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Effect of saline water on cucumber (*Cucumis sativus* L.) yield and water use under drip irrigation in North China

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ABSTRACT

Saline water has been included as an important substitutable resource for fresh water in agricultural irrigation in many fresh water scarce regions. In order to make good use of saline water for agricultural irrigation in North China, a semi-humid area, a 3-year field experiment was carried out to study the possibility of using saline water for supplement irrigation of cucumber. Saline water was applied via mulched drip irrigation. The average electrical conductivity of irrigation water (EC_{iw}) was 1.1, 2.2, 2.9, 3.5 and 4.2 dS/m in 2003 and 2004, and 1.1, 2.2, 3.5, 4.2 and 4.9 dS/m in 2005. Throughout cucumber-growing season, the soil matric potential at 0.2 m depth immediately under drip emitter was kept higher than −20 kPa and saline water was applied after cucumber seedling stage. The experimental results revealed that cucumber fruit number per plant and yield decreased by 5.7% per unit increase in EC_{iw}. The maximum yield loss was around 25% for EC_{iw} of 4.9 dS/m, compared with 1.1 dS/m. Cucumber seasonal accumulative water use decreased linearly over the range of 1.5–6.9% per unit increase in EC_{iw}. As to the average root zone EC_e (electrical conductivity of saturated paste extract), cucumber yield and water use decreased by 10.8 and 10.3% for each unit of EC_e increase in the root zone (within 40 cm away from emitter and 40 cm depths), respectively. After 3 years irrigation with saline water, there was no obvious tendency for EC_e to increase in the soil profile of 0–90 cm depths. So in North China, or similar semi-humid area, when there is no enough fresh water for irrigation, saline water up to 4.9 dS/m can be used to irrigate field culture cucumbers at the expense of some yield loss.

1. Introduction

The availability of fresh water for agricultural use is declining in many areas of the world due to the increasing water needs of industries and municipalities. Thus, agriculture faces challenges of using low quality wastewater and saline water for crop production. Many studies indicate that these water resources traditionally classified as unsuitable for irrigation can be used successfully to grow crops without long-term hazardous consequences to crops and soils if proper management strategies are established. These strategies include adopting advanced irrigation technology, selecting appropriately salt-tolerant crops, leaching salts below the crop root zone (Rhoades et al., 1992; Oster, 1994; Shalhevet, 1994). In China, especially in North China, the increasing water shortages make it urgent to develop safe and efficient management of saline water resource for agricultural irrigation.

Saline water has been successfully used to irrigate field-grown tomato and oleic sunflower in North China in recent years (Wan et al., 2007; Chen et al., 2009). It was found that when several management strategies were adopted, saline water up to 4.9 dS/m and 10.9 dS/m can be applied respectively to irrigate tomato and oleic sunflower without obviously negative effects on the yields and soil salinity. The main management strategies include applying saline water with mulched drip irrigation, keeping the soil matric potential (SMP) at 0.2 m depth immediately under emitter higher than −20 kPa throughout the growing season.

Cucumber (*Cucumis sativus* L.) is one of the most popular and widely grown vegetable crops in the world, and is considered moderately sensitive to salt stress, since it can tolerate an EC_e (electrical conductivity of saturated paste extract) of about 2.5 dS/m and fruit yield decrease by 13% with each unit of EC_e increasing above the threshold value (Maas and Hoffman, 1977). The responses of cucumber to saline water irrigation were recorded by some investigators. Sonneveld and Voogt (1978) indicated when the electrical conductivity of irrigation water (EC_{iw}) ranged from 0.1 to 4.5 dS/m, greenhouse cucumber yields decreased linearly as EC_{iw} increased, and the yield reduction was about 17% per unit increase

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in EC_{iw}. Jones et al. (1989) found that EC_{iw} of 4.0 dS/m significantly decreased cucumber yield. Chartzoulakis (1992) reported cucumber (cv. Pepinex) growth reduced significantly when the EC_{iw} was higher than 1.2 dS/m, and the relative yield reduced by 16% per unit increase in EC_{iw} above 1.3 dS/m. Al-Harbi indicated that cucumber (cv. Farbiola) was able to tolerate nutrient solution with EC_{iw} higher than 4.5 dS/m without a significant reduction in yield (Al-Harbi, 1994a), and high EC_{iw} had a greater effect during the day than during the night due to its effect on cucumber water uptake (Al-Harbi, 1994b). Ho and Adams (1994) demonstrated that dry weight of cucumber (cv. Corona) fruit was not affected until the EC_{iw} was higher than 5.5 dS/m, and the reduction was 9% for each unit of EC_{iw} increasing between 5.5 and 8 dS/m. All of these mentioned studies were performed in greenhouse or in hydroponics cultures, which are relatively well controlled growing conditions.

In North China, cucumbers are often planted in open field in early spring or later summer, and supplemental irrigation is essential. In open field, rainfall may contribute a substantial amount of water to crop need, and reduce the need of irrigation water required for salt leaching. The objectives of the study were (1) to study the responses of open cultivated cucumber to saline water irrigation, and explore the possibility of using saline water for supplement irrigation of cucumber in North China; and (2) to optimize saline water irrigation management strategies to maintain cucumber productivity and the salt balance in the soil.

