Food and Agriculture Organization of the United Nations

GLOBAL SYMPOSIUM on SOILS and WATER

02-05 October, 2023

Soil and water: a source of life

How to improve the water utilization efficiency of salt-affected soils?

Shuwen Hu, Ph.D. Professor

China Agricultural University

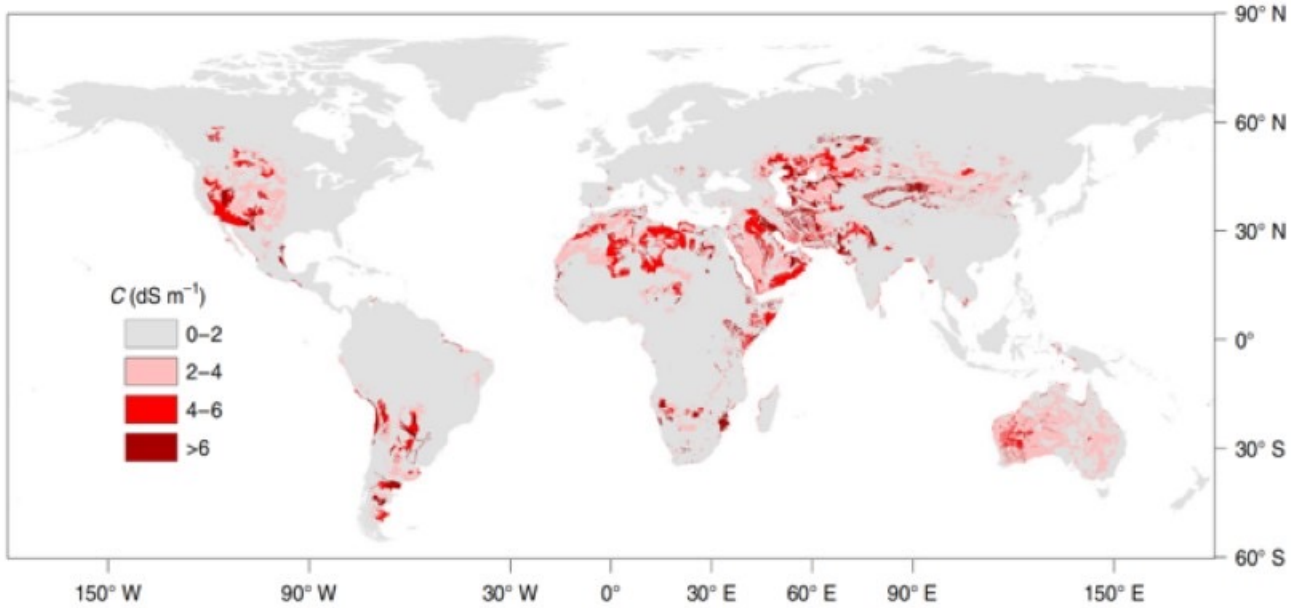
shuwenhu@cau.edu.cn

Contents

1. Background

- Salt-affected soils (SAS) are global issues, increasing at a rate of 1-2% annually
- Salt-affected soils impact over 1,000 million hectares of land worldwide
- Soil salinization has become one of the major environmental and socioeconomic issues globally, which would be further exacerbated with climatic change

Distribution of saline-alkali land in the world



SAS is categorized into four major types:

(1) **Sodic soil**, mainly Na_2CO_3 and $NaHCO_3$

(2) **Coastal salinized soil**, primarily NaCl

(3) **Mixed saline-alkali soil**, NaCl, Na_2SO_4 and Na_2CO_3

(4) **Secondary salinization soil**, NaCl, Na_2SO_4 and $NaHCO_3$

Current salt-affected soil reclamation technology

Physical remediation

Hidden pipe, guest soil, lift the field, tectorial technology, straw cover

↓

Reduce the salt concentration in the topsoil layer

Chemical remediation

Organic acid, gypsum, aluminum sulfate, biochar, furfural residue, polymers

↓

Remove the Na^+ and desalinate

Plant remediation

Salt-tolerant crops: cotton, sunflower, rice, sugar beet, grass, etc

↓

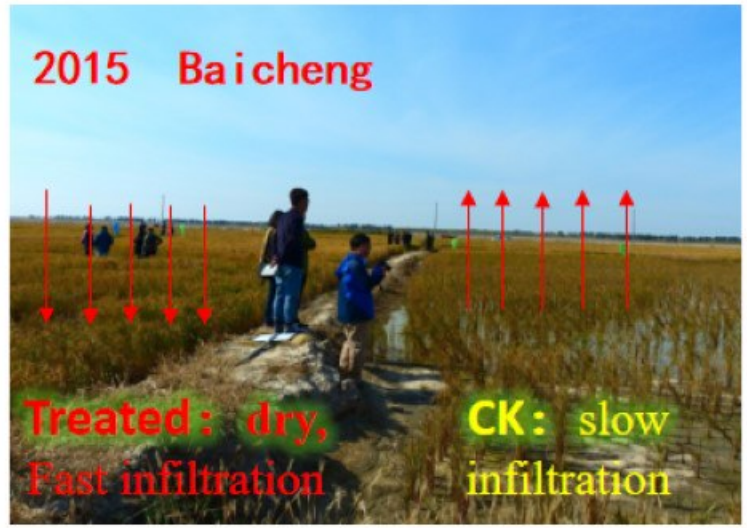
Enrich salt and improve structure

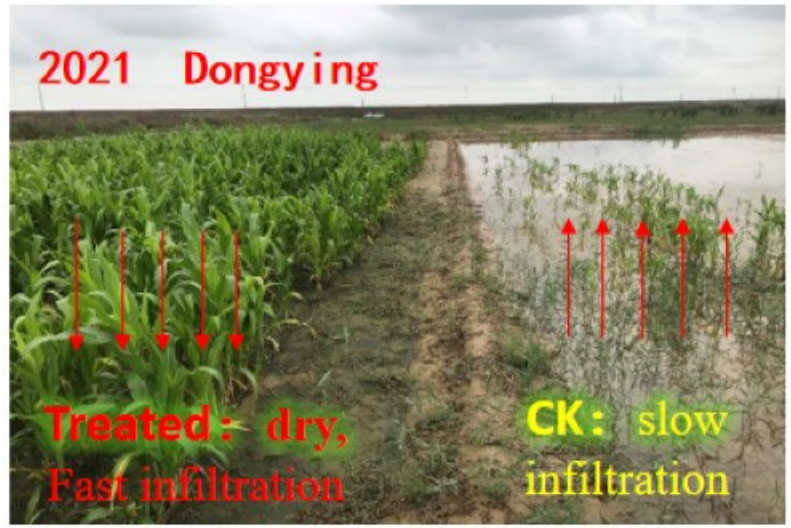
The management of salt-affected soil is an extremely **complex systematic engineering** challenge and unable be effectively addressed by only 1 or 2 technologies!

Saline alkali areas generally suffer from water scarcity, and the key point is the **scientific use of water resources**

Difficulties in reclaiming saline-alkali soil

1. Sodic soil's poor structure, sticky, harden
2. High salt content
3. Low nutrient content
4. The poor structure induced slow water infiltration rate resulting the low desalting efficiency
5. The key point is **improve the soil structure** to reduce the ratio of *evaporation to infiltration of* water





