Reclaiming Coastal Saline Soils by Freezing Saline Water Irrigation: Mechanisms and Application

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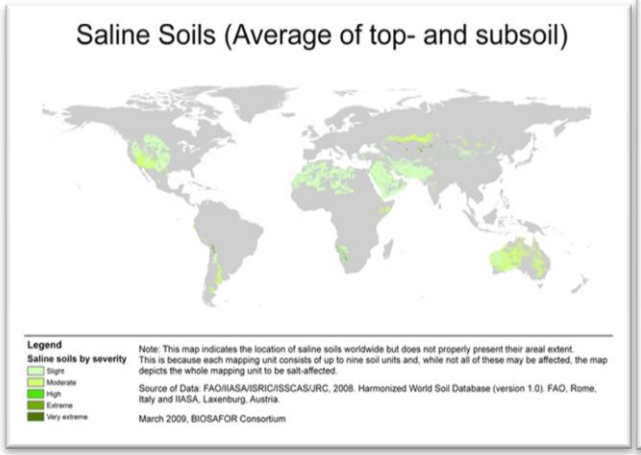
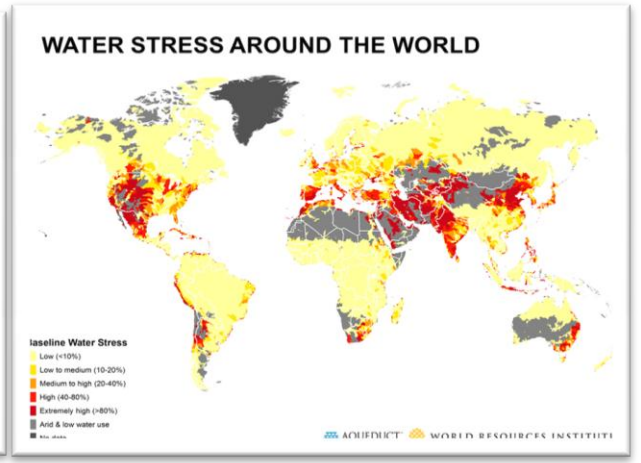
Outline

- Background
- Major progress
- Future focus

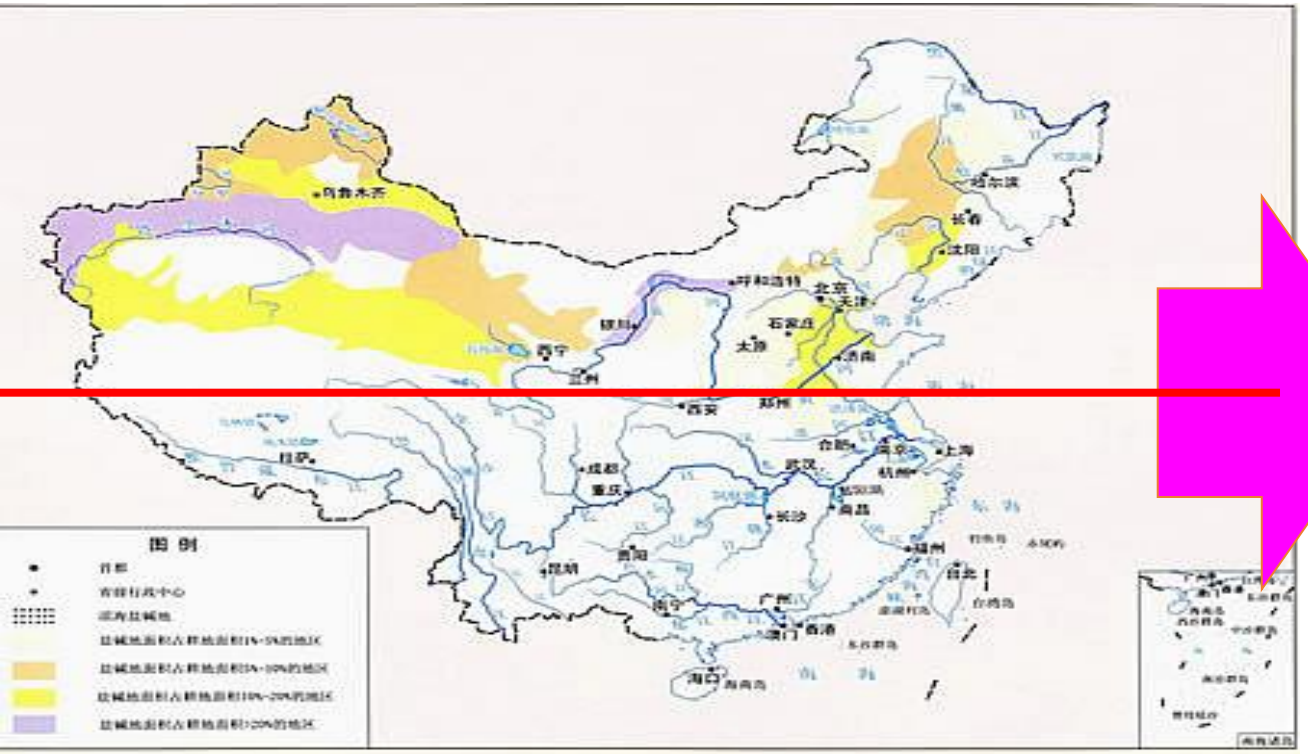
Soil salinization

- Soil salinization is the major constrain for the crop production in the world especially in arid and semi-arid regions, where soil salinization and water shortage are co-exist in arid and semi-arid regions around the world.





Current situation of soil salinization in China



- 99 million ha salt affected soils
- 38 million ha modern saline soils


Surendra

Reclamation approach

- **Physical methods**
  - Surface scraping
  - Deep ploughing
- **Chemical methods**

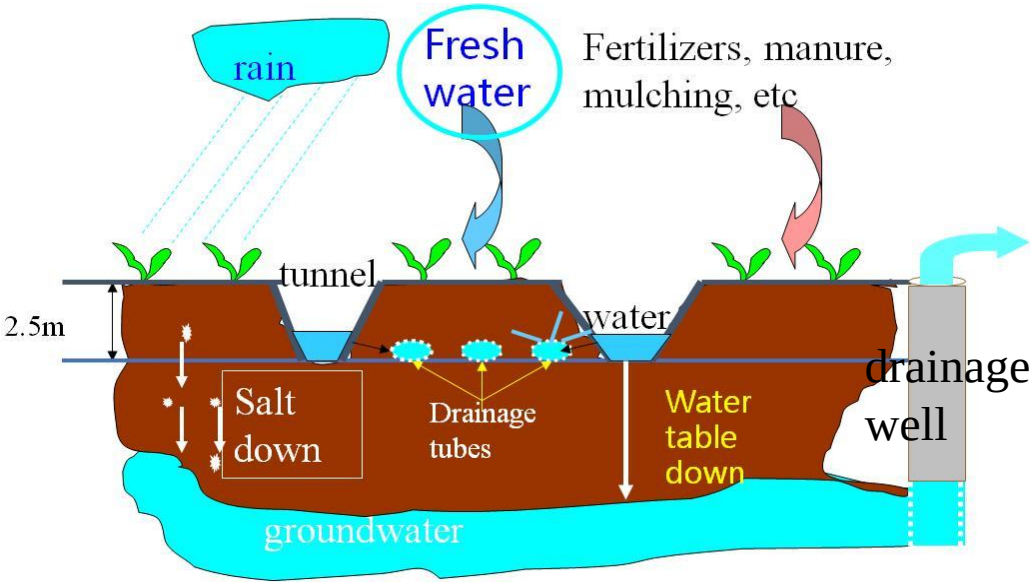
  Use of gypsum

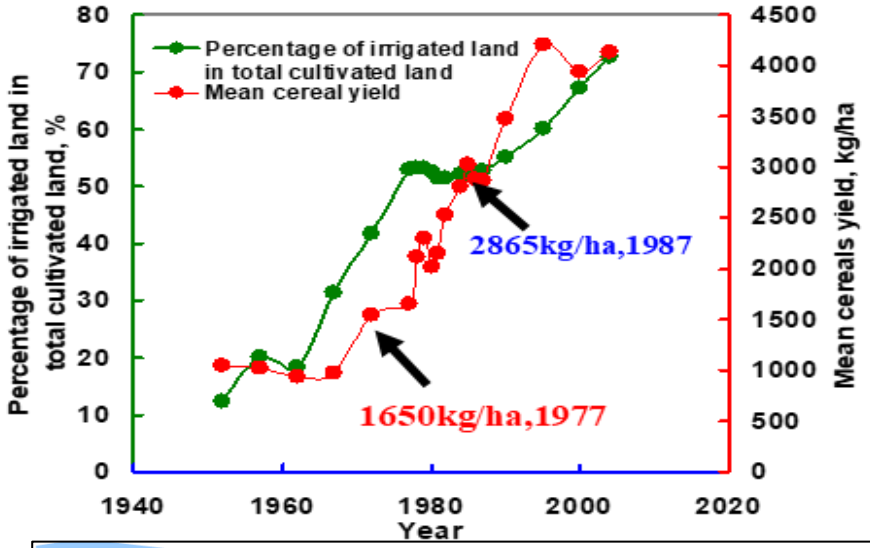
  Use of acid
- **Biological methods**

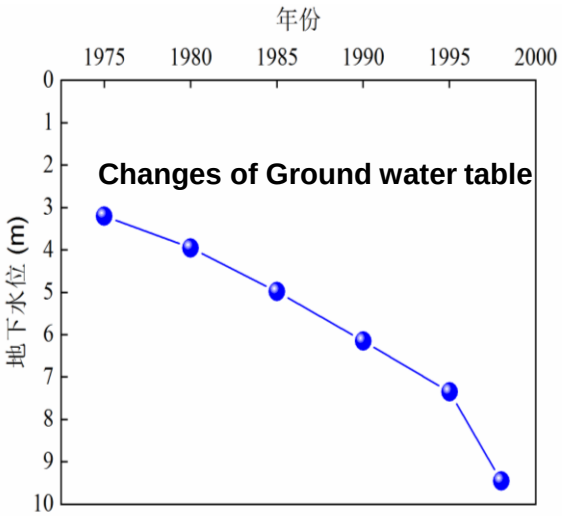
  growing salt tolerant plants, growing rice etc
- **Engineering methods: Leaching and drainage (the most efficient method)**

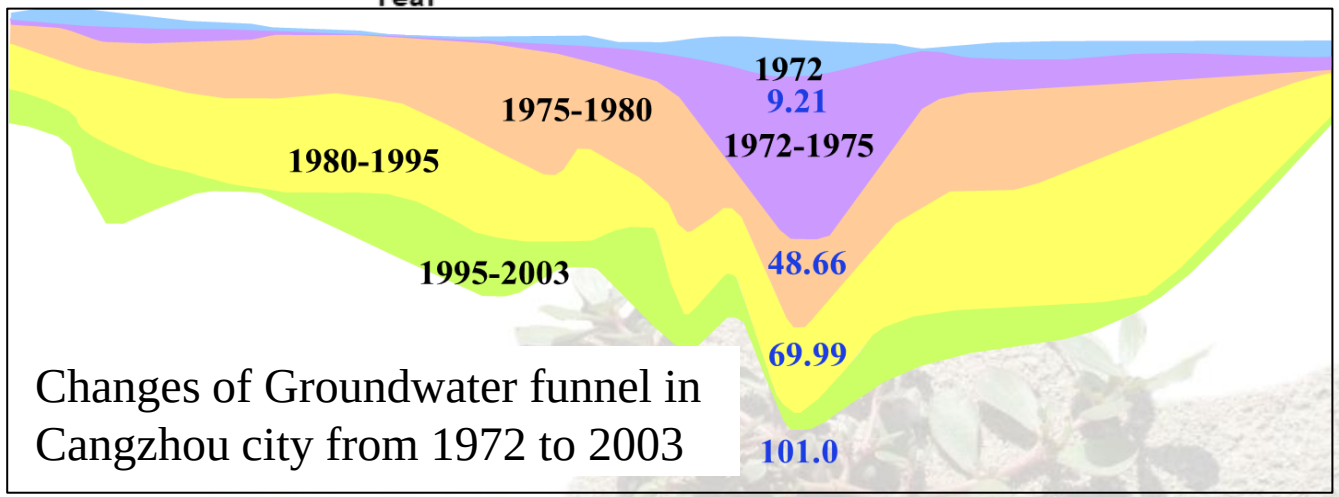
Reclamation of saline soils benefited from leaching and drainage, but also induced the depletion of ground water resources

