Effects of an alternative water source and combined agronomic practices on soil salinity and irrigated cotton in coastal saline soils

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Abstract
The ongoing experiment for cotton (*Gossypium hirsutum L.*) was conducted at the Zhongjie Farm, Huanghua city of Hebei province in the coastal salinity-affected areas in North China Plain, to determine the effects of alternative irrigation water sources /methods and agronomic practices on changes in soil water-salt contents and soil pH during cotton growth stages, and also on seedling emergence and yields of cotton. The experiment was set-up using split-plot design with two water sources as main treatments (well water /desalinized sea-ice water); two irrigation methods (+PAM (Polyacrylamide) /-PAM); and four fertilization modes: check (CK), mineral fertilizer (F), mineral+organic fertilizer (FM), and mineral fertilizer+gypsum (FG). The 10-cm top-soil salt contents at seeding decreased by about 18%, 32%, 34% and 55% with F, FM, FG and PAM under well-water irrigation, respectively, and by about 40%, 23%, 23% and 58% with F, FM, FG and PAM under sea-ice water irrigation, respectively, as compared with PAM-untreated CK. Using PAM-treated irrigation, the 10-cm top-soil salinity significantly decreased to about 2.3-3.9 g/kg from 4.6-8.6 g/kg (PAM-untreated). The top-soil salt contents at seeding stage also adversely affected seedling emergence ($r = -0.71^{**}$), and resulted in yield reduction ($r = -0.50^{**}$). PAM-treated irrigation, either using well-water or desalinized sea-ice, in combination with gypsum, shows the best practice for soil desalinization, and hence seedling emergence and cotton yields, and could be acceptable for crop irrigation in the coastal saline areas.

Key Words
Coastal areas, cotton, fertilization, irrigation, polyacrylamide.

Introduction
The coastal area surrounding the Bohai Sea (including 3 provinces and 2 cities, viz. Hebei, Liaoning, Shandong, Tianjin and Beijing) is one of the important key regional economic development belts and food production bases in China. Fresh-water shortage is the most limiting factor to crop production in the coastal areas surrounding the Bohai Sea, thus searching for usable water resources and effective water-saving irrigation methods for improvement of crop production on the salinity-affected land has been of a great interest in recent years. The use of “new water” through desalinisation of seawater or brackish water for crop irrigation has been also receiving great attention in water-starved countries throughout the world (Fang and Chen 1997; Wolff and Stein 1999; Pereira *et al.* 2002; Qadir *et al.* 2003; Qadir and Oster 2004; Li *et al.* 2008; Zhao *et al.* 2008). In China, recently the sea-ice resource of Bohai Sea has been considered to be a potential resource of fresh water (Shi *et al.* 2003; Li *et al.* 2005). Shi *et al.* (2003) observed in the investigated area in Behai Gulf that salt separation from sea ice in freezing process results in lower salinity (about 1.4-4.0 g/L) in sea ice with an average of 2.64 g/L, far less than that of sea water (about 26-29 g/L). The salinity of refrozen sea water ice decreases further to 0.5-2.0 g/L, close to the salinity of freshwater (Shi *et al.* 2003).

Using melt and desalinized sea-ice water for crop irrigation has been tested with simple and low-cost desalinization techniques (by sea-ice freezing-melting processing through temperature control) under the recent research project support in China (Xu *et al.* 2006; Zhang *et al.* 2006; Hu *et al.* 2009; Zheng *et al.* 2009). However, under the saline conditions, influenced by capillary up-flow from salt-rich shallow ground water, irrigation should meet both the crop water requirements and the leaching (or desalination) requirements (Minhas 1996). Thus, integrated irrigation management, combined with other agronomic practices, including hydraulic, physical, chemical, biological and engineering practices, may help both increase the efficiency of infiltration and use of irrigation water, and improve the efficiency of the reclamation, amelioration and utilization of salt-affected soils. Whether sea ice can be used as freshwater also depends on the salinity and alkalinity of the thawed sea ice (Shi *et al.* 2003). However, the changes in soil water salt contents and salinity and alkalinity relations when the sea-ice water is used for crop irrigation are still unclear.

The objective of the research is to determine the effects of various irrigation (water sources /water additives by PAM) and fertilization practices (soil amendment additions by gypsum or organic fertilizer combined) on the changes in soil water-salt contents and soil pH during cotton growth stages, and on cotton seedling emergence and yields, to provide an assessment of using desalinized sea-ice water as an alternative irrigation water source and integrated agronomic practices of soil water-salt management for cotton production in the salinity-affected and freshwater-limited coastal areas of the Bohai Sea in China.