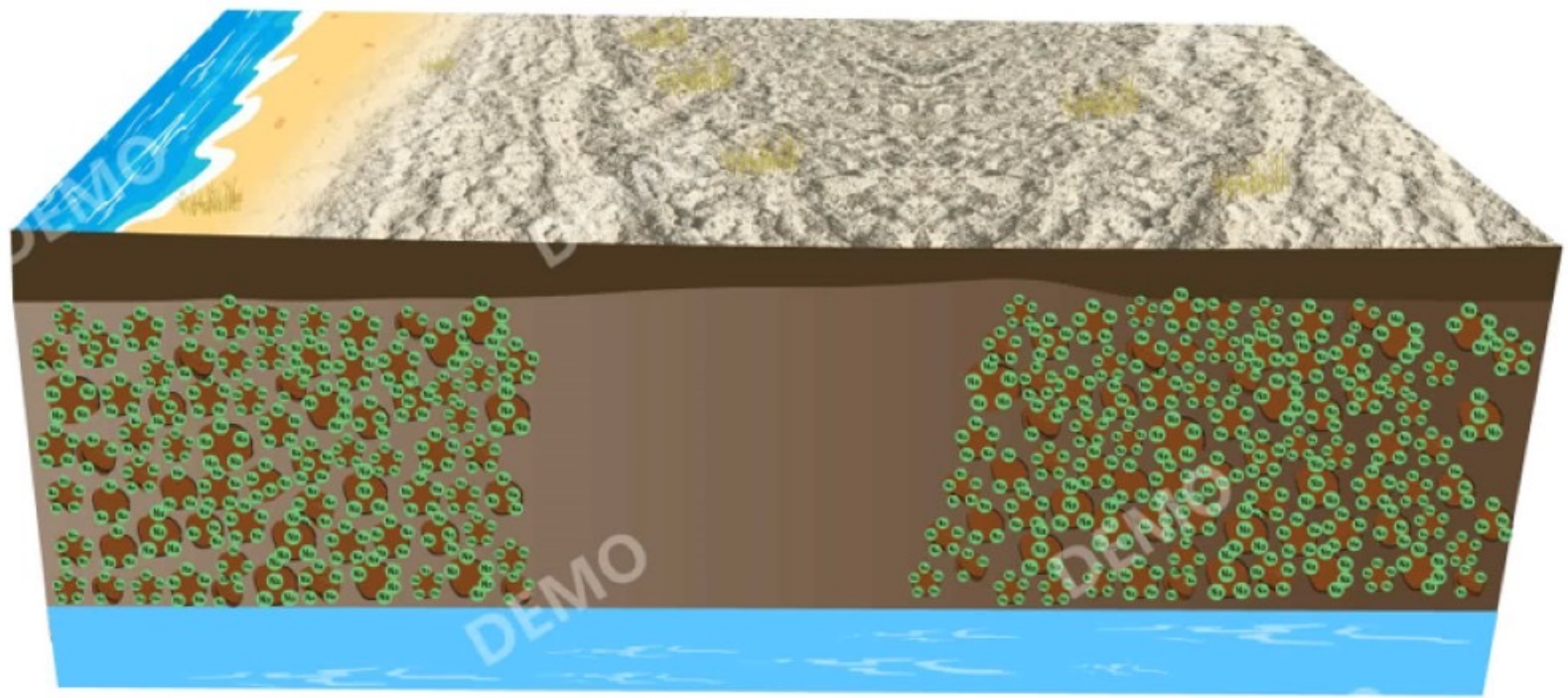
Contents

Illustration of the systematic restoration of saline-alkali land model

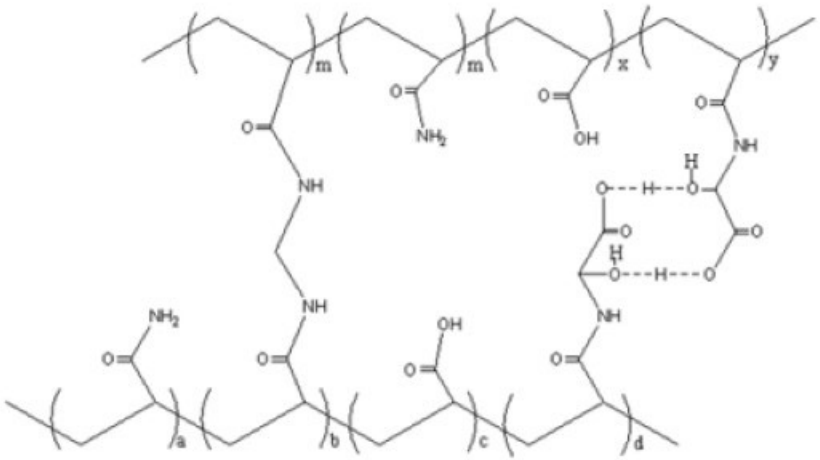
“Remolding the soil granular structure with amendments, efficient desalting, a combination of dredging and blocking, and reclamation of fertile land”

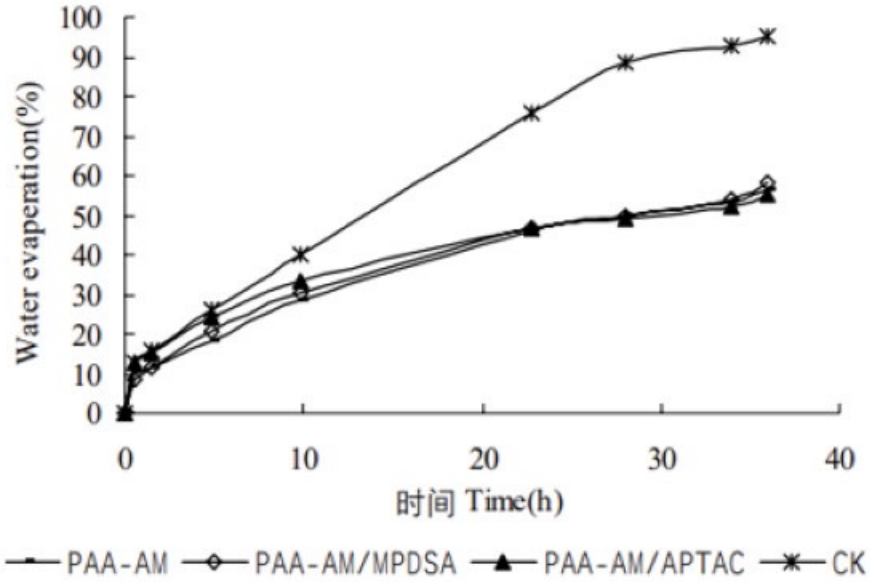
中国農業大學
CHINA AGRICULTURAL UNIVERSITY

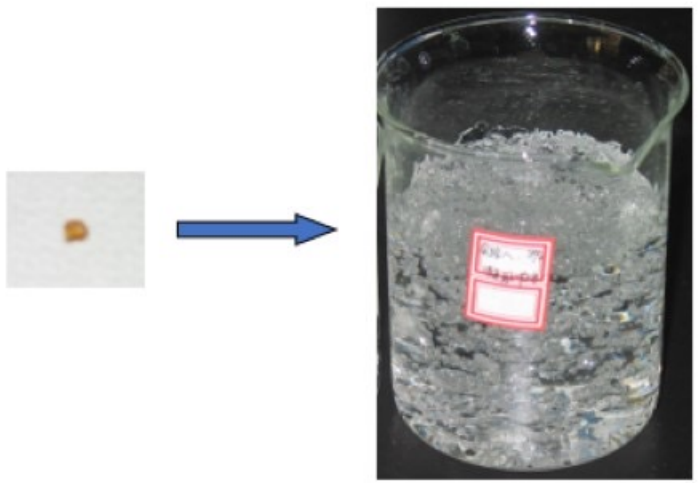
Develop new type of cellulose modified material to "agglomerate" small particles of saline alkali soil to form large particles, reshaping the soil's "granular structure"



We developed new type of super absorbent materials to increase the effective water content of salt-affected soil