Leaching and drainage





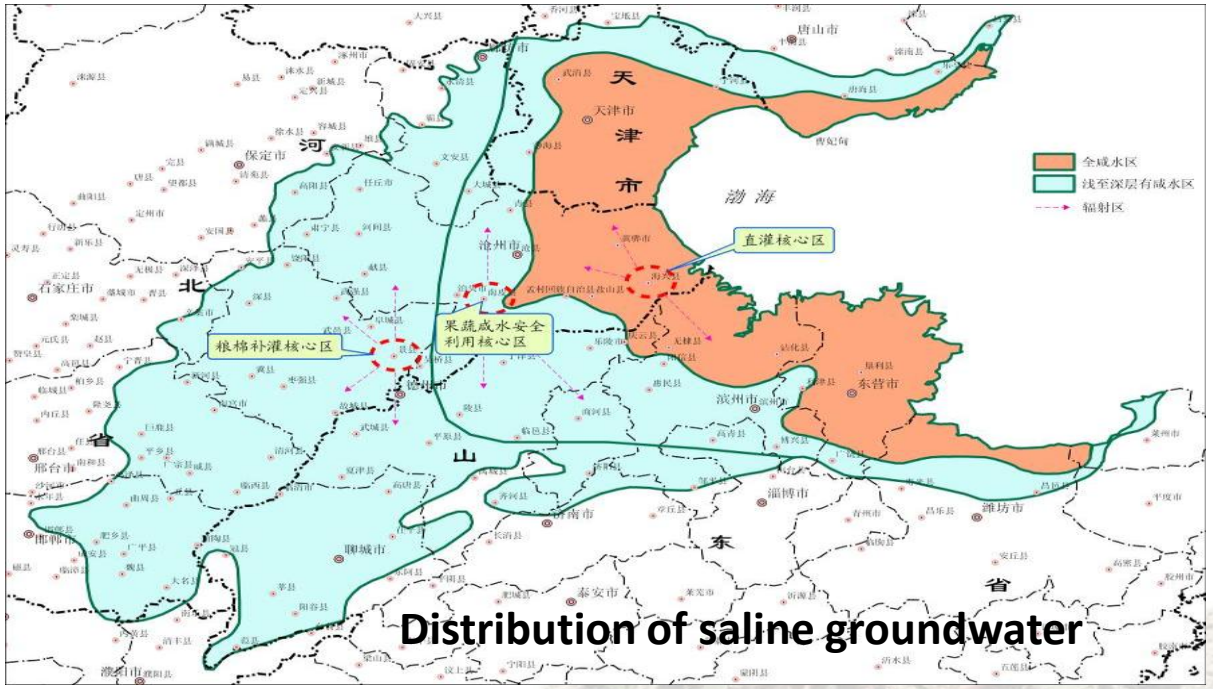




Changes of Groundwater funnel in Cangzhou city from 1972 to 2003

Problems for reclamation of saline soils at present

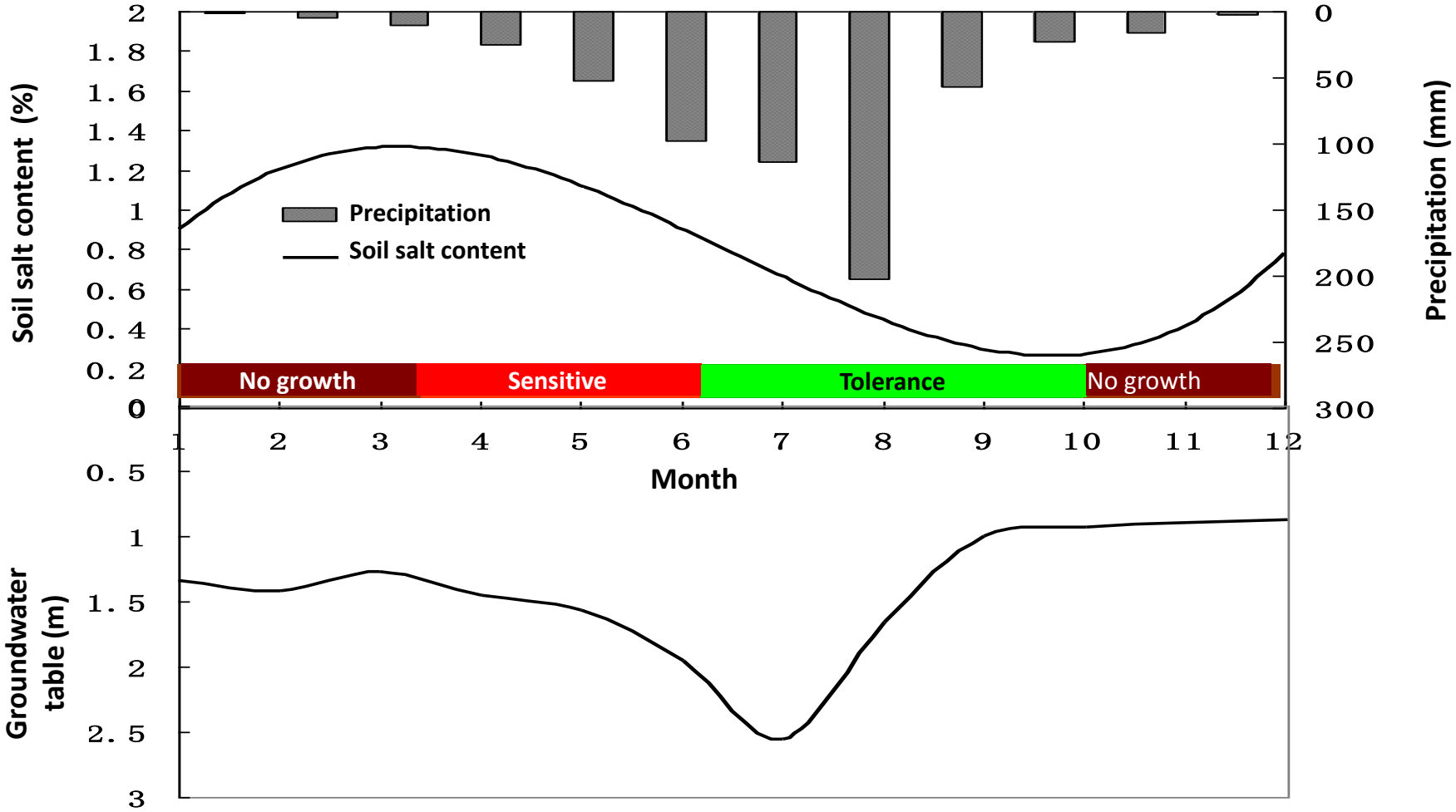
- Fresh water shortage
- Shallow ground water is saline
- Quick increasing population need more land, more food, more fresh water etc.



Distribution of saline groundwater


What can we do?!

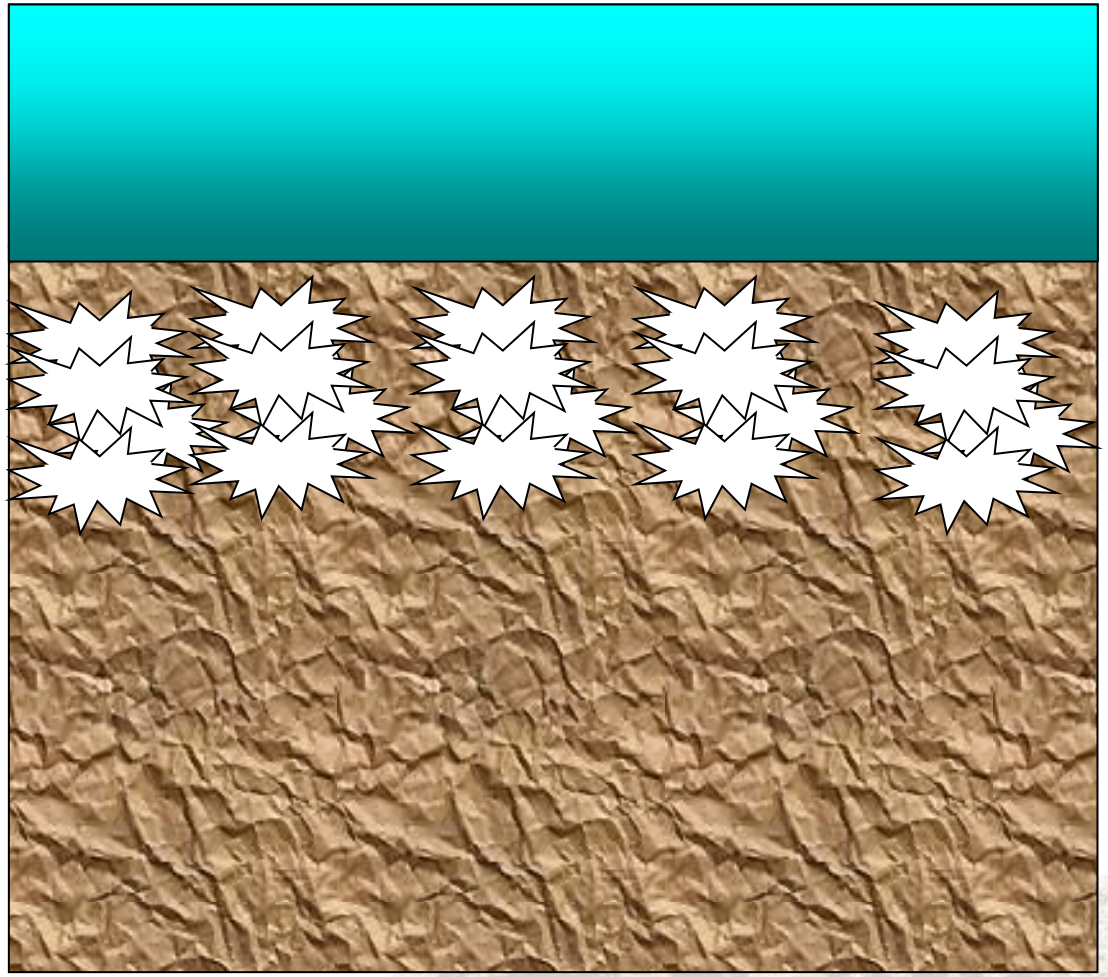
The relationships among seasonal soil salt dynamics, rainfall and crop growth in monsoon climate region, China



Hypothesis

■Saline water can be desalinized by freezing and thawing process due to the difference of ice point

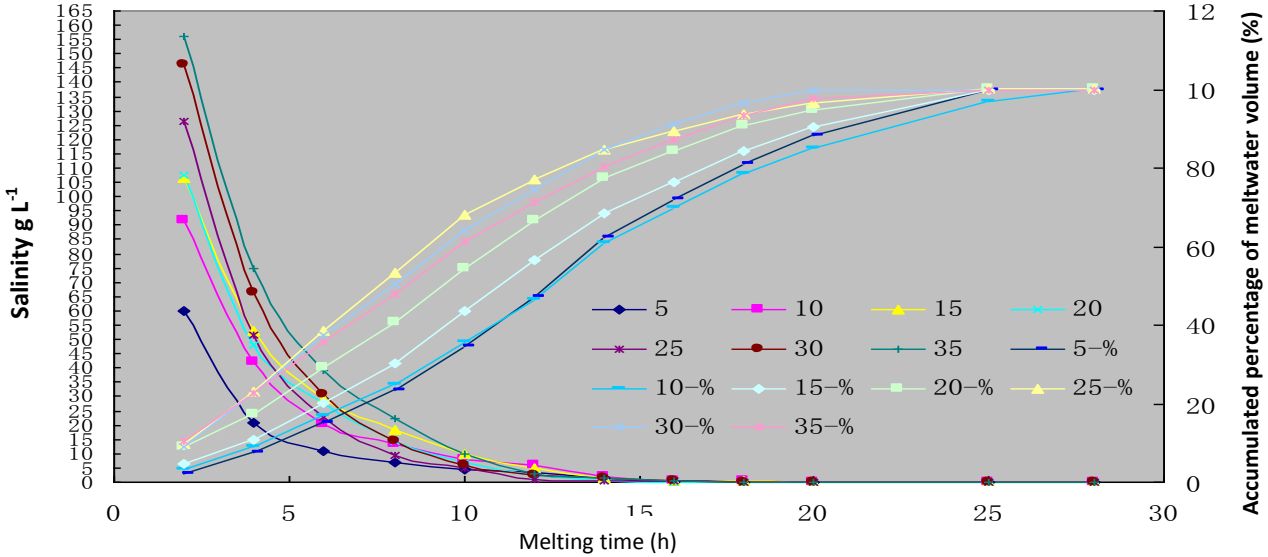
■When irrigating with saline water in winter, it will be frozen to ice; when saline ice melting in spring, initial melted high salinity water infiltrates firstly and then the later melted slightly salinity water even fresh water infiltrate to leach the surface soil salt to deep soil profile. The surface soil may be desalinized



