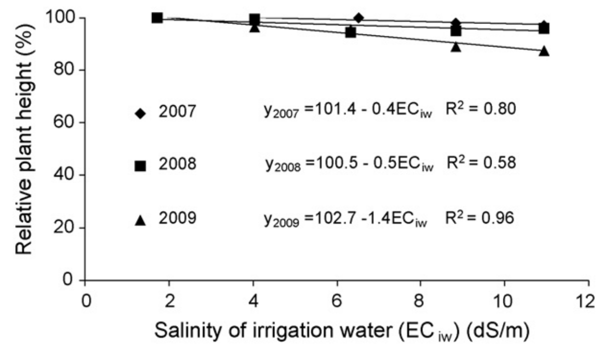

Fig. 4. Relationship between relative plant height of waxy maize and salinity of irrigation water (EC_{iw}) in 2007–2009.

the differences of plant height among five treatments existed all the time during the growth stage of waxy maize. This could be attributed to the large amount of rain during the emergence in 2007 which alleviate the negative impacts on waxy maize seedling. There was a linear relationship between plant height and water salinity (Fig. 4), the decreasing rate of plant height with the increase of 1 dS/m in EC_{iw} was little at the harvesting day of waxy maize.

In 2008, LAI differed significantly among the treatments during the early growing season such as on the 23rd day after sowing, LAI decreased with increasing of salinity of irrigation water, and LAI of plant irrigated with saline water for 10.9 dS/m was the lowest among the five treatments. However, the differences of LAI among treatments reduced with the growth of waxy maize, with eventually no significant differences on the harvesting day. In 2009, the lowest value of LAI was 27.5% as high as the highest value of LAI on the early growing season (27th day after sowing), but caught up later, the value increased to 82.3% on the harvesting day. It indicated that the effect of water salinity on LAI of waxy maize was little when $EC_{iw} \leq 10.9$ dS/m.

In general, irrigated with saline water would cause a setback of growth for waxy maize during the early growth stage, e.g., the higher the EC_{iw}, the shorter the plant, the lower the LAI. However, the plant irrigated with saline water for EC_{iw} even up to 10.9 dS/m was able to catch up in growth of plant on the late growth stage. This could be attributed to the rain during the growing period of waxy maize which may alleviate the negative impacts on waxy maize. The other reason may be related to the application of drip irrigation system, which can provide a condition with constant high soil moisture by controlling the SMP at 0.2 m depth directly underneath the drip emitter above −20 kPa, and could alleviate the negative impacts of saline water irrigation even with high salinity level.

3.5. Yield and irrigation water use efficiency (IWUE)

Table 3 shows four parameters related to the yield of waxy maize for different treatments in 2007–2009, these parameters include weight of 100 seeds, number of row per ear, number of kernel per row, and yield of fresh fruit per hectare.

In 2007, the values of all parameters decreased as the salinity of irrigation-water increased, weight of 100 seeds and number of kernel per row differed significantly among the treatments, while the number of row per ear and the yield of fresh ear were not significantly different among different treatments even when EC_{iw} was as high as 10.9 dS/m. In 2008, number of kernel per row was not significantly different among the treatments, but the weight of 100 seeds, the number of row per ear, and the yield of fresh fruit differed significantly among the treatments, plants irrigated with saline water for $EC_{iw} \leq 4.0$ dS/m yielded the most per unit area. In 2009, the

Table 3
Yield parameters of waxy maize for different treatments 2007–2009.