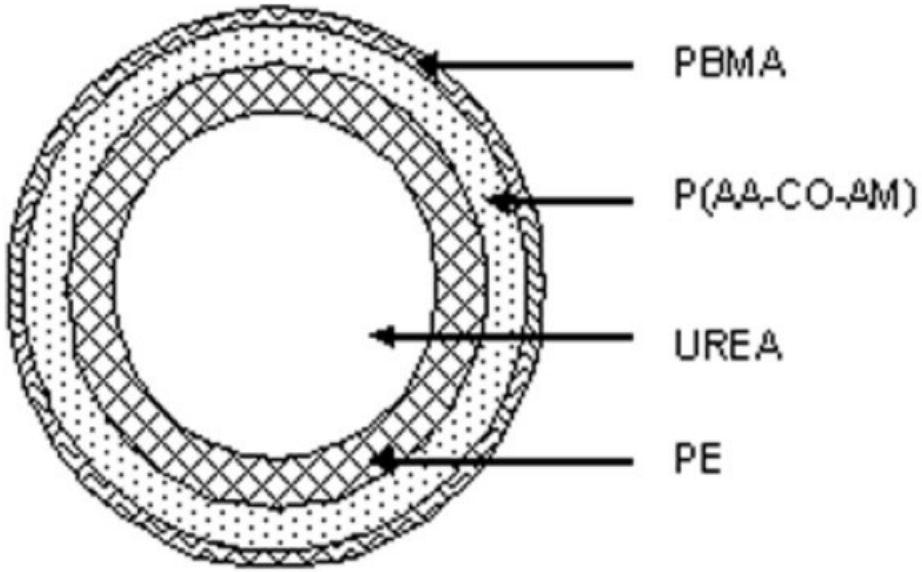




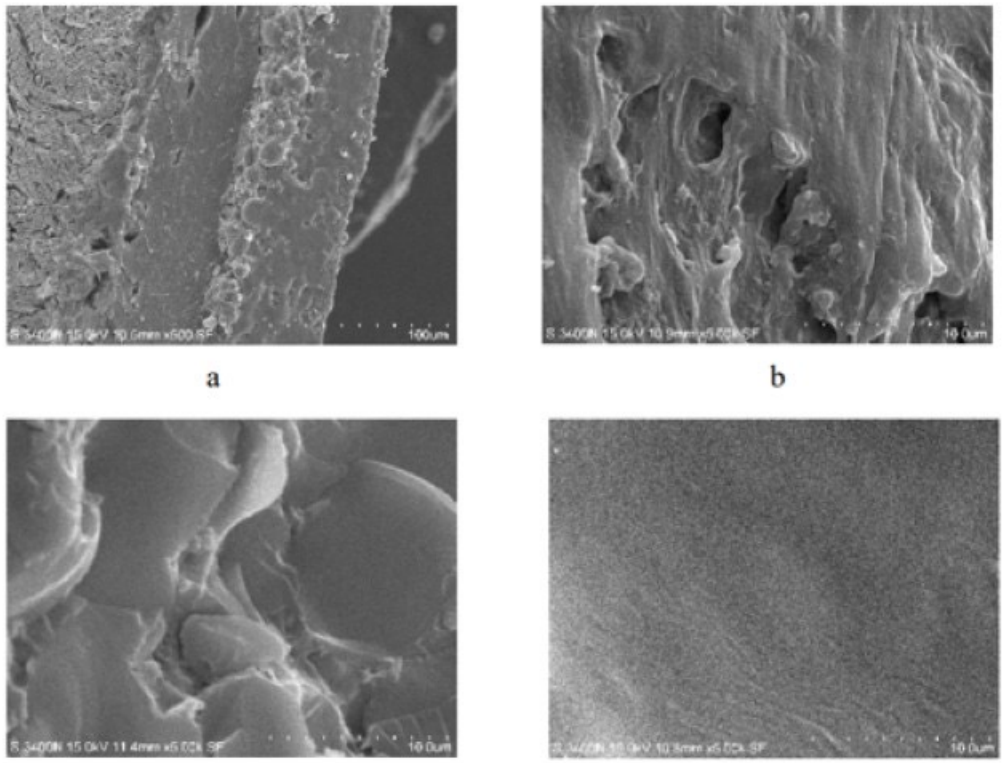
It maintains the water and nutrient supply of the rhizosphere soil for a long time, greatly improving the germination rate of seeds

Zhou, J. Appl. Poly. Sci., 2009

In order to increase the effective water content of salt-affected soil, we developed new type of super absorbent materials



TCWF (Triple coated controlled-release water retention fertilizer)

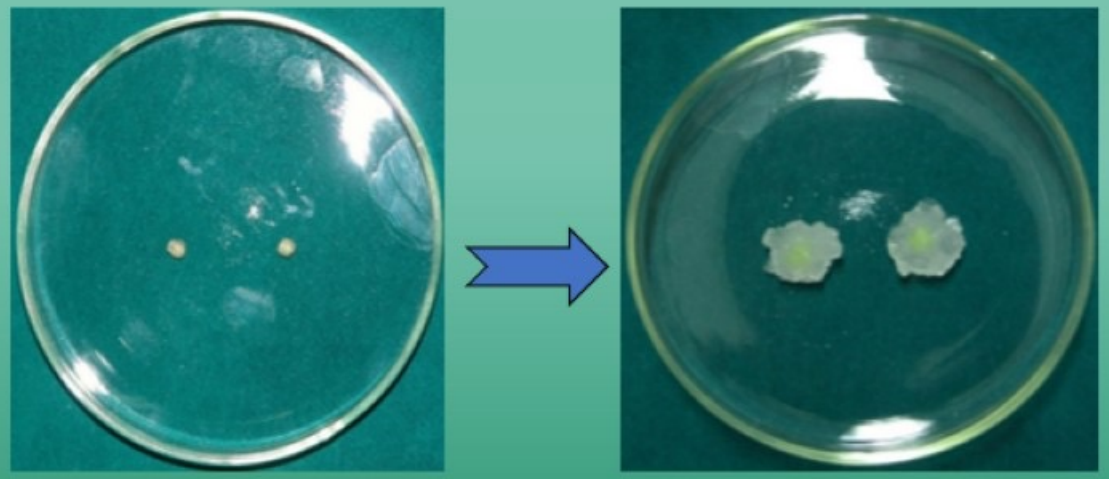


The SEM of TCWF

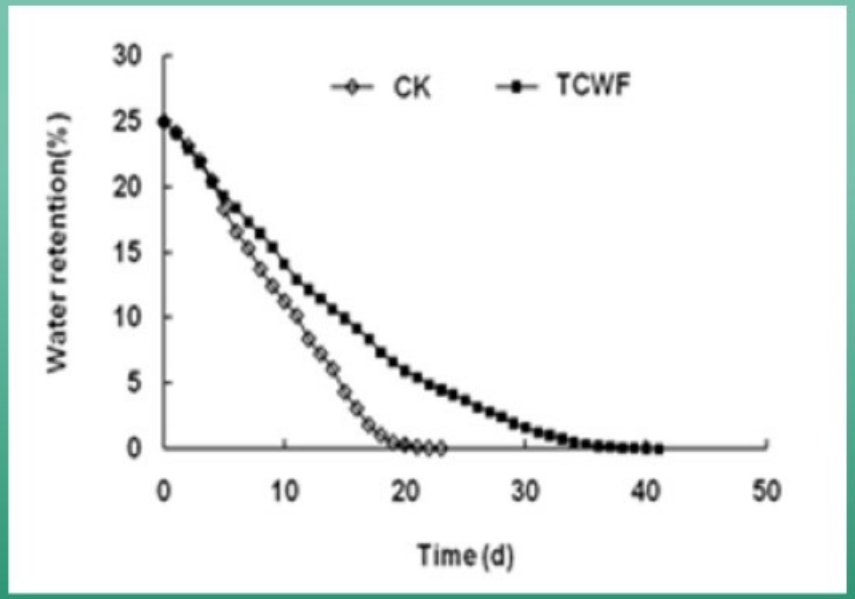
TCWF can absorb surrounding water and slowly release it, which is both a "small water reservoir" and a "small fertilizer reservoir"

Tao, J. Appl. Poly. Sci., 2011

We produced new type of water retaining controlled release fertilizer



Before water absorption **After absorbing water**



The new type of water retaining controlled release fertilizer can absorb surrounding water and slowly release it, which is both a "small water reservoir" and a "small fertilizer reservoir"

Tao, J. Appl. Poly. Sci., 2011

We created "Remolding soil granular structure, efficient desalination" restoration of saline-alkali land system engineering technology model