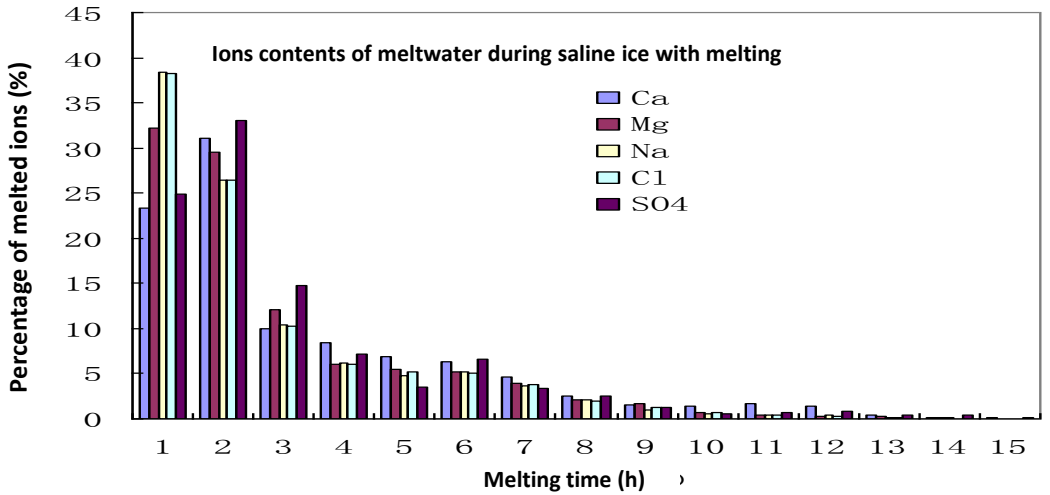
Outline

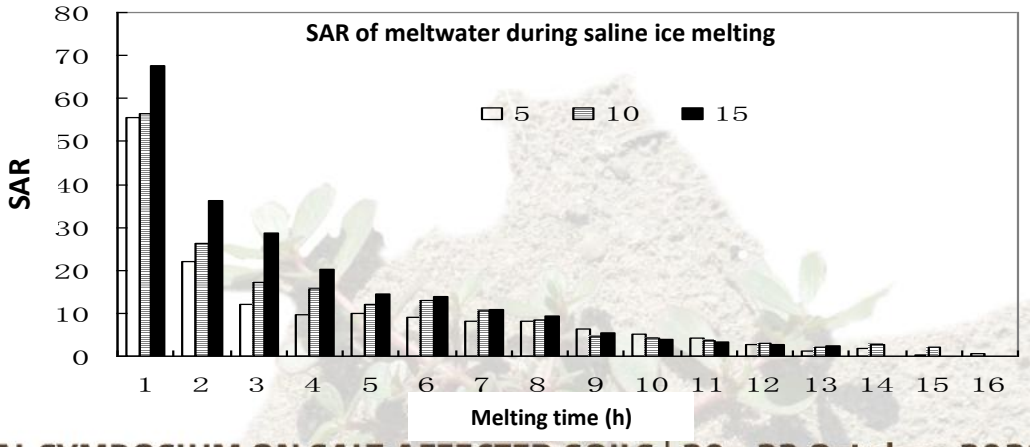
- Background
- **Major progress**
- Future focus

☐Changes of meltwater salinity and volume during saline ice melting



Salinity and accumulated volume percentage of meltwater during saline ice melting under room temperature(15°C)

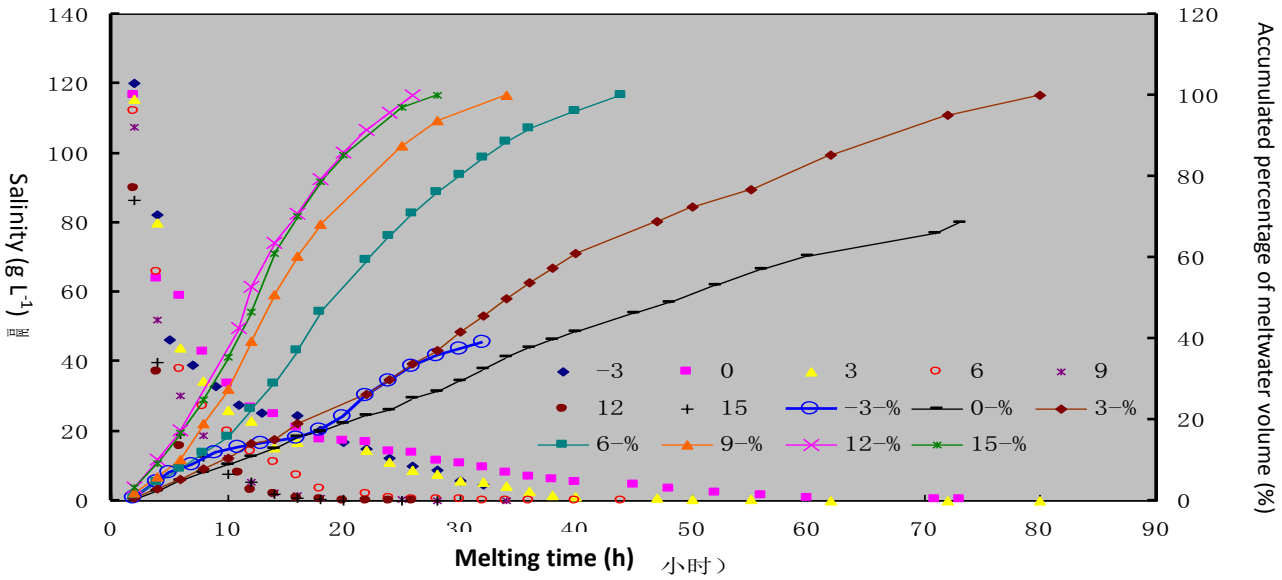




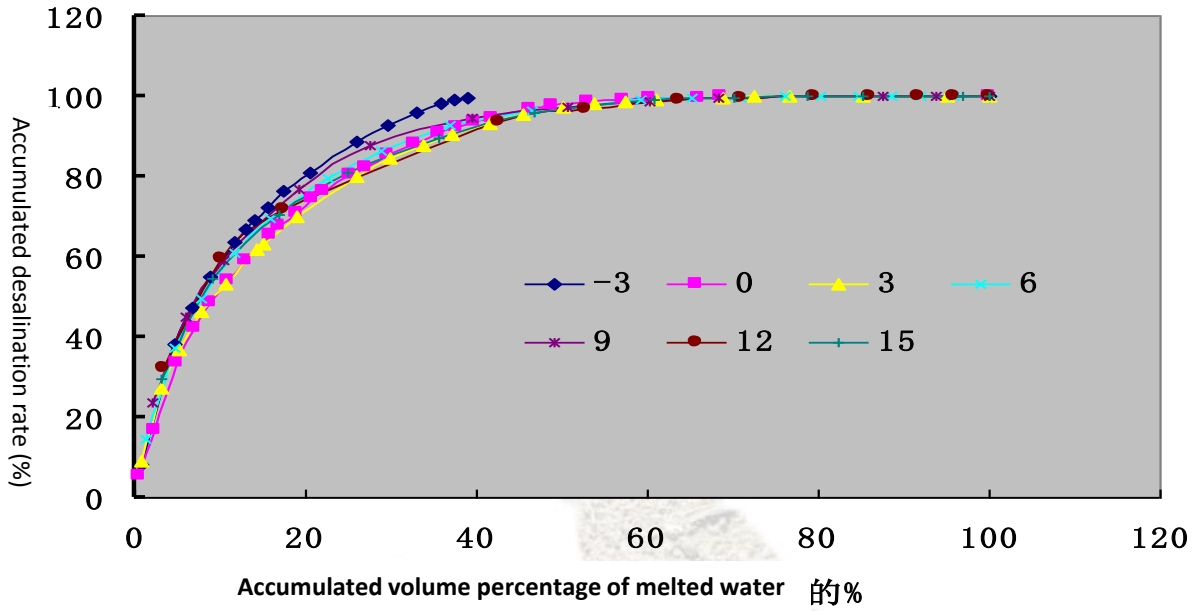
The desalination effect of saline ice melting was obvious, and the melt speed of Na^+ and CL^- was faster then other ions, which affected the SAR of meltwater.

K. Guo, X. Liu / Agricultural Water Management 139 (2014) 1–6

The temperature of ice melting affected the desalination during saline ice melting. Though the melting speed was low during saline ice melting at low temperature, while the desalination rate was high.



The salinity and accumulated volume percentage of meltwater during saline ice (10g/l) melting under different temperature.



Relationship of accumulated desalting rate and accumulated volume percentage during saline ice (10g/l) melting under different temperature

- Based on above results, the binary linear regression equation of meltwater (with salinity less than 5g/L) percentage with melting temperature and initial ice salinity was built up, which as the guideline for freezing saline water irrigation in winter.

$Y_{5g/l}$=74.052-0.945Tm-1.018Si R^2=0.877**

$Y_{4g/l}$ =71.867-0.536Tm-0.942Si R^2=0.803**

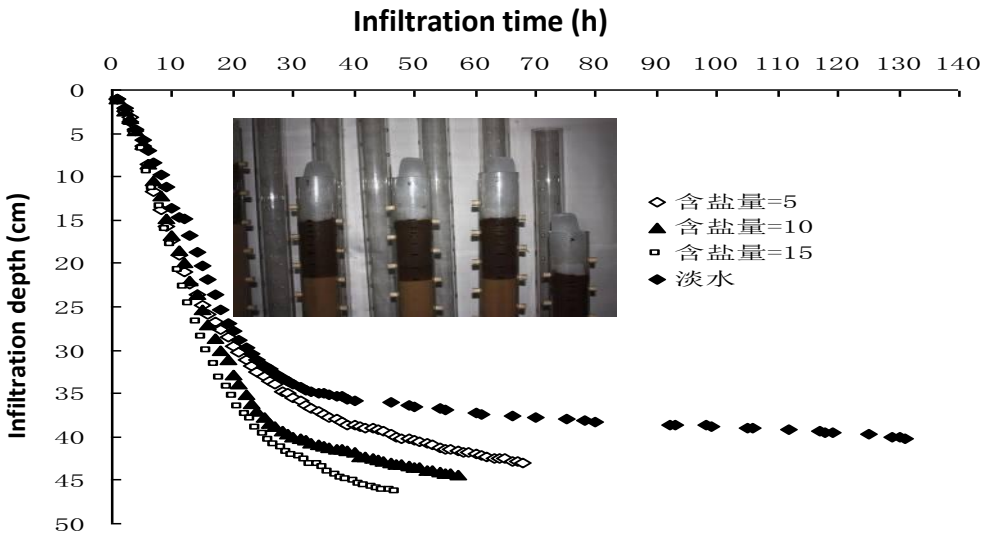
$Y_{3g/l}$ =66.823-0.962Tm-0.842Si R^2=0.788**

$Y_{2g/l}$ =66.757-1.087Tm-0.879Si R^2=0.813**

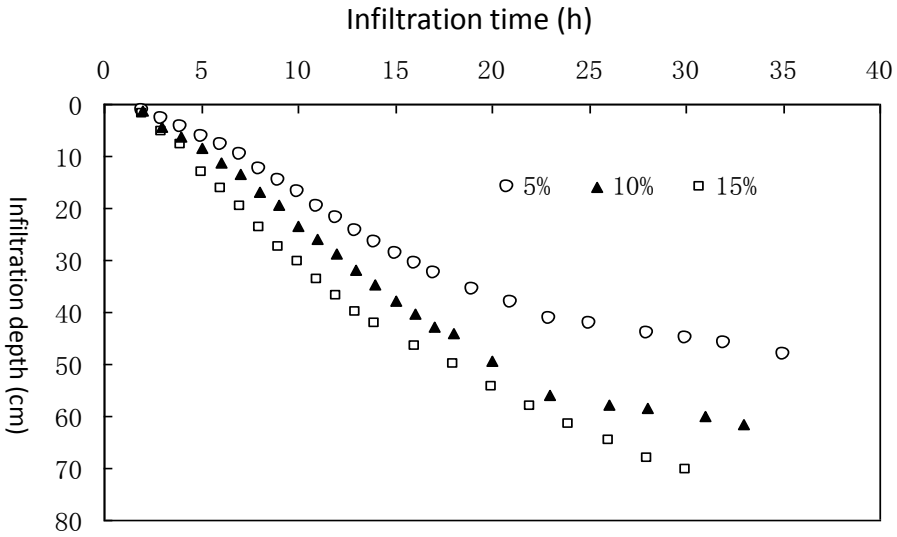
$Y_{1g/l}$ =60.365-1.148Tm-0.731Si R^2=0.759**

where Y, the volume percenteage of meltwater which salinity below a value to total volume of source water (%); Tm, the temperature during saline ice melting(℃). Si, the origional salinty of saline ice.(g L^{-1})。