Year	EC_{iw} (dS/m)	Weight of 100 seeds (g)	Number of row per ear	Number of kernel per row	Yield of fresh fruit (kg/ha)
2007	1.7	19.3[a]	13.7[a]	32.4[a]	9097[a]
	4.0	18.7[a]	14.3[a]	30.5[ab]	9030[a]
	6.3	19.4[a]	14.5[a]	32.4[a]	9082[a]
	8.6	17.0[b]	14.7[a]	31.4[ab]	8751[a]
	10.9	17.7[b]	14.2[a]	30.1[b]	8784[a]
2008	1.7	18.2[a]	15.3[a]	36.3[a]	9918[a]
	4.0	17.4[b]	15.8[a]	36.1[a]	9816[a]
	6.3	16.7[b]	14.4[ab]	35.4[a]	9416[ab]
	8.6	14.9[d]	14.4[ab]	35.6[a]	8956[bc]
	10.9	15.3[c]	13.8[b]	35.0[a]	8715[c]
2009	1.7	20.0[a]	15.7[a]	38.2[a]	11,241[a]
	4.0	18.3[b]	15.3[ab]	36.8[ab]	11,377[a]
	6.3	16.7[b]	14.9[ab]	35.0[c]	9263[b]
	8.6	15.3[d]	15.0[ab]	35.1[bc]	8561[b]
	10.9	13.6[e]	14.8[b]	32.4[d]	8396[b]

Values in a row followed by the same letter are not significantly different at $P \leq 0.05$.

value of all parameters decreased as the salinity of irrigation-water increased, but the value of these parameters were not significantly different when the $EC_{iw} \leq 4.0$ dS/m.

From Fig. 5, it can be seen that the yield decreased as the salinity of irrigation-water increased, and there is a negatively linear relationship between relative yield and salinity of irrigation water (EC_{iw}). A unit increase in EC_{iw} reduced yield by 0.4%, 1.4%, and 3.3% in 2007, 2008, and 2009. The lower decrease in yield in 2007 compared to that in 2008 and 2009 may be caused by the rain event. For one hand, the precipitation distribution in 2007 was more evenly than that in 2008 and in 2009. For the other hand, there was a large rain (61.3 mm) in the emergence period in 2007. The highest decreasing rate in 2009 may be caused by the more saline water applied. Therefore, it seems that the precipitation will offset the negative impact of salinity of irrigation water.

Irrigation water use efficiency (IWUE), which is calculated by dividing the total yield of waxy maize by the total quantity of irrigation water, is the relation between yield and quantity of irrigation water. Results showed that there was a quadratic relationship between IWUE and EC_{iw} for waxy maize under drip irrigation with saline water (Fig. 6). The relationship in 2009 was different to those in 2007 and 2008. The reasons may be that much more water was applied in 2009 than that in 2007 and 2008 while the yield of fresh fruit was not significantly different among the three years.

3.6. Variation of soil salinity and the relationship between yield and soil salinity

The soil salinity presented an increasing tendency at the end of the first year experiment compared to the initial soil salinity before experiment (Table 4). After the first year of irrigation with saline water, the soil salinity increased in all treatments, the higher the irrigation-water salinity, the higher the soil salinity.

Compared to the end of the first year experiment, the soil salinity of all treatments decreased at the beginning of the second year experiment. The reason could be that the removal of mulch after harvesting and the rain during the non-growing season was helpful for leaching the salts from soil. At the end of the second year experiment, the soil salinity under drip irrigation with saline water of $EC_{iw} \leq 4.0$ dS/m did not increase compared to the soil salinity at the end of the first year experiment, but the soil salinity increased when EC_{iw} increased from 6.3 to 10.9 dS/m.

Compared to the end of the second year experiment, the soil salinity of five treatments increased at the beginning of the third year experiment. It might be due to the transfer of salts from lower to upper soil depth with deep ploughing at 60 cm depth before the start of experiment. At the end of the third year experiment, soil salinity did not increase compared to the soil salinity at the beginning of the third year when $EC_{iw} \leq 4.0$ dS/m, but the soil salinity increased when EC_{iw} increased from 6.3 to 10.9 dS/m.