Authorized 16 patents and published over 20 Sci papers

saline-alkali land

Research

Test analysis

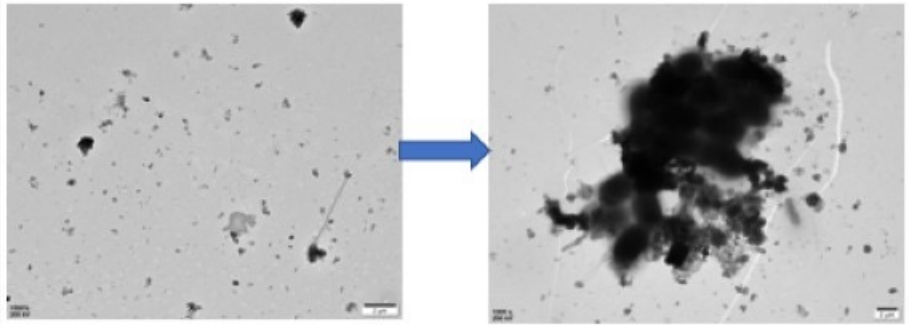
Discussion

Improvement strategy

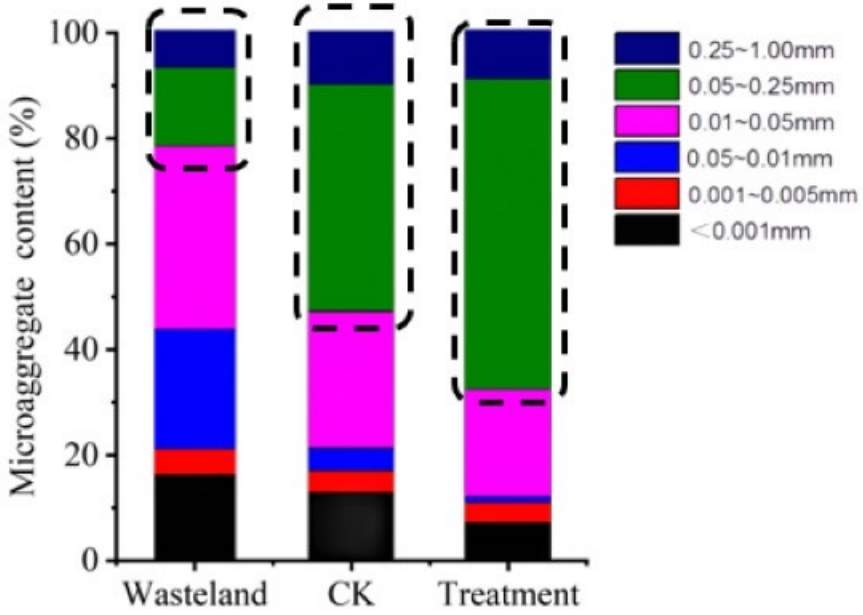
- Engineering restoration
  - Land leveling, irrigation and drainage system and field layout
- Soil remediation
  - Soil physical structure reconstruction / granular structural remodeling agent
  - Soil chemical biological balance - ion balance and ecological balance preparation
- Soil fertilization
  - Water control, nutrient balance technology
  - Soil fertility enhancement and straw returning technology
- Plantation management
  - Screening technology of resistant varieties seed and seed treatment agents
  - Anti-stress management technique
- Sustainable maintenance
  - Regional planting and grass ecological restoration technology
  - Regional saline-alkali orientation enrichment and separation technology
  - Water table control, salt washing wastewater recycling

Contents

Remodeling granular structure → Soil permeability increased → Alkalinity and salinity decreased