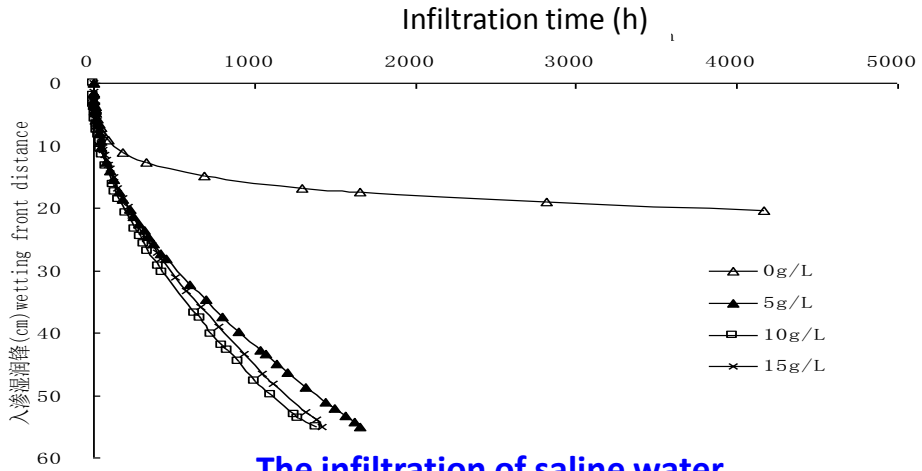
☐The infiltration of saline ice meltwater to coastal saline soil



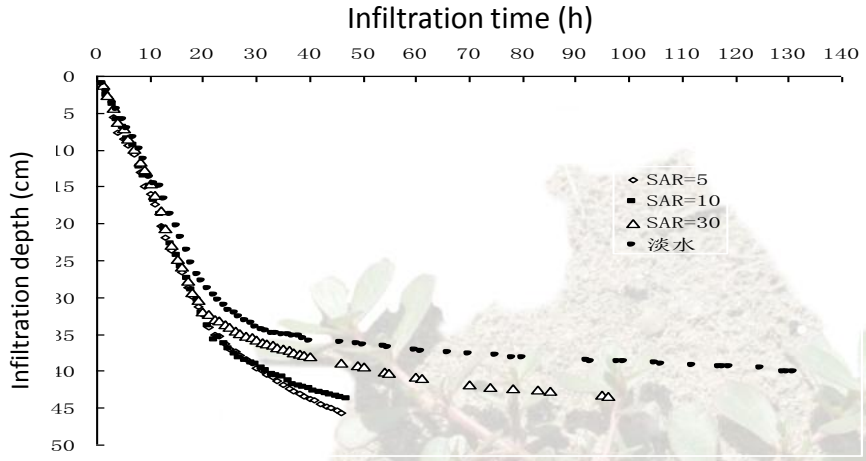
The infiltration of saline ice meltwater



The infiltration of saline ice meltwater to coastal saline soil with different soil moisture



The infiltration of saline water

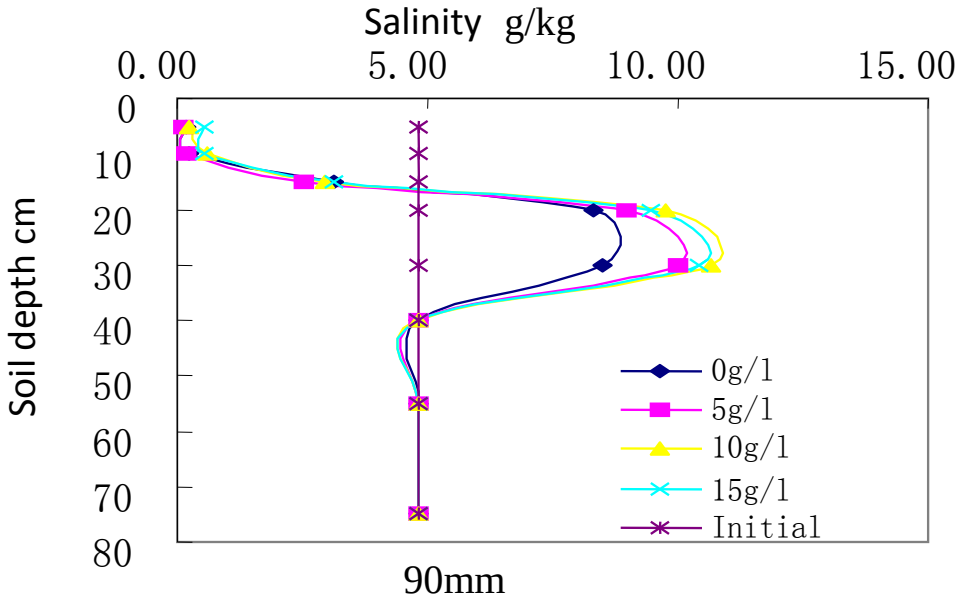


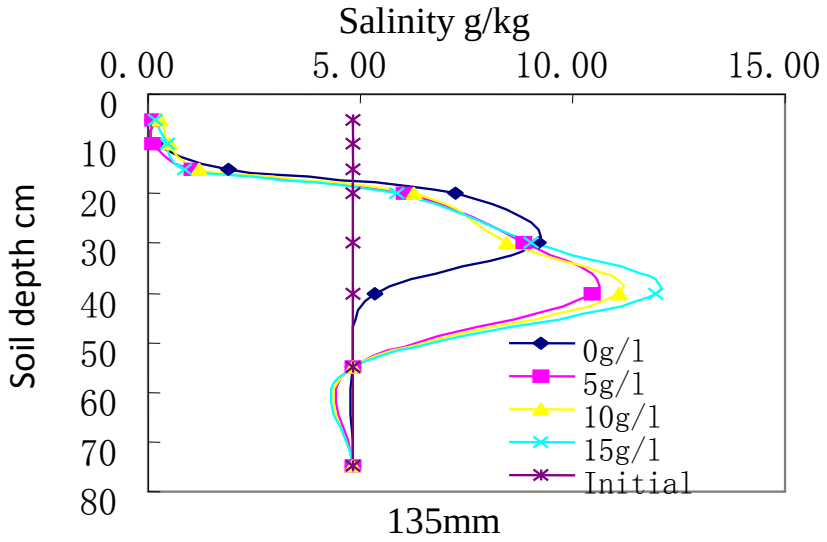
The infiltration of meltwater from different SAR saline ice

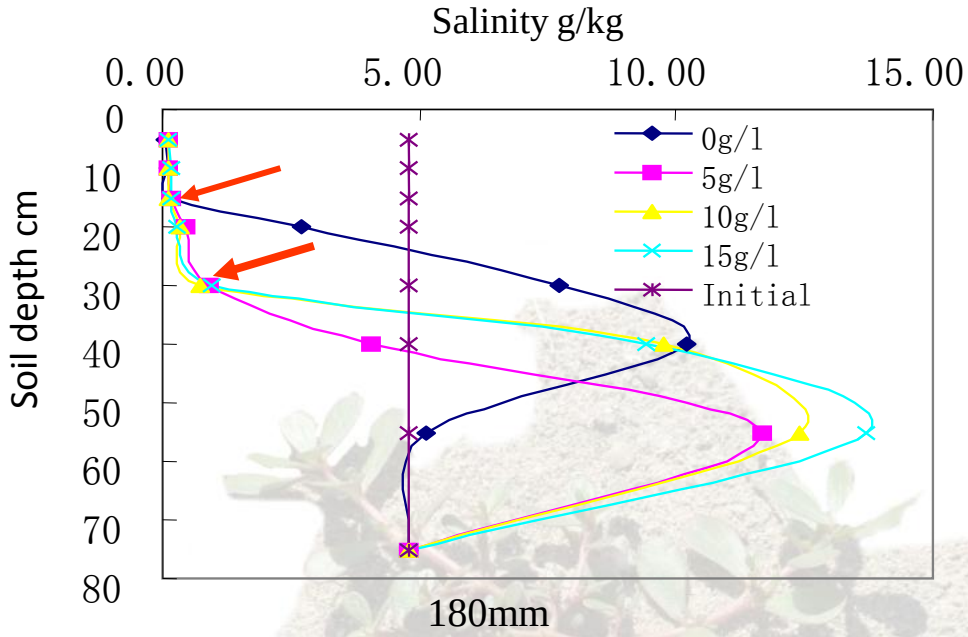
- The infiltration speed was faster in melting saline ice of high salinity than that of low salinity.
- The infiltration speed increased with the increase of initial soil water content under a certain range of soil water condition.
- The SAR of saline ice affected the infiltration of meltwater, the speed increased with the decrease of SAR of saline ice, but that all faster than salt-free ice.

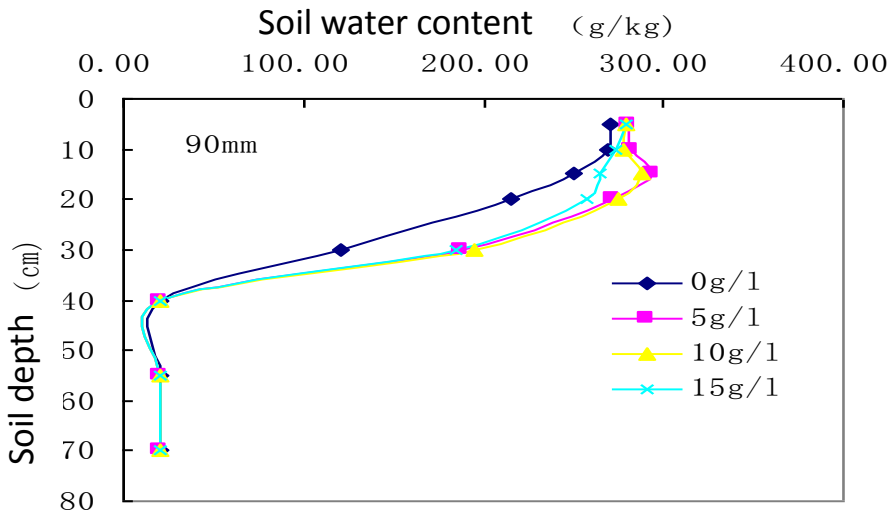
Soil columns experimental results indicated that the desalting depths of saline ice treatments were greater than that of salt-free ice.

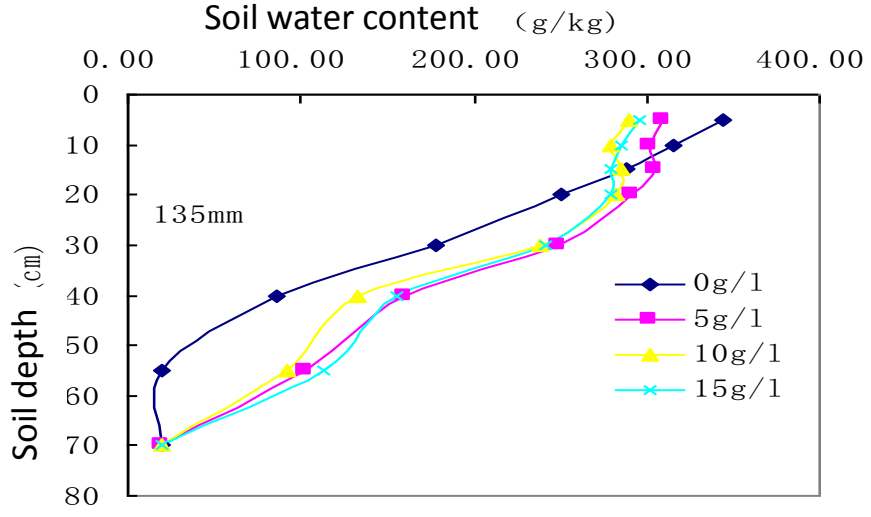
Zhigang Li, Xiaojing Liu*, Xiumei Zhang, Weiqiang Li.2008. Agricultural Water Management 95:498-502

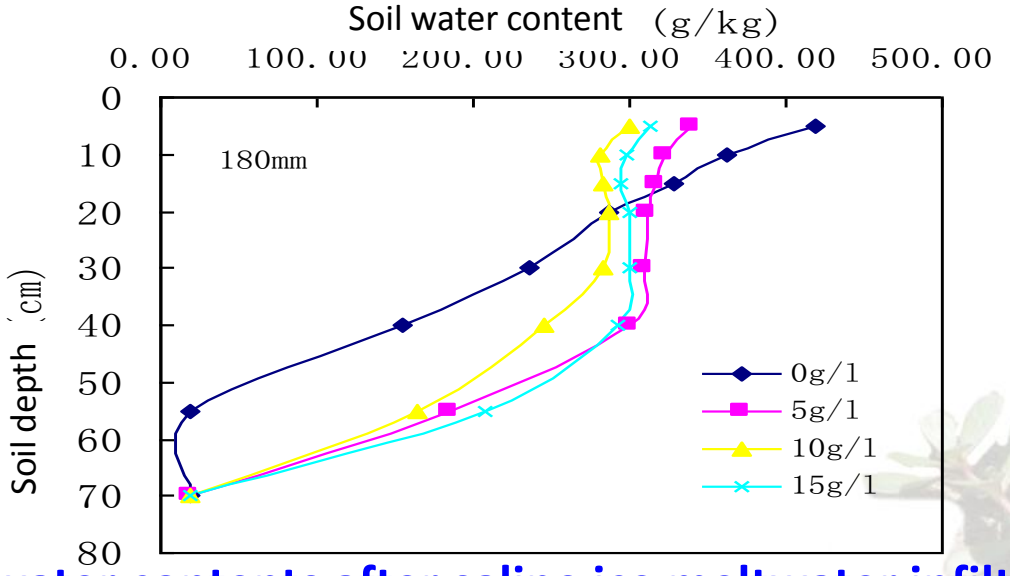












Soil water contents after saline ice meltwater infiltration

It was also obtained better desalination effect in saline ice than salt free ice, even the SAR of saline ice was high.