In general, the soil salinity at waxy field could be maintained in relative balance under drip irrigation with saline water when

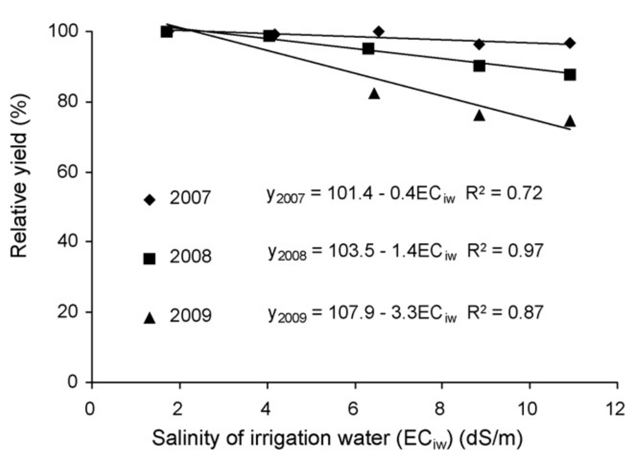

Fig. 5. Relationship between relative yield and salinity of irrigation water (EC_{iw}) in 2007–2009.

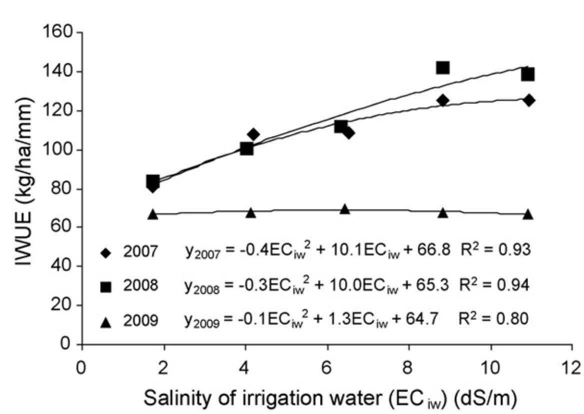

Fig. 6. Relationship between irrigation water use efficiency (IWUE) and salinity of irrigation water (EC_{iw}) in 2007–2009.

Table 4
Soil salinity in the vertical transect perpendicular to the drip tapes for each treatment in 2007–2009.

EC_{iw} (dS/m)	Soil depth (m)	Electrical conductivity of saturated-soil extract (EC_e) (dS/m)					
		2007		2008		2009	
		4/13	9/21	4/30	8/28	5/4	8/13
1.7	0–0.4	1.55	1.96	1.78	1.60	2.98	3.17
	0.4–0.8	1.92	2.18	2.05	1.93	4.32	3.52
	0.8–1.2	2.33	2.60	2.08	2.43	4.54	4.14
	Average	1.93	2.25	1.97	1.99	3.94	3.61
4.0	0–0.4	1.55	2.71	2.34	2.02	4.10	3.66
	0.4–0.8	1.92	2.42	2.18	2.39	4.75	5.26
	0.8–1.2	2.33	2.65	2.34	2.78	4.69	5.17
	Average	1.93	2.59	2.29	2.39	4.52	4.70
6.3	0–0.4	1.55	2.76	2.80	2.91	3.96	5.83
	0.4–0.8	1.92	2.06	2.29	2.93	4.34	6.52
	0.8–1.2	2.33	2.28	2.55	2.99	4.34	5.45
	Average	1.93	2.37	2.55	2.94	4.21	5.93
8.6	0–0.4	1.55	3.94	3.29	4.01	5.33	6.39
	0.4–0.8	1.92	2.39	3.46	4.79	6.88	8.14
	0.8–1.2	2.33	2.70	2.95	3.82	5.11	6.35
	Average	1.93	3.01	3.23	4.21	5.77	6.96
10.9	0–0.4	1.55	6.12	3.90	5.03	5.64	6.91
	0.4–0.8	1.92	3.90	4.89	4.86	7.59	8.22
	0.8–1.2	2.33	3.32	3.43	4.23	5.86	7.17
	Average	1.93	4.45	4.07	4.71	6.36	7.43