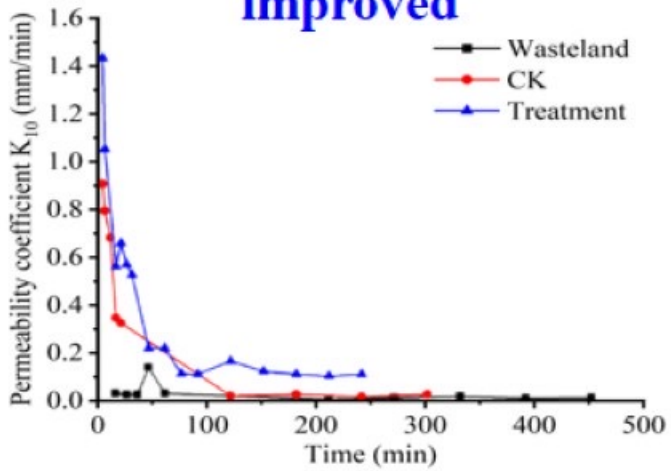


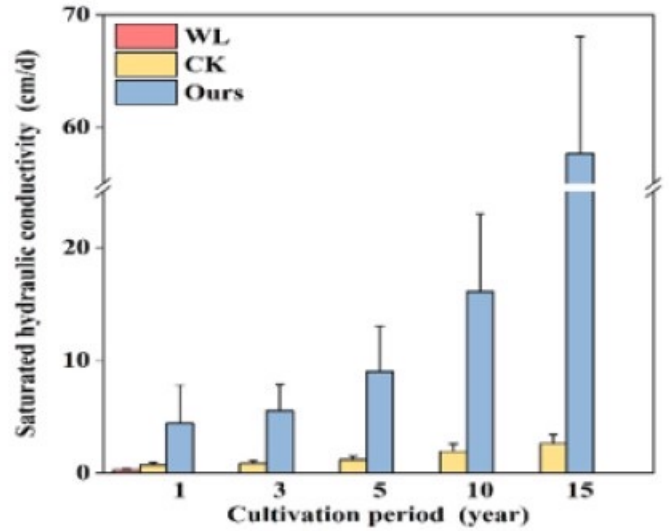
Soil colloid flocculation



The content of macro-aggregates increased

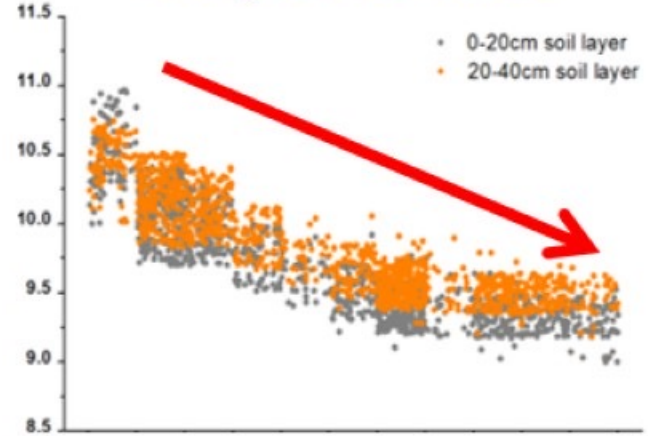
Soil permeability improved

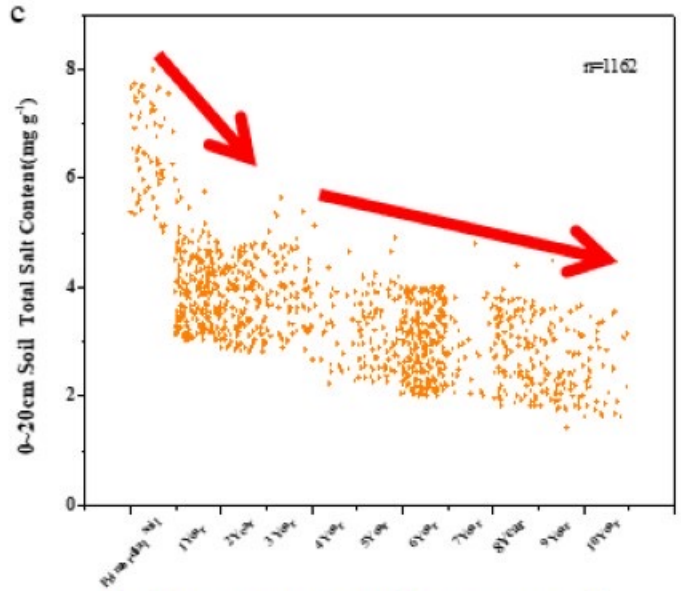




Saturated hydraulic conductivity increased

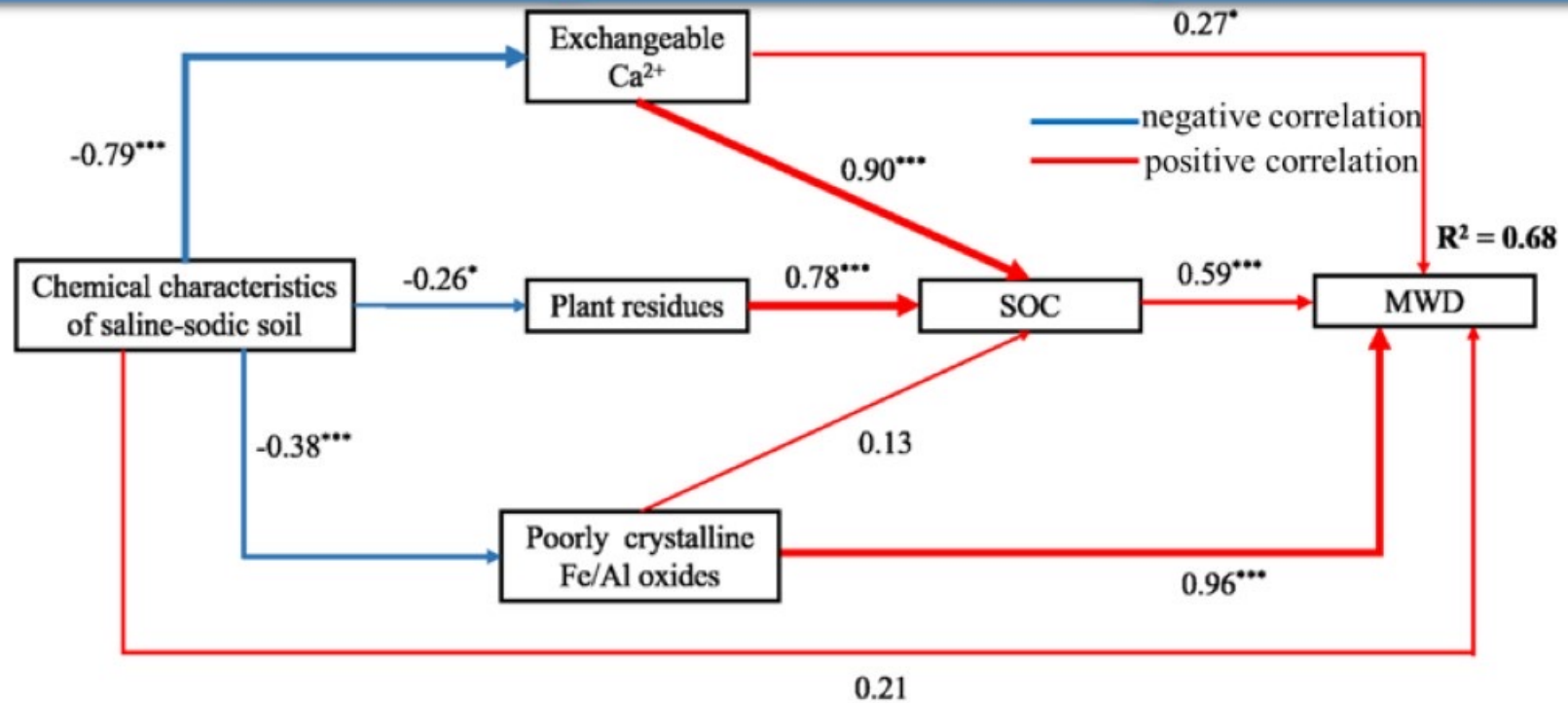
Soil pH decreased





Salt content decreased

Mechanism of aggregate formation and stability based on the "remodeling soil structure" improvement model



Feng, Land Degr. Dev., 2021

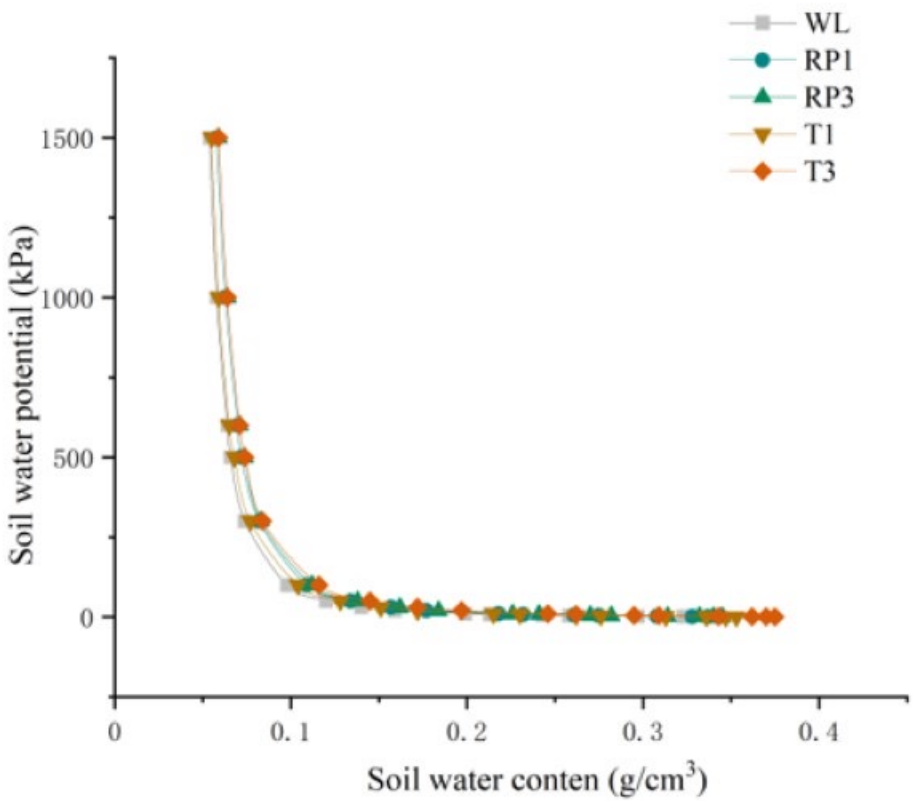
$\chi^2 = 19.3$, df = 7, $p = 0.38$, n = 36,

The formation of saline-alkali soil aggregates can be divided into two stages:

(1) **Exchangeable Ca^{2+}**, **amorphous Fe-Al oxide** and **organic matter** are factors that promote the formation of soil aggregates

(2) **Soil microbial exudates** enhance the formation of highly stable macroaggregates

Soil hydraulic properties



Soil water retention curves

Zhang, unpublished data

Fig.1 Effects of Rice planting for 1 year（RP1）, rice planting for 3 years（RP3）, rice planting for 1 year after soil improvement（T1）, and rice planting for 3 years after soil improvement(T3) on the wet range (0-1500kPa) of soil water retention curves. WL represents wasteland.