Distribution of soil salt in coastal saline soil after infiltration of melting saline ice with different SAR salinity at 10g L^{-1}

treatments	Soil depth (cm)							
	0-5	5-10	10-15	15-20	20-30	30-40	40-50	50-70
SAR=5	**0.11±0.00**	**0.12±0.01**	**0.17±0.01**	**0.25±0.01**	**2.84±0.12**	8.75±0.34	5.58±0.23	2.126
SAR=10	**0.15±0.00**	**0.18±0.01**	**0.19±0.01**	**0.26±0.01**	**2.45±0.23**	9.57±0.18	5.44±0.62	2.126
SAR=30	**0.22±0.00**	**0.24±0.00**	**0.27±0.01**	**0.52±0.06**	4.90±0.33	8.85±0.25	4.56±0.26	2.126
fresh	**0.10±0.01**	**0.13±0.00**	1.12±0.06	1.97±0.07	4.18±0.11	7.26±0.13	4.53±0.09	2.126

☐Field technological system of reclamaiming coastal saline soil by freezing saline water irrigation.

Experimental site was located at coastal saline waste land of haixing county hebei province. Altitude of this area was 2m, and salinity of groundwater was higher than 25g $L^{-1}$with shallow groundwater table of 1m. Salinity of water in derange was range from 8 to 15g L^{-1}.

Soil was silty sandy loam, the highest soil salinity that was more than 1% occurred in spring. The drainage system was established in 1980s, while the soil was under reclamation due to fresh water shortage.

Establishment of irrigation regime

- **Based on the water requirements of salt leaching and the discipline of desalination of saline ice melting， we suppose of that irrigated water all frozen into ice， the leaching equation of freezing saline water irrigation can be described by as follow:**

$$V = M/Ys$$

where V was leaching amount of freezing saline water irrigation m^3/hm^2; M was leaching amount of fresh water m^3/hm^2; Ys was the amount percentage of meltwater with different salinity to the total amount(%)

- **We supposed the soil salt moving vertically and leaching water blending with salt solution completly, the salt leaching equation based on the sample theory of salt movement was listed as follow :**

$$M = 100H\gamma(\theta_f S_0/Sa-\theta_0)+e-P$$

M, amount of fresh water leaching ($m^3\ hm^{-2}$); H, planning salt leaching depth (m); θ_f – filed capacity （gravimetric%）;θ_0, original soil gravimetric water contents(%); S_0, soil salt content before leaching(%); Sa, soil salt content that intent to reached after leaching; γ, soil bulk density; e, the evaporation during leaching period; P, rainfalls during leaching period.

- Based on the caculation, field experiments about freezing saline water irrigation time, irrigation regime were set up in coastal saline area.
- Results indicated that it was suitable to apply irrigation in early January when the air temperature was below -5 ℃. The irrigation regime was 120-180mm with salinity less than 15g/l water.
- While due to high evaporation, the salt will be still acumulated on soil surface if there was no controling meth after infiltration of saline ice meltwater in spring.

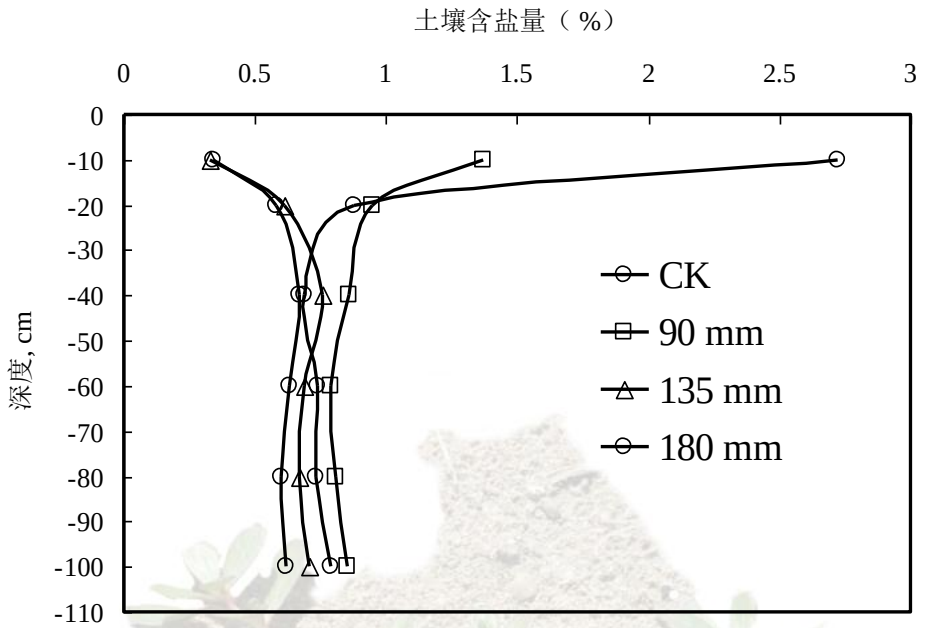
Average air temperature from Dec. to Mar. of 2009-2011

days	Dec.	Jan.	Feb	Mar
1-10	2.08	-5.55	-2.28	3.41
10-20	-1.97	-7.41	-3.02	8.32
20-30	-3.70	-6.28	1.63	8.02

Variation of soil salt content of different irrigation time

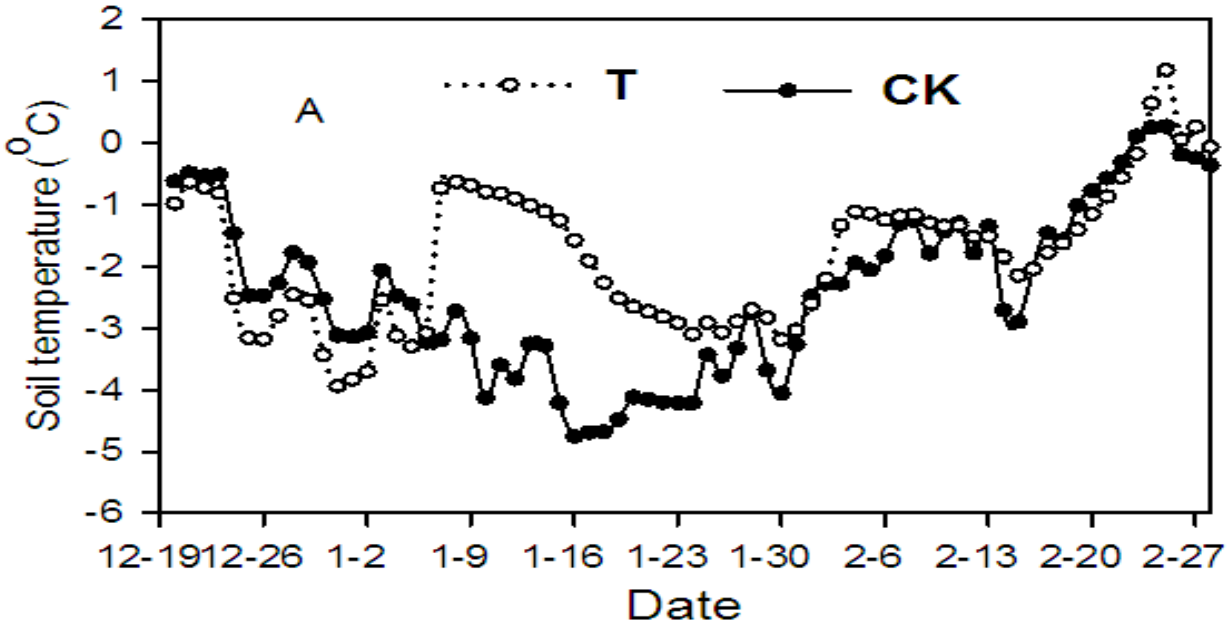
Irrigation time	6-Jan	20-Jan	5-Feb	23-Mar	4-May
CK	2.17	2.21	2.07	1.94	2.2
Irrigation in 7-Jan	1.25	0.81	0.65	0.67	0.92
Irrigation in 20-Jan	1.79	1.38	0.68	0.67	0.93
Irrigation in 5-Feb	1.41	1.68	1.52	0.87	1.1

*irrigation regime: 135mm, irrigation water salinity 12.5g L^{-1}

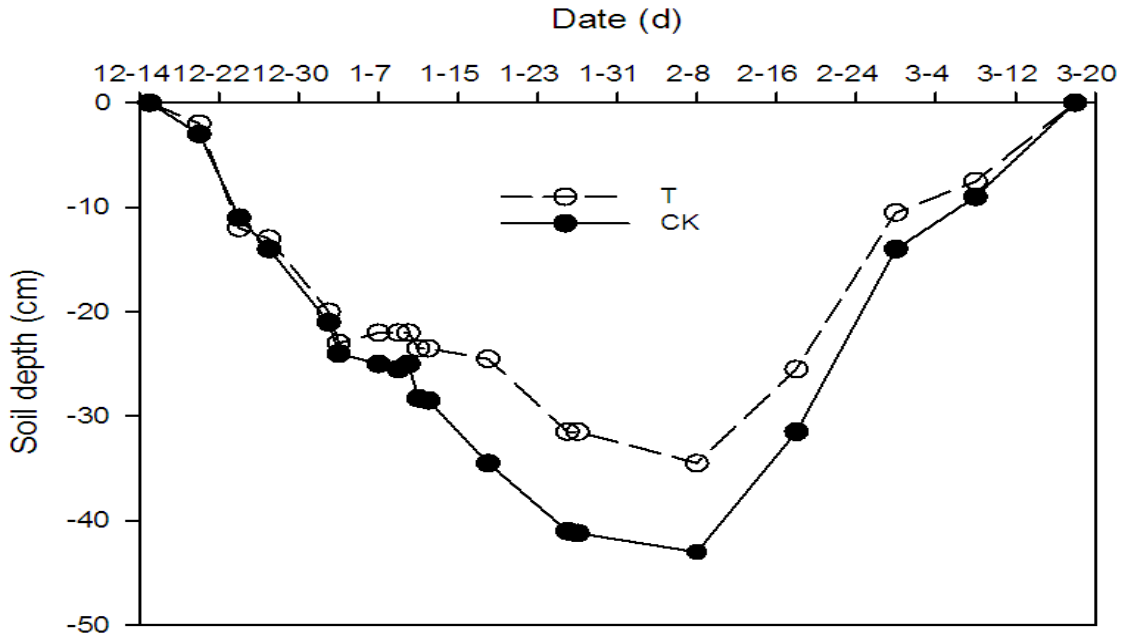


Effect of different irrigation regime on the soil salt content after the meltwater infiltration in spring (irrigation time:10-Jan; irrigation water salinity: 12.5g L^{-1})

- Moreover， the ice mulching in winter can reduce the soil salinization coursed by soil freezing and thawing through improving the soil temperature and reducing the frozen soil depth.
- The frozen temperature of saline soil with salinity at 0.4% was -0.108 ℃. Salinity and water content of 1m were increase by 0.031% and 1.68mm when the soil frozen layer increasing 1cm. Freezing saline water irrigation reduced about 0.26% soil salt accumulating in frozen layer through reducing of the soil frozen depth of 8.5cm.