Methods

The ongoing field experiment was carried out at the Zhongjie Farm, Huanghua city of Hebei province (117°23'-117°29'E, 38°19'-38°29'N, located in dry semi humid region of northern China), on a loamy-clay soil with a moderate - high salinity level, in the coastal area near the Bohai Sea in China. The initial 20 cm layer salt contents ranged from 4 to 11 g/kg due to field flooding in 2006. Soil pH was about 8.4. The groundwater table level is around 0.9-1.6 m deep. The average annual rainfall is about 620 mm. Spring cotton (Gossypium hirsutum L.), one crop per year, is one of the dominant crops. Spring drought, accompanying high salinity at the soil surface inhibits seed germination and seedling emergence, which in turn adversely affects cotton growth and yields. Thus, irrigation is necessary to alleviate both water and salt stress
The experiment was set-up using split-plot design with two water sources as main treatments: well-water and desalinized sea-ice water; two irrigation methods as sub-treatments (+PAM (Polyacrylamide)/-PAM); and four fertilization methods as sub-treatments: 1) CK， 2) mineral fertilizer (F), 3) mineral + organic fertilizer (FM), and 4) mineral fertilizer + gypsum (FG). The salt contents of well-water and desalinized sea-ice water were about 1 and 3 g/L, respectively. Mineral fertilizer applications were 180 N (urea, 46% N), 150 P_2O_5 (superphosphate, 12% P_2O_5), and 90 K_2O kg/ha (Potassium fertilizer, (K_2SO_4, 50% K_2O). Commercial organic fertilizer application was 4500 kg/ha. The contents of organic carbon, total N, total P, total K and moisture were 38%, 2.35%, 1.39%, 1.25% and 42.9%, respectively for organic fertilizer. Gypsum and PAM applications were 5000 kg/ha and 10 ppm, respectively. Plots of 6 x 5 m^2 were laid down randomly in triplicate.
The pre-field experimental preparation for cotton crops was conducted in April 2007. To lower the ground water-table against soil water-logging and salinity-rising, a raised bed with drains around was built in the experimental site field. Irrigation water (about 55.5 mm) and fertilizer treatments were implemented before cotton crop planting (on the 27th of April). The 2nd irrigation treatment was on the 6th of July. Cotton was seeded in early May (the 2nd of May), at distances of 60 cm and 80 cm between rows and at 30 cm within the rows. The local salt-tolerant spring cotton (*Lumianyan no. 21*) variety was used. To prevent evaporation and salinity-rising, plastic film cover was practised on the seeded soil surface at sowing.
Soil samples were collected at depths of 0-10, 10-20, 20-40, 40-60, 60-80, and 80-100 cm for soil moisture, salt content, and pH value determination taken at seeding and main growth stages of cotton. Electrical conductivity (EC) and pH value were measured in a 1:5 (by weight) soil-water extract using an EC/pH meter WM-22EP. Soil salt content can be converted by the relationship of total dissolved salts (TDS) to EC as follows:

$$\text{TDS (mg/L)} = \text{EC } (\mu\text{S/cm at } 25^{\circ}\text{C}) \times 0.6 \qquad (1)$$

Seedling emergence and cotton yields were measured at seedling stage (29 May) and harvest (23 October), respectively. Statistical analysis was done with the GLM /REG procedure of the SAS Institute, Inc. (2004).

Results

Changes in top soil salt contents and pH at cotton growth stages

Mean soil salt contents and soil pH in the top 10 cm layers changed during the cotton growing periods as shown in Table 1. Mean 10-cm top-soil salt contents greatly changed from 4.8 g/kg (ranging from 1.8 to 15.5 g/kg) at seeding to 2.3 g/kg (ranging from 1.0 to 6.3 g/kg) at harvest with increased seasonal rainfall between July and Sept.; while mean 10-cm top-soil pH slightly changed from 8.5 (ranging from 7.9 to 9.1) at seeding to 8.4 (ranging from 7.95 to 8.93) at harvest.
The big variation in top-soil salinity at seeding was related to the top-soil redistribution because of pre-field preparation in April of 2007, and flooding in 2006 (in which cotton yields were heavily lost due to waterlogging and salinity). The salt contents of the 10-cm top-soil at seeding were also influenced by various irrigation and fertilization treatments, decreasing by about 18%, 32%, 34% and 55% with F, FM, FG and PAM under well-water irrigation, respectively, and by about 40%, 23%, 23% and 58% with F, FM, FG and PAM under sea-ice water irrigation, respectively, as compared with PAM-untreated CK (data not shown). Either using well-water or desalinized sea-ice water irrigation with PAM application, the 10-cm top-soil salt contents significantly decreased to about 2.3-3.9 g/kg (+PAM) from 4.6-8.6 g/kg (-PAM) ($P<0.05$).

Table 1. Statistical data for cotton yield (kg/ha), soil salinity (g/kg) and pH in 10-cm top-soil layers (n=48) measured during the period of May 2 at seeding to Oct 27, 2007 at harvest.