The soil water content of T3 is the highest under each pressure

Soil hydraulic properties

Soil maximum water content and soil saturated hydraulic conductivity

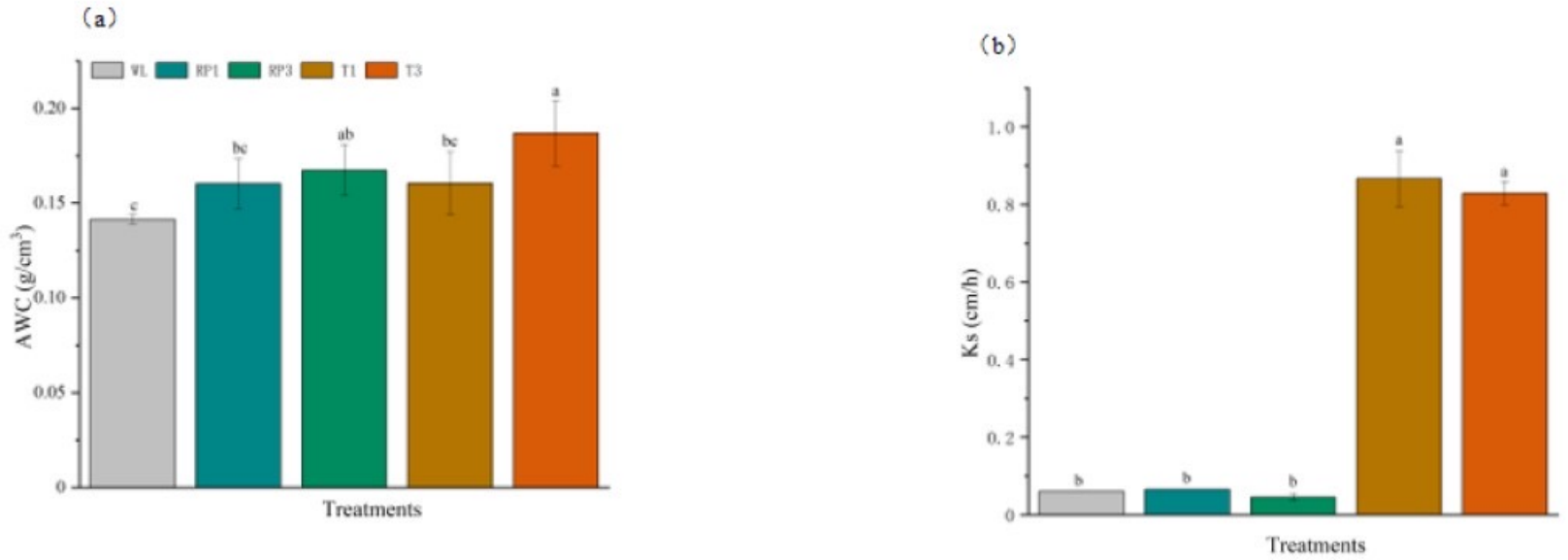


Fig.2 Effects of Rice planting for 1 year（RP1）, rice planting for 3 years（RP3）, rice planting for 1 year after soil improvement（T1）, and rice planting for 3 years after soil improvement(T3) on the maximum available water content（AWC）（a）and saturated hydraulic conductivity（Ks）（b）. WL represents wasteland. AWC define as the difference in the soil moisture content at pressure of 10 and 1500kPa.

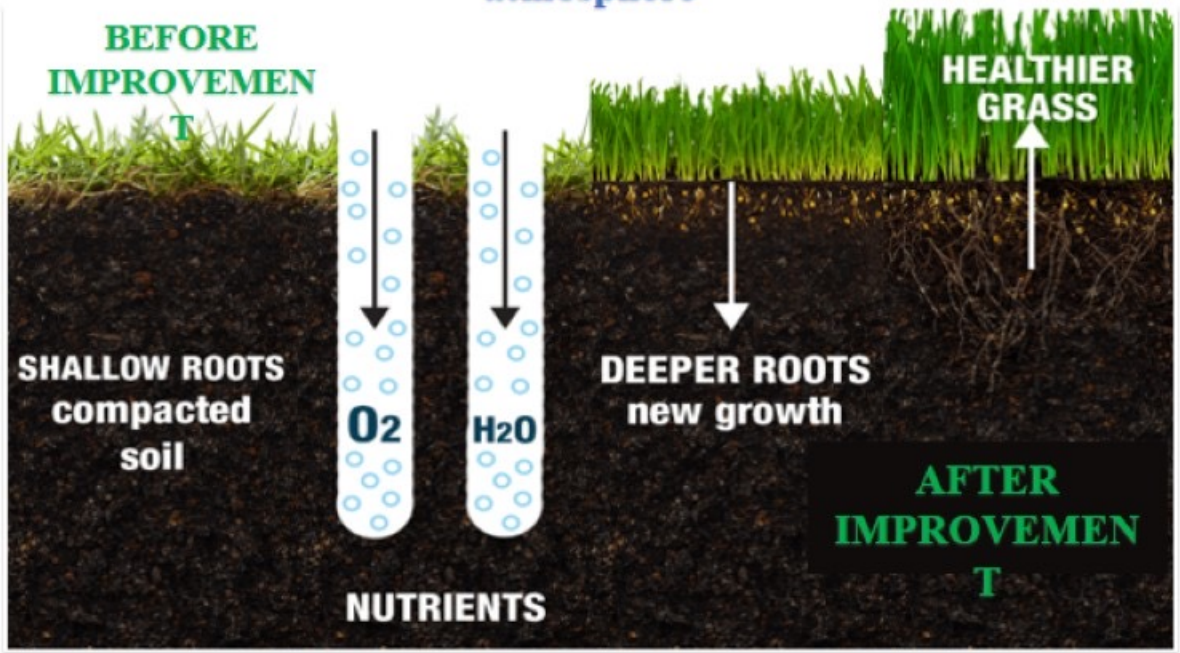
1. The AWC values increased with the increase of wasteland reclamation years. The AWC values of rice planting after soil improvement was larger

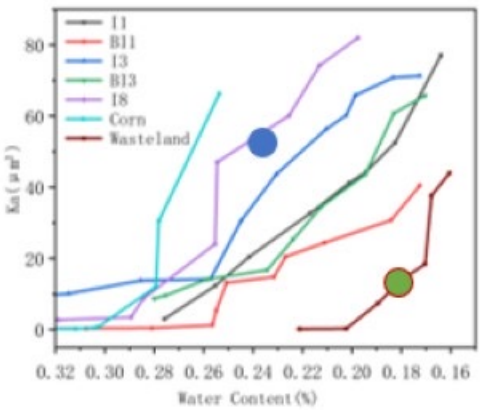
2. The improved soil water conductivity has been significantly improved

Zhang, unpublished data

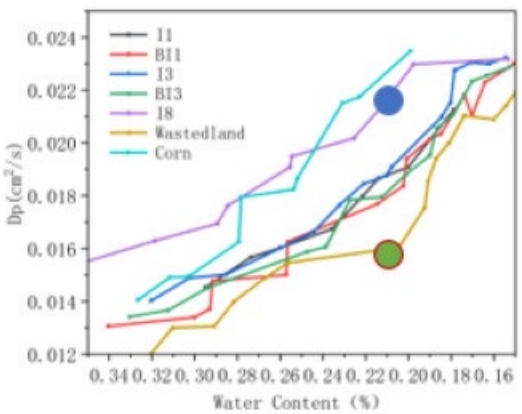
Correlating Saline-soil Gas Transport with X-Ray CT Measurements