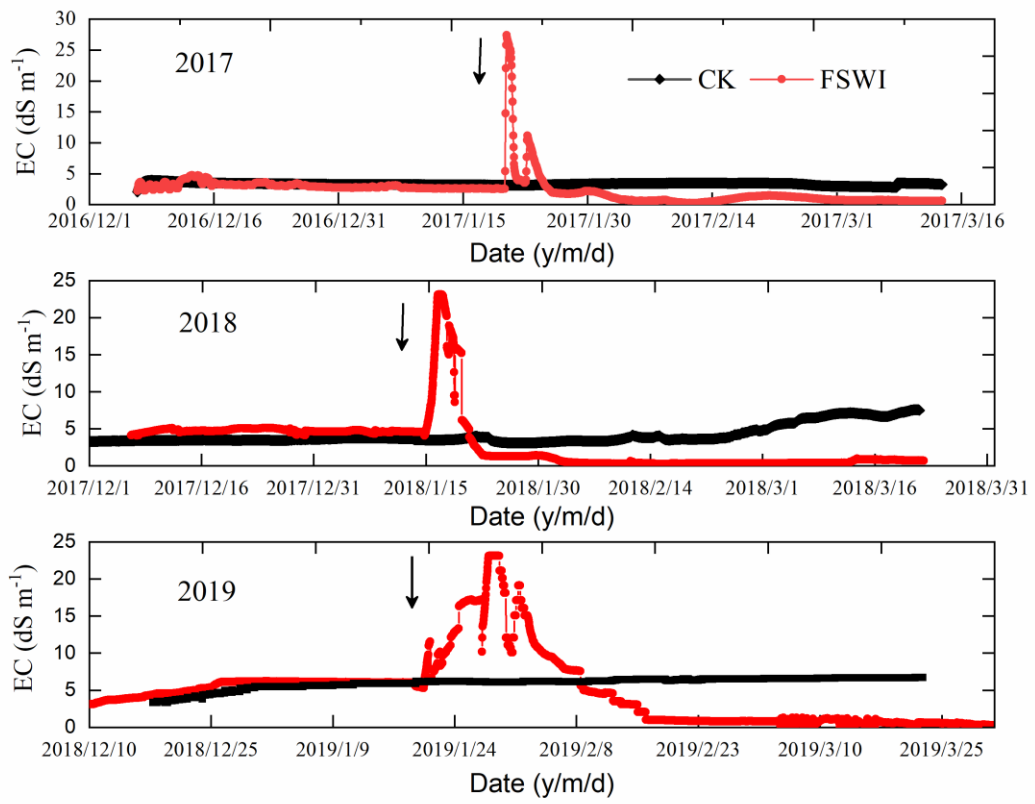
Variation of temperature in upper soil layer (0-5cm) in freezing saline water irrigation and CK



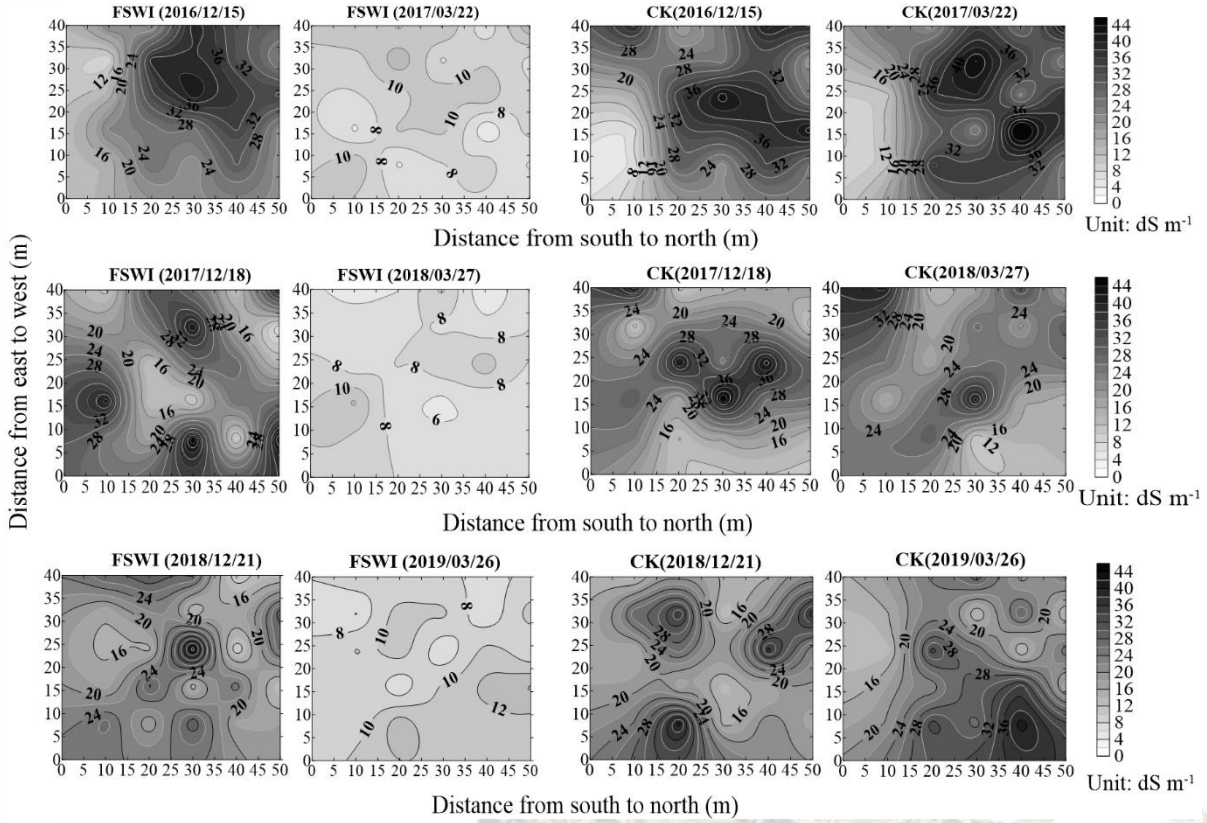
Depth of soil frozen layer under mulching of saline ice

K Guo, X Liu. Irrigation Science,2015, 33(6), 441-452

- During saline ice melting and infiltrating, the salt leaching mainly occurred in the initial 30 days after irrigation, and the soil EC increased initially and then decreased to below 4 dS/m gradually
- The soil EC were relatively uniform in the horizontal transects of the 0–20 layer after meltwater infiltration



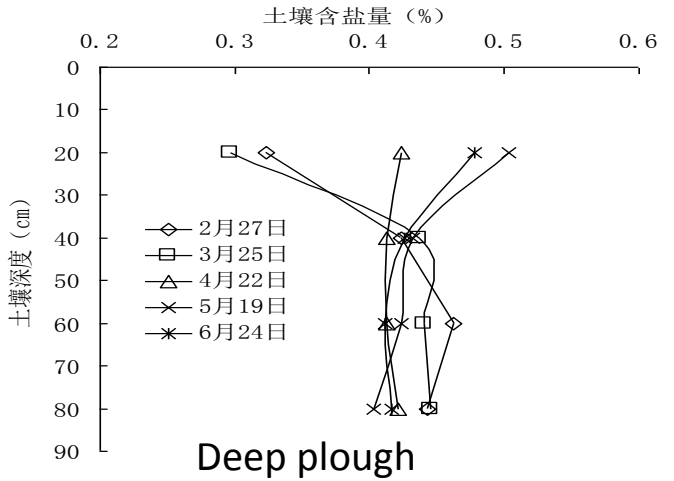
Soil EC during saline ice melting and infiltrating into saline soil



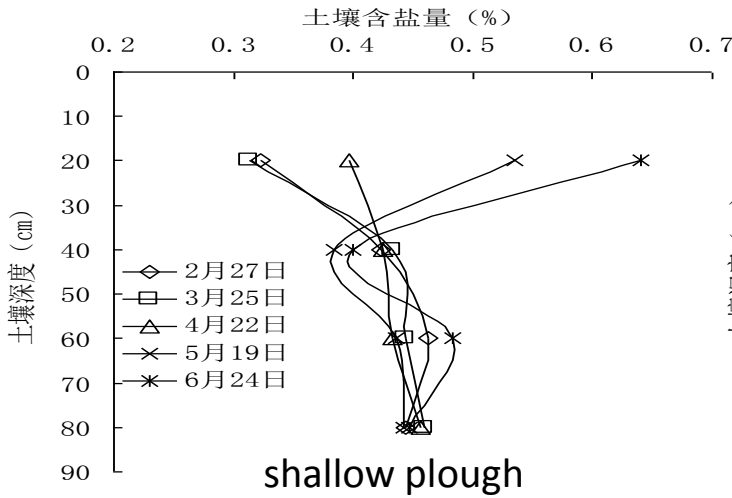
The soil EC distribution before and after meltwater infilteration

K Guo, X Liu. CATENA,2021, 204, 105420

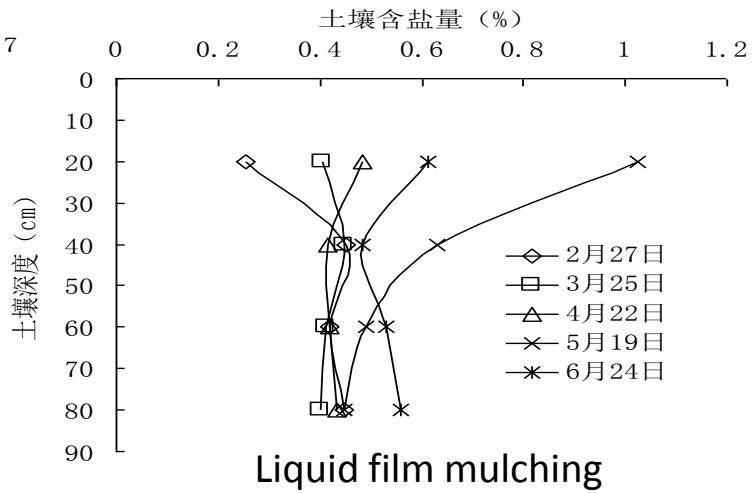
To control soil salinization in spring, mulching experiments were conducted.