2. Methods and materials

2.1. Experimental site

A 3-year (2003–2005) field experiment was conducted at Tongzhou Experimental Station for Water Cycle and Modern Water-saving Irrigation Research, Institute of Geographic Science and Natural Resource Research. The Station (latitude: 39°36′ N; longitude: 116°48′ E; 20 m above sea level) is located in the southeast region of Beijing, about 60 km away from Beijing city. It is a temperate semi-humid monsoon climate, with mean annual temperature 11.3 °C and mean annual global radiation 5.24 GJ/m^2. Average annual precipitation is 620 mm, with 80% concentrated during the July-September period. The dominant soil in the experiment was a silt loam. In 0–30 cm plow layer, its average bulk density was 1.35 g/cm^3, and soil organic matter content was about 1.3%.

2.2. Experimental design

The experiment consisted of a control treatment and four saline water treatments. The control treatment was local groundwater (fresh water) with an EC_{iw} of 1.1 dS/m. Artificial saline water were produced by adding $NaHCO_3$, Na_2SO_4, $MgSO_4$, $MgCl_2$ and $CaCl_2$ to local groundwater in molar proportion of 0.50:0.05:0.25:0.10:0.10, which is similar to the ionic compositions of the aquifer in Cangzhou area, one of the largest areas with moderately saline water (2–5 dS/m) resource in North China. The average EC_{iw} were 2.2, 2.9, 3.5 and 4.2 dS/m in 2003 and 2004, and were 2.2, 3.5, 4.2 and 4.9 dS/m in 2005, respectively. Ionic composition for local groundwater and saline water in this trial is listed in Table 1. All of the treatments were replicated three times following a completely randomized design. The locations of the treatments at the experimental site was kept unchanged each year, in order to observe accumulative salinity hazards on crop and soil.

2.3. Agronomic practices

Each plot consisted of three raised beds, with a width of 1.4 m between bed centers. The beds were 0.6 m wide, 4.4 m long and 0.15 m high. The area of each plot was 18.48 m^2. Every treatment plot was a gravity drip system. In the front of each plot, a tank, with volume about 120 L, was installed at a 1 m level. Drip tube (Xinjiang Tianye Co.) with 0.2 m emitter spacing and a flow rate of 3.0 L/h at the operating pressure of 0.1 MPa was placed on the center of each raised bed. Under this gravity drip irrigation system, the actual operating pressure was between 0.012 and 0.017 MPa, and the actual flow rate was about 0.9 L/h.

Cucumber (*C. sativus* L.) seeds cv. 'zhongnong' were used in the 3 years. The seeds were sown in the field on May 4, May 14 and April 30 in 2003, 2004 and 2005, respectively. Double row plantings (in a zigzag) spaced 0.3 m apart per bed and interplant spacing was 0.4 m. About three weeks later, cucumber seedlings were thinned to leave only one seedling at each location maintaining a plant density of approximate 35,720 plants/ha. Cucumbers were allowed to grow naturally without pruning. Plant protection was needed each year, and disease control and pest management were the same for all treatments.

Black polyethylene mulches (1.2 m wide by 0.08 mm thick) were applied over the beds on May 31 (27 days after sowing: DAS), May 12 (2 days before sowing), and June 2 (33 DAS) in 2003, 2004 and 2005, respectively. Because rainfall helps wash the soluble salts out of the soil profile, the polyethylene mulches were removed after each growing season.

2.4. Irrigation

During cucumber-growing periods in the 3 years, irrigation was applied only when the SMP at 0.2 m depth immediately under drip emitter was close to −20 kPa, except at seeding stage. In order to ensure plants grow normally, fresh water was applied immediately after seeding and during the cucumber seedling stage (0–35 days after seeding).

The treatment was initiated at the end of seedling stage, which was on June 7 (34 DAS), June 15 (32 DAS), and June 16 (47 DAS) in 2003, 2004 and 2005, respectively. In 2005, treatments were delayed about 10 days because of prolonged seedling period due to bad weather on seeding days.

Table 1
Ionic composition of local groundwater and saline water in 2003, 2004 and 2005.

$\overline{EC_{iw}}$[a] (dS/m)	Ionic concentration (mmol/L)								SAR[b]
	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+	
1.1	0.4	6	2.7	1.7	0.6	4	0.7	2.7	1.3
2.2	0.4	10.8	6.0	5.0	1.0	5.0	2.6	10.5	4.3
2.9	0.4	13.8	9.2	5.8	2.2	7.2	3.4	13.5	4.4
3.5	0.4	17.7	13.0	6.4	1.2	8.3	4.3	17.3	5.7
4.2	0.4	19.4	13.8	8.5	2.0	8.1	5.4	21.5	6.8
4.9	0.4	23.1	17.1	9.8	2.3	9.8	6.4	25.7	7.4

[a] $\overline{EC_{iw}}$ means the average electrical conductivity of the irrigation water.
[b]SAR means sodium adsorption ratio.