Soil aeration refers to the gas exchange between soil air and atmosphere



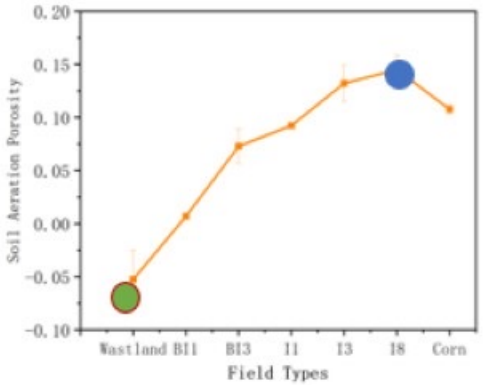


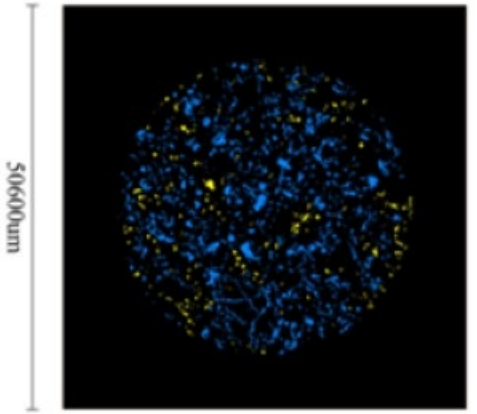
(a)Air Permeability



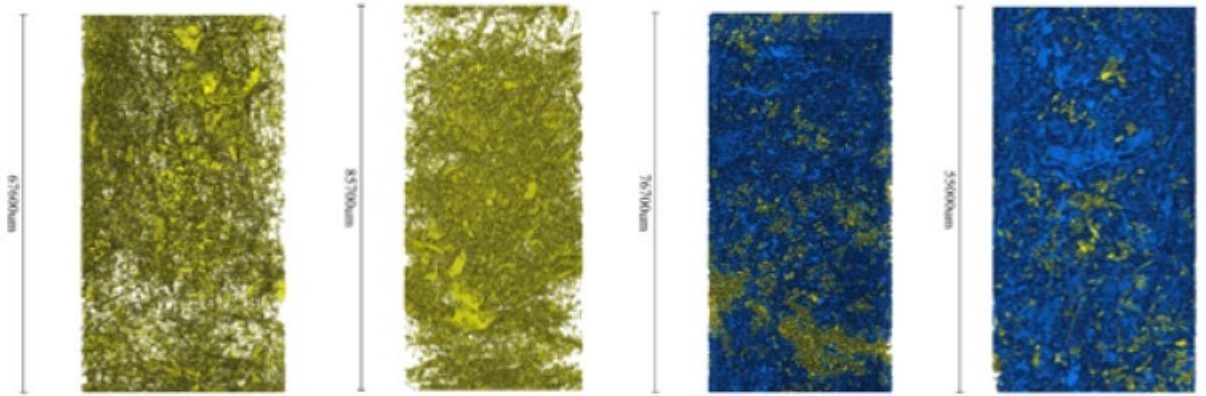
(b) Gas Diffusivity

(c)Aeration Porosity at 12cmH_2O





(d)2D Picture of Connected and Disconnected Pores



(d)3D Picture of Connected and Disconnected Pores

1.Wastedland 2.Improve 1 year 3.Improve 3 year 4.Improve 8 year

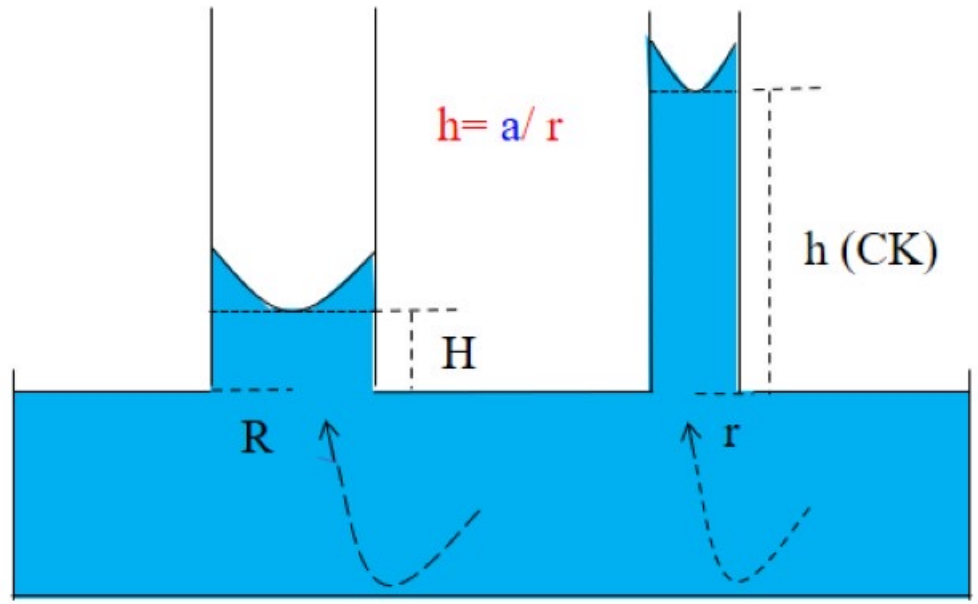
Ge, unpublished data

Comprehensive method to suppress soil salt return

Salt return rate under different treatments

Treatment	Base liquid change /mL	Water absorption rate /mL h^{-1}	Total salt accumulation /g kg^{-1}	Salt accumulation rate /g kg^{-1} d^{-1}
Waste land	1395	3.63	*9.01*	0.56
Other technique	1830	4.77	8.93	0.56
Our reclamation	1850	4.82	5.56	0.35

Soil capillary effect



1. Larger diameter, lessened capillary effect
2. Returned straw, root residue's neutralization
3. Controlled the groundwater level

$RCOOH+Na_2CO_3 \rightarrow RCOONa+NaHCO_3$

$RCOOH+NaHCO_3 \rightarrow RCOONa+CO_2+H_2O$

Wang, J. Agr. Sci. Agrotech, 2022

Response of soils microorganism to saline-sodic soils under long-term rice-based cropping system: increased diversity and abundance

Rebuild microbiological community

Ammonia-oxidizing archaea (Nitrososphaera)

↓ 1-2 years

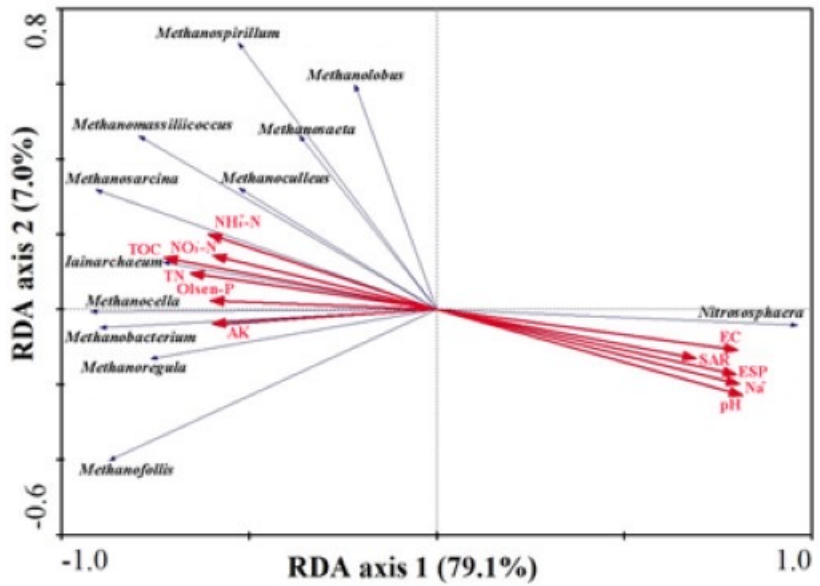
Anaerobic methanogenic archaea

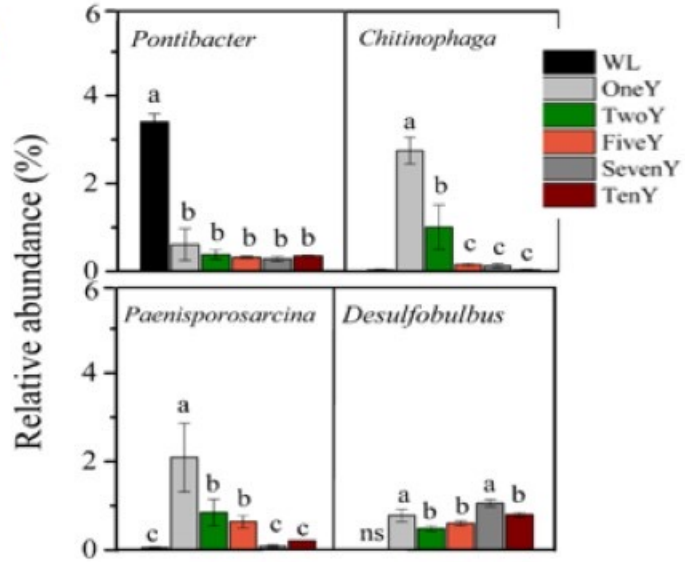
↓ 3-5 years

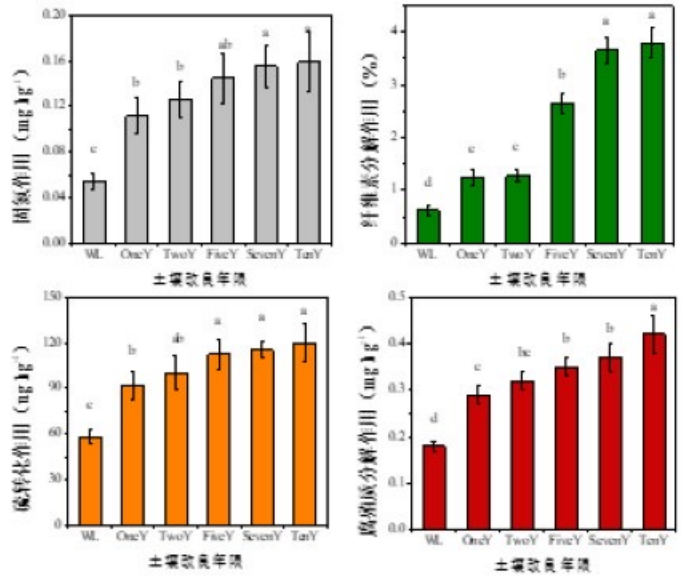
Aerobic archaea

↓ 6-10 years

Methanogenic archaea became stable







1. **Within the span of 1-5 years, the rates of soil carbon sequestration, cellulose decomposition, sulfur conversion, and humus decomposition continued to increase**
2. **After 5 years**, the increase has **stabilized**