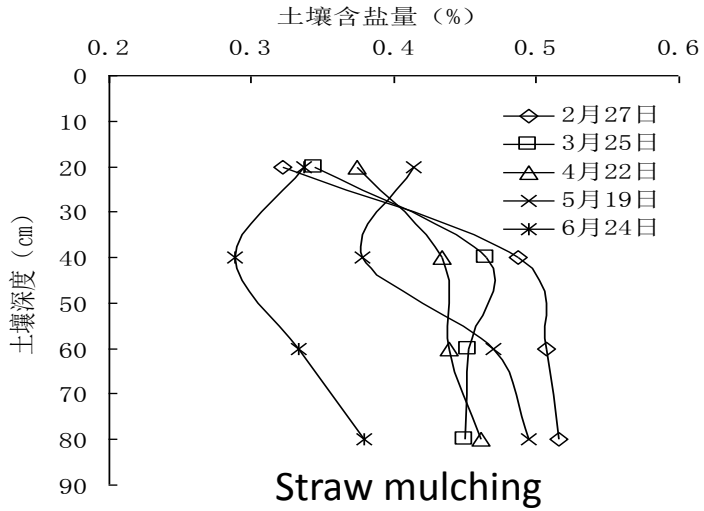
Deep plough



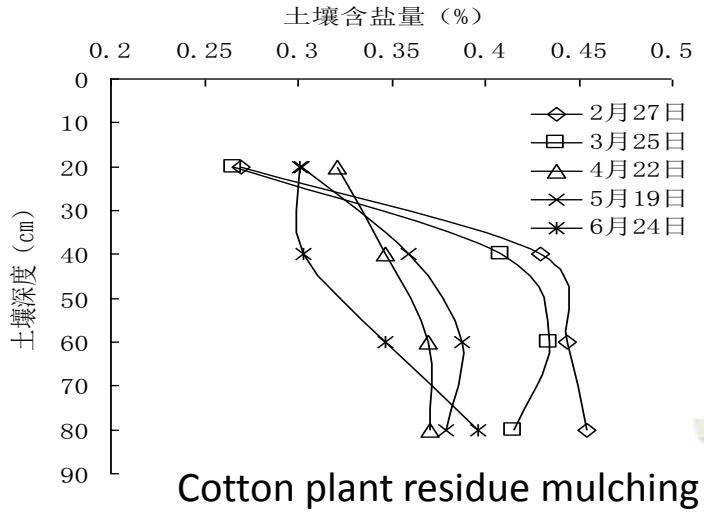
shallow plough



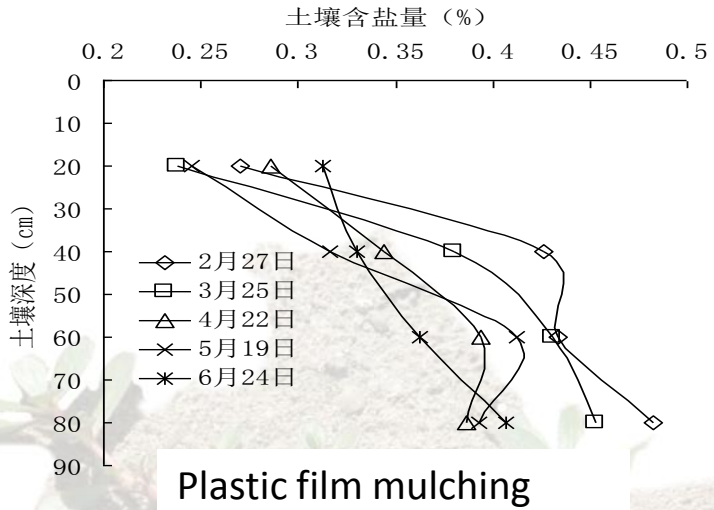
Liquid film mulching



Straw mulching

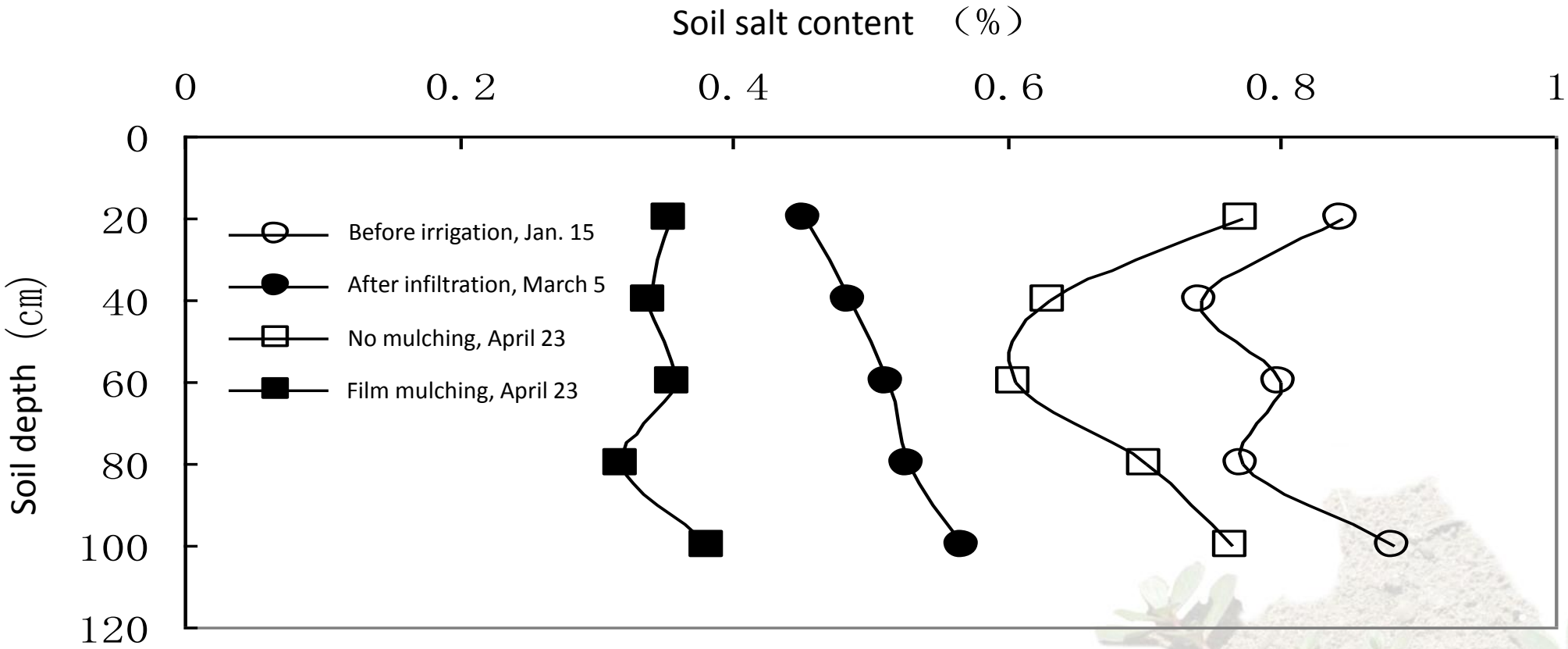


Cotton plant residue mulching



Plastic film mulching

Plastic film mulching effect on soil salt changes after melted saline ice water infiltration (2008)

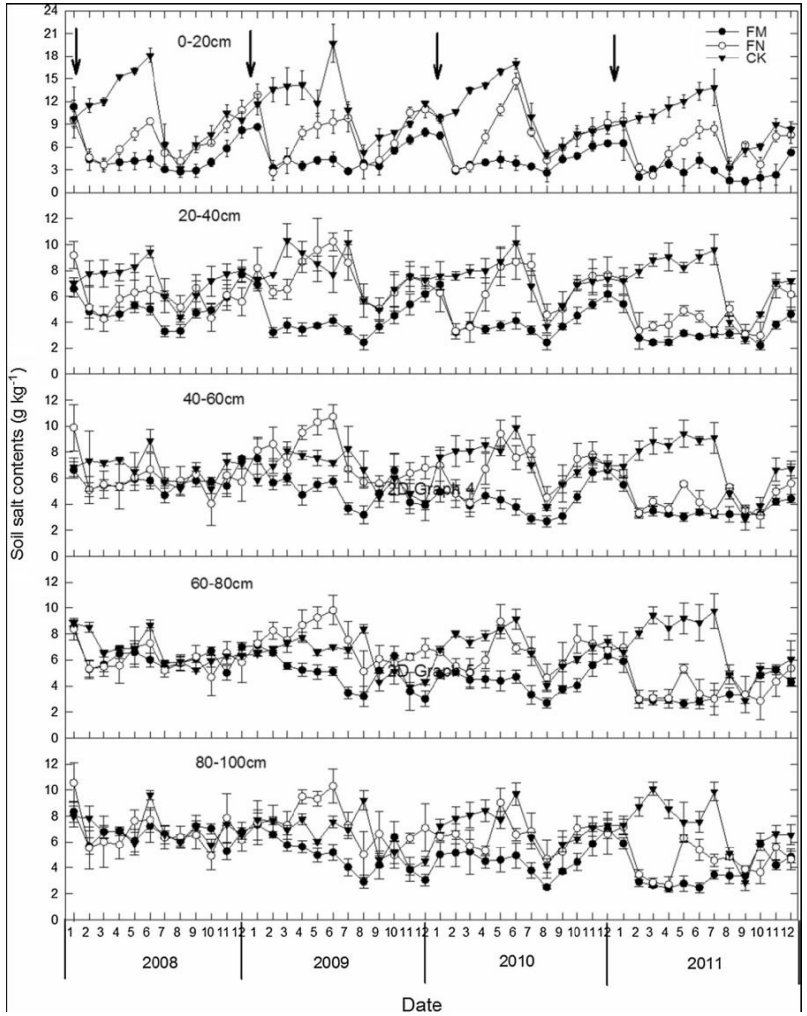


Drainage methods

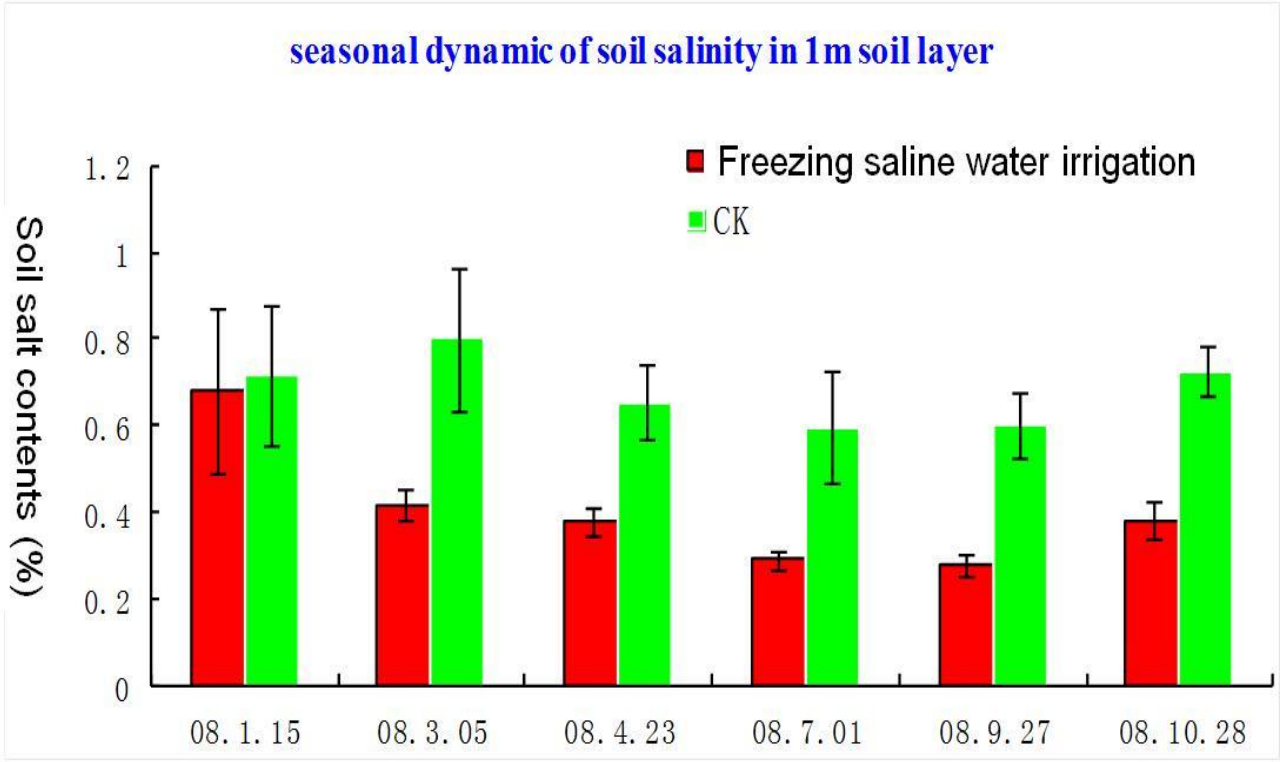
Recommendation for integrate management of coastal saline soil by freezing saline water irrigation

- Irrigation time: in early and middle January when temperature is <-5℃
- Irrigation depths:　160-180mm
- Irrigation water quality: water salt content <15g/l
- Irrigation methods: flood irrigation or sprinkling irrigation
- Salinization control: plastic film mulching after infiltration of melted saline ice water
- Other measures: drainage system, application of modify agends, coated fertilizer etc.

Effect of freezing saline water irrigation

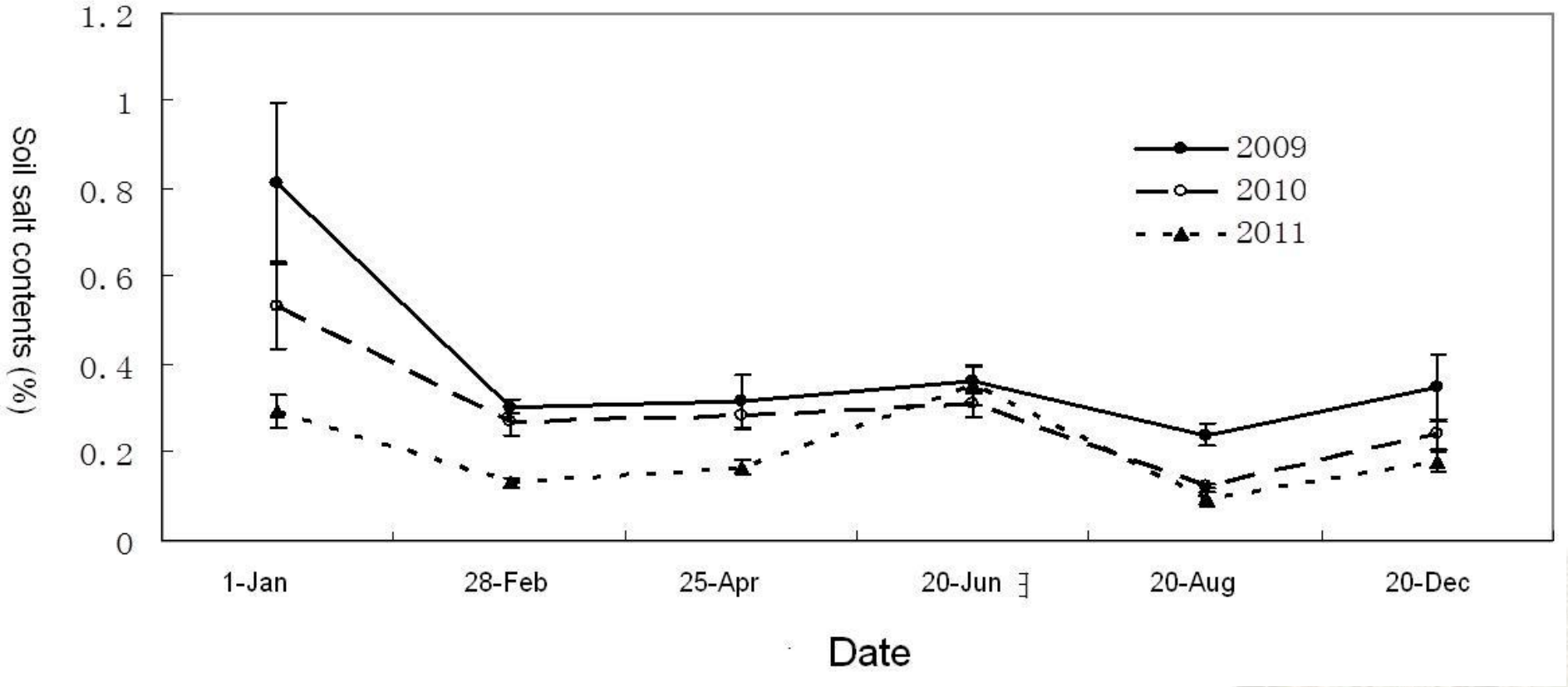


Monthly dynamics of soil salinity under saline ice water irrigation from 2008 to 2011.