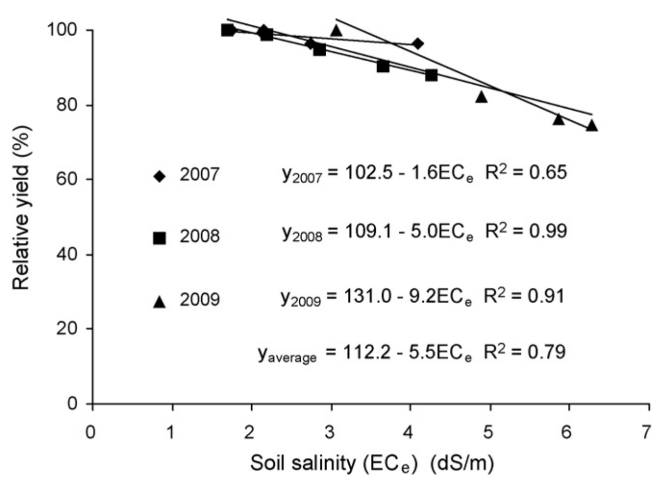

Fig. 7. Relationship between relative yield and soil salinity (EC_e) in 2007–2009.

$EC_{iw} \leq 4.0$ dS/m. This disagreed with the results of Chen et al. (2009) that the soil salinity in 0–120 cm depth could be maintained in balance at an oleic sunflower field by drip irrigation with saline water even when the EC_{iw} was as high as 10.9 dS/m. The reason for this phenomenon may be that the control target of soil matric potential was low and the salt could not be leached efficiently. Therefore, higher value of soil matric potential should be controlled for waxy maize if saline water with EC_{iw} higher than 4.0 dS/m was applied by drip irrigation.

A unit increase in EC_e reduced yield by 1.6%, 5.0%, and 9.2% in 2007, 2008, and 2009, respectively (Fig. 7), it also showed a slope of 5.5% decrease per dS/m for the three years. This is very different from the accepted values given by Mass and Grattan (1999) that maize yield reduced by 12% per unit increase in EC_e. The reason for the discrepancy was most likely due to characterization of effective soil salinity under drip irrigation.

4. Conclusions

Three years of field experiments were carried out in 2007–2009 in North China Plain, to study the effects of drip irrigation with saline water on emergence, vegetative growth, yield of waxy maize, and the effects on soil salinity. It can be concluded that seedling emergence rate of waxy maize was not affected by drip irrigation with saline water, but the seedling biomass such as plant height, fresh mass, and dry mass decreased with the increase in salinity of irrigation water. The plant height and LAI decreased as the salinity of irrigation-water increased. There were significant differences in plant height and LAI during the early growth stage: the higher the salinity of irrigation water was, the lower the value of the plant height and LAI was, and the differences in plant height and LAI reduced at the later growth stage. The yield decreased about 0.4–3.3% for every 1 dS/m increase in EC_{iw}. The IWUE increased as salinity of irrigation-water increased, when the EC_{iw} of irrigation <10.9 dS/m.

However, if there was effective precipitation (above 10 mm) during the growing period especially in the emergence period and even distribution of precipitation, the impact of salinity of irrigation water on plant including emergence, vegetative growth, and the yield would be alleviated.

The soil salinity would increase at the beginning of drip irrigation with saline water, and the higher the salinity of irrigation water correspond to the more increase in the soil salinity. Subsequently, the soil salinity of 0–120 cm soil depth could be maintained in relative balance under drip irrigation with saline water of EC_{iw} below 4.0 dS/m when SMP was kept above −20 kPa.

From the results of the experiments, in North China Plain or similar semi-humid area where are more than 500 mm annual precipitation, several management practices including raising bed, mulching with black polyethylene before sowing, and maintaining SMP at 0.2 m depth directly underneath the drip emitters higher than −20 kPa should be used for drip irrigation with saline water on waxy maize.

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