Iterm	Salinity _May 2	Salinity _July 10	Salinity _Sept 15	Salinity _Oct 27	pH _May 2	pH _July 10	pH _Sept 15	pH _Oct 27
Min.	1.8	1.2	1.7	1.0	7.90	7.91	7.50	7.95
Max.	15.5	18.9	13.9	6.3	9.09	9.06	8.74	8.93
Mean	4.8	5.9	5.6	2.3	8.51	8.38	8.10	8.40
SE.	0.4	0.6	0.4	0.2	0.04	0.04	0.04	0.03
SD.	2.9	4.2	2.9	1.1	0.27	0.25	0.30	0.23
CV(%)	59.8	70.3	53.0	45.5	3.1	3.0	3.8	2.8

Relationships between cotton seedling emergence /yields and top soil salinity /pH

Relationships between cotton seedling emergence /yields and the 10-cm top-soil salt contents /pH are shown in Table 2. The 10-cm top-soil salt contents during cotton growth stages, especially at seeding stage (for May 2) adversely affected seedling emergence (r = -0.71**), and significantly resulted in yield reduction (r = -0.50**). Cotton yields significantly decreased with a reduction in seedling emergence (r = 0.62**), related to the 10-cm top-soil salt contents at seeding, but not to the top-soil pH values. Apparently, the 10-cm top-soil salt content at cotton seeding is the most important yield-limiting factor. Although generally there were significant negative relations between the 10-cm top-soil salt and pH during cotton growing periods, they have less impact on cotton yields than the soil salt content at seeding stage.

Table 2. Correlation coefficients (r) for cotton yields (kg/ha), seedling emergence (%), and the 10-cm top-soil salt contents (g/kg) and soil pH measured during the periods of May 2 to Oct 27, 2007.

Item	Cotton Yield	Seedling emergence	Salinity _May 2	Salinity _July 10	Salinity _Sept 15	Salinity _Oct 27
Seedling emergence	0.624**					
Salinity_May 2	-0.499**	-0.708**				
Salinity_July 10	-0.400*					
Salinity_Sept 15	-0.278					
Salinity_Oct 27	-0.079					
pH_May 2	-0.297	0.141	-0.428**			
pH_July 10	-0.057			-0.689**		
pH_Sept 15	0.104				-0.440**	
pH_Oct 27	-0.125					-0.703**

Note: * and ** refer to significance at P< 0.05 and P< 0.01 respectively.

Relationships between profile soil salinity and moisture / pH

The correlation coefficients (r) between soil moisture and salinity at seeding show positively significant relations when PAM treated, but insignificant relations for untreated soil in the 0-10, 10-20, and 20-40 cm soil depths (Table 3).

Table 3. Correlation coefficients (r) for soil salinity (g/kg) versus moisture (%) /pH in the 0-10, 10-20, 20-40, 40-100 cm soil profile at seeding (May 2, 2007).

Irrigation method		Soil moisture 0-10 cm	10-20 cm	20-40 cm	40-100 cm	Soil pH 0-10 cm	10-20 cm	20-40 cm	40-100 cm
	Soil salinity								
+PAM	0-10 cm	0.355*				-0.116			
	10-20 cm	0.631**	0.436*			0.158	-0.348		
	20-40 cm	0.599**	0.549**	0.452*		0.200	-0.187	-0.025	
	40-100 cm	0.410**	0.502*	0.372	0.194	0.178	-0.050	0.253	-0.166
-PAM	0-10 cm	-0.275				-0.792**			
	10-20 cm	0.145	-0.081			-0.262	-0.588**		
	20-40 cm	0.049	-0.162	-0.335		-0.617**	-0.350	-0.612**	
	40-100 cm	-0.144	-0.271	-0.328	-0.298	-0.508**	-0.200	-0.417	-0.652**

Note: * and ** refer to significance at P< 0.05 and P< 0.01 respectively.

Soil moisture contents in the top 0-10 and 10-20 cm were also positively related to the deep soil salinity when PAM treated, showing that PAM-treated irrigation promoted salt downward transfer with irrigation water movement due to increased infiltration rate. The relationships between profile soil pH and salinity at seeding were not significant when PAM treated, while negative significant relationships between them were found in the 0-10, 10-20, 20-40 and 40-100 cm soil depth when untreated (Table 3). This indicated that the decline in salt contents in soil profiles with PAM-treated irrigation did not cause a significant increase in profile soil pH values.

Conclusions

The PAM-treated irrigation, either using well-water or desalinized sea-ice, combined with gypsum is best practice for soil desalinization from top to deep soil layers, and hence seedling emergence and cotton yields. The desalinized sea-ice water used as an alternative water source for crop irrigation in the salinity-affected coastal areas could be effective using an integrated agronomic practice (such as PAM-treated irrigation combined with gypsum application).

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