The soil salinity of 1m soil layer in the whole growth period of crop all bellow 0.4% after freezing saline water irrigation, which was higher than 0.6% in CK.

- **The cotton can be sowed and grown normally in coastal saline soil at first year after freezing saline water irrigation. Soil salinity decrease with the irrigation times (years), and crop yield also increased year by year by freezing saline water irrigation.**



Soil contents of upper soil layer (0-20cm) of freezing saline water irrigation from 2009 to 2011

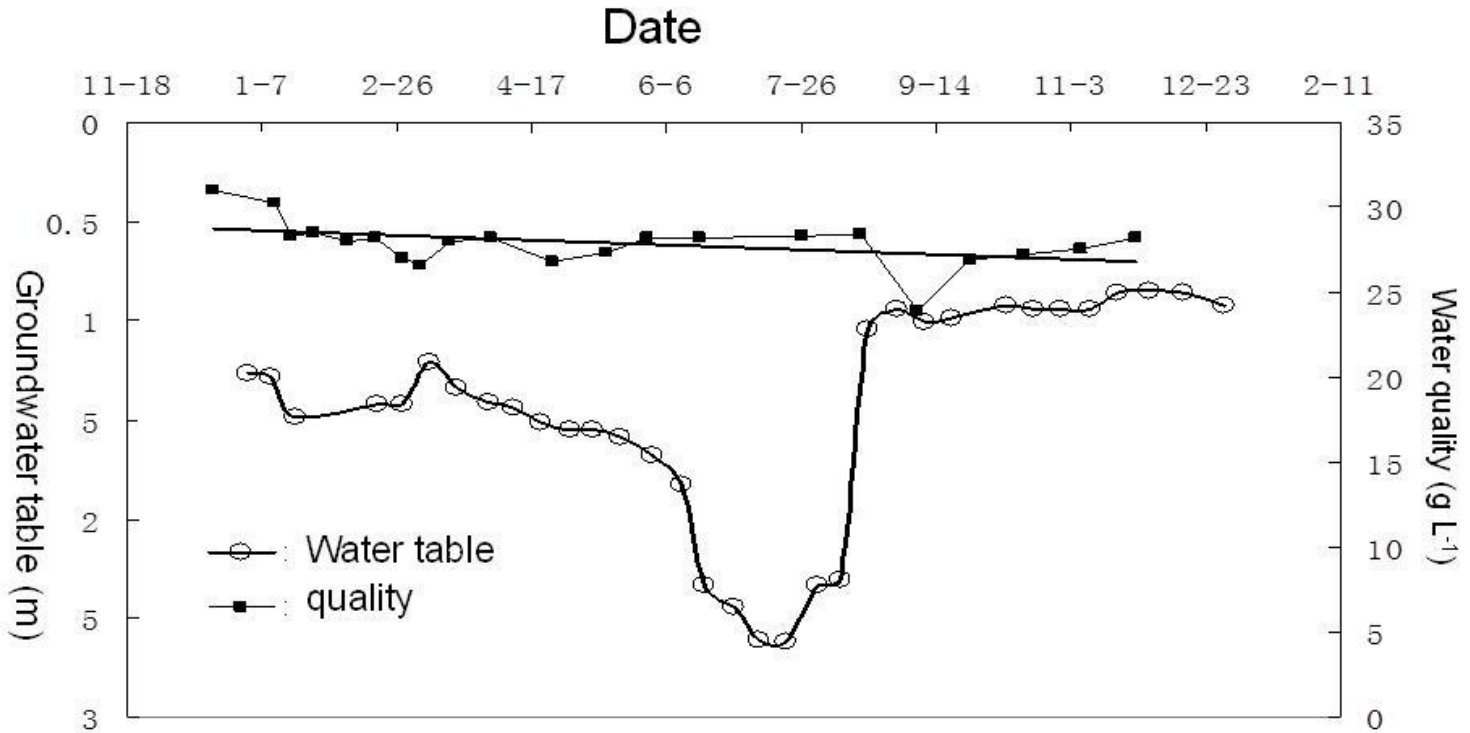
The germination and yield of crops under freezing saline water irrigation

years	Treatments	Cotton				Sunflower					Sugar beet			
		Germination (%)	Plant height (cm)	Boll/ plant	yields (Kg ha^{-1})	Germination (%)	Plant height (cm)	diameter cm	Yield /plant (g)	yields (Kg ha^{-1})	survival %	Wight of root g	yields (Kg ha^{-1})	Soluble solid matter %
2009	ck	0. 9	52. 5	2. 3	15	1. 23	35. 2	9. 0	7. 15	5. 25	18. 7	255. 0	**3175.5**	22. 33
	FI	89. 4	80. 3	8. 7	2644. 5	97. 9	51. 4	14. 2	24. 8	**1462.5**	85. 1	1326. 3	**75280.5**	23. 41
2010	ck	0. 4	60. 0	5. 1	12	1. 56	34. 3	6. 5	4. 9	**5.1**	11. 8	259. 8	**2041.5**	21. 77
	FI	87. 6	90. 1	11. 2	3241. 5	95. 8	80. 3	17. 3	42. 9	**2737.5**	80. 2	1160. 3	**62068.5**	24. 02
2011	ck	1. 2	59. 6	3. 2	31. 5	0. 67	28	0	0	0	5. 6	220. 7	**817.5**	21. 16
	FI	85. 2	86. 7	12. 5	**3607.5**	92. 0	81. 1	17. 5	50. 6	**3102**	83. 2	1093. 0	**63105**	23. 97

*FI : freezing saline water irrigation; CK : control

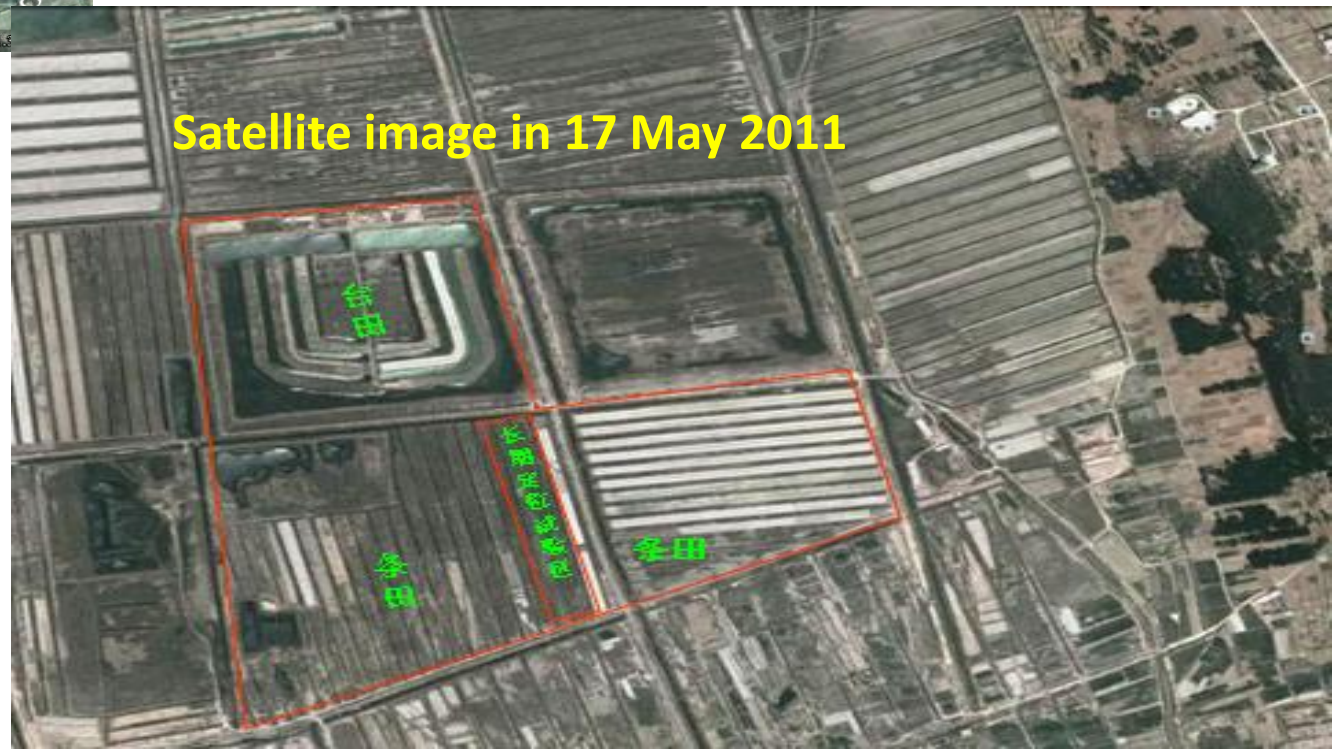
◆**The application of freezing saline water irrigation reduced the groundwater table, and it supplied the better condition of storage of rain and improvement of groundwater quality.**

◆**According to the results calculated by equation of water and salt balance, the soil salt stated in the leaching situation from irrigation period to harvest of crops. And the water was balanced in this period basically.**



Variation of groundwater table and quality in 2011


2008/2/15
Satellite image in 15 Feb 2008
Google
© 2011 Mapabc.com
影像拍摄日期：2008/2/15
2008


Satellite image in 17 May 2011
养田
养田
养田

Barren land before reclamation

Saline ice in field after irrigation

Cotton growth after reclamation

Technology of reclamation of coastal saline soil by freezing saline water irrigation (xiaoshan haixing county hebei province**)**










“两创一综合”冬季咸水结冰灌溉改良盐碱地技术简介


cotton


Sweet sorghum


Seashore mallow


Jerusalem artichoke


Sugar beet


sunflower

This study has been awarded the First prize for the Progress of Science and Technology of Hebei Province in 2015

河北省科学技术奖

证 书

为表彰河北省科学技术奖获得者，特颁发此证书。

项目名称：滨海平原盐碱区适生种植技术集成研究与示范

奖种类别：科学技术进步奖

奖励等级：一等

获 奖 者：刘小京

2016年1月26日

2015 年度·证书号：2015JB1012-1

证书号第489597号

发明专利证书

发明名称：利用苦咸水自然冻冰改良盐碱地的方法

发 明 人：刘小京；田魁祥；李伟强；王容；高福存；张新州

专 利 号：ZL 2005 1 0012450.3

专利申请日：2005 年 4 月 11 日

专 利 权 人：中国科学院遗传与发育生物学研究所

授权公告日：2009 年 4 月 22 日

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“咸水冬季结冰灌溉改良盐碱地技术”项目获突破性进展

盐碱荒地不长农作物历史将被改写

为我省300万亩滨海盐碱地的开发利用提供了重要技术支撑

本报讯(记者张丽辉)历经3年艰苦攻关，国家863计划项目和省科技支撑计划项目——“咸水冬季结冰灌溉改良盐碱地技术”项目取得突破性进展，盐碱荒地不能生长农作物的历史将被改写。

9月16日，省科技厅组织有关专家对“咸水冬季结冰灌溉改良盐碱地技术”进行了现场检测。海兴县小山乡和中捷管理区滨海盐碱地试验结果显示，在冬季采用含盐量1.5%以下的咸水进行结冰灌溉，在春季融冰时土壤层含盐量可降到0.4%以下，而没进行咸水结冰灌溉的土壤含盐量则高达1.2%以上。

3年来，中科院遗传与发育生物学研究所农业资源中心的科技人员采用该项技术，在历史上从未种植过作物的盐碱地上，播种的棉花、油葵、甜高粱和海滨锦葵出苗率高达90%以上，各种作物长势良好。

据专家介绍，我省滨海盐碱荒地有300多万亩，是重要的后备耕地资源地区，虽发展能源植物和固碳植物最具潜力的地区；且咸水资源储量丰富，可开采的资源量在50多亿立方米，仅沧州地区就有4亿多立方米，目前的利用率不足5%。

Outline

- Background
- Major progress
- **Future focus**

Future focus

- Modelling the dynamics of soil salt and water in field under freezing saline water irrigation condition
- Long time monitor of catchment salt and water balance
- The adapting mechanism of cotton roots to saline soil
- Technologies transfer

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Thank you very much for your attention!