Feng, Land Degr. Dev., 2019
Du, Arch. Agron. & Soil Sci., 2021

Explored the impact of cultivated rice fields on organic carbon in saline alkali soil

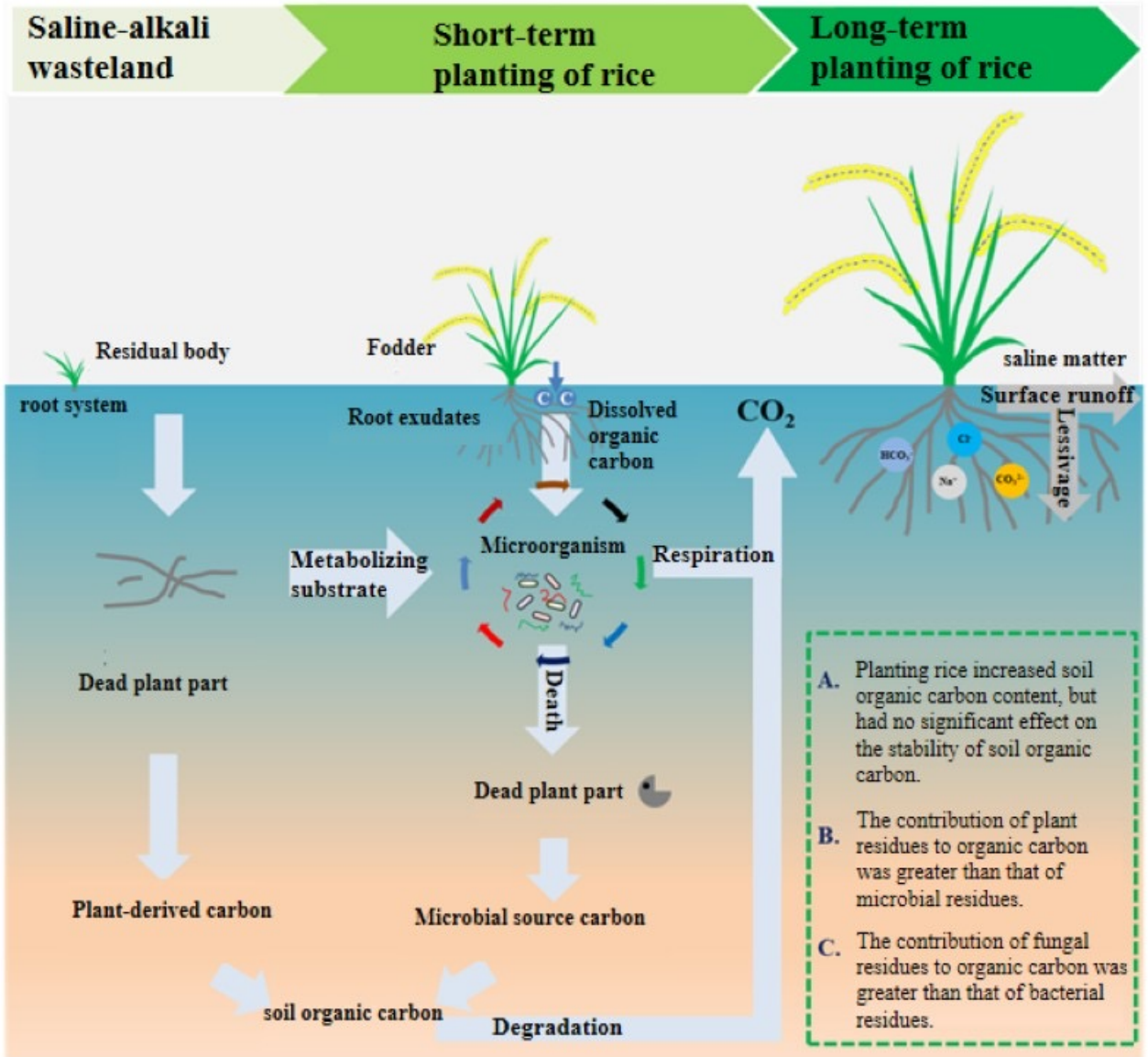


Fig.28 Conceptual model of contribution of plant residues and microbial residues to soil organic carbon in saline-alkali paddy field

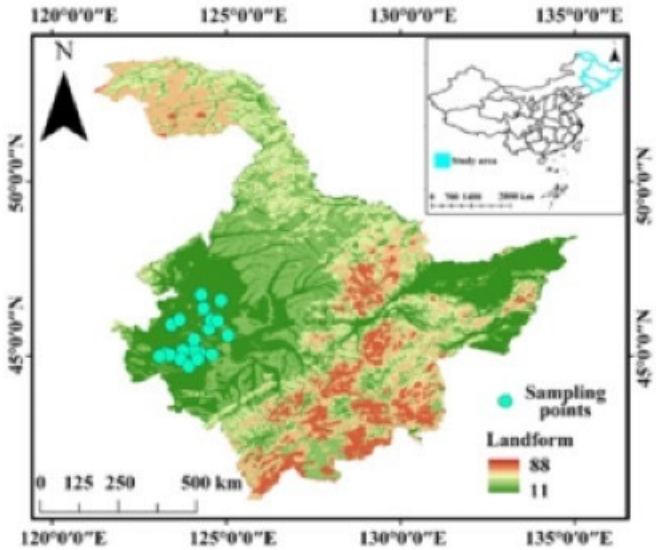
With the increase of rice planting years :

- ✓ Soil salinity and alkalinity decreased, and microbial biomass increased
- ✓ Soil total organic carbon content increased
- ✓ The amount and contribution of plant residues and microbial residues increased
- ✓ Contribution of plant residues > contribution of microbial residues
- ✓ Fungal residue contribution > bacterial residue contribution
- ✓ Planting rice had no significant effect on organic carbon stability

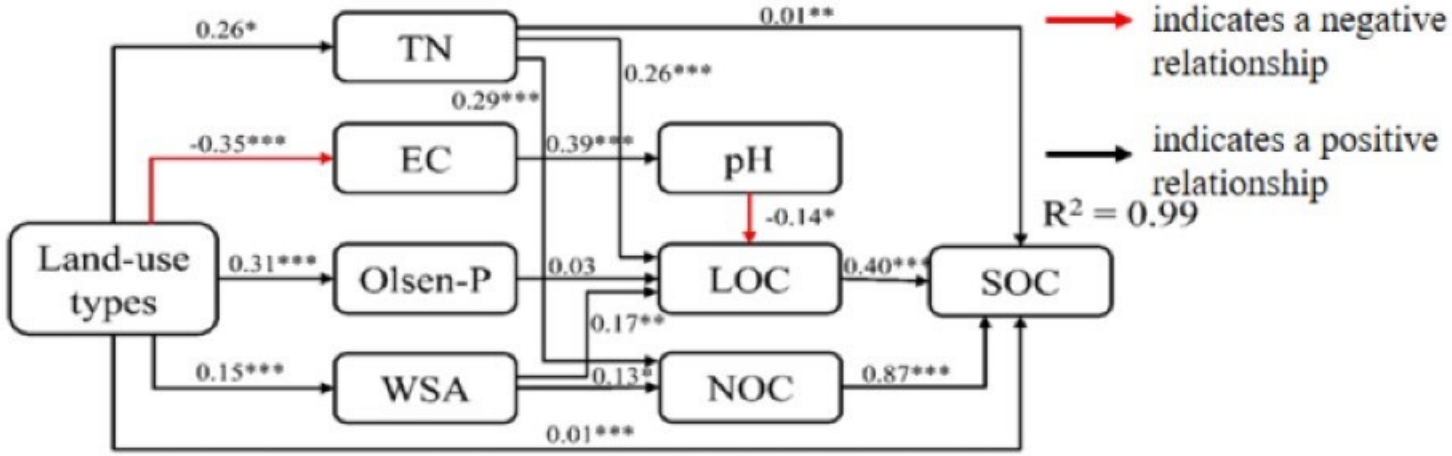
❑ **The results of this study are crucial for further understanding the sequestration potential of organic carbon in saline-alkali soil**

Du, Sci. Total Environ., 2023
Du, Submitted to Euro. J. S. S.

Variation characteristics and influence factors of organic carbon components in saline-alkali soil



Sample sites in Songnen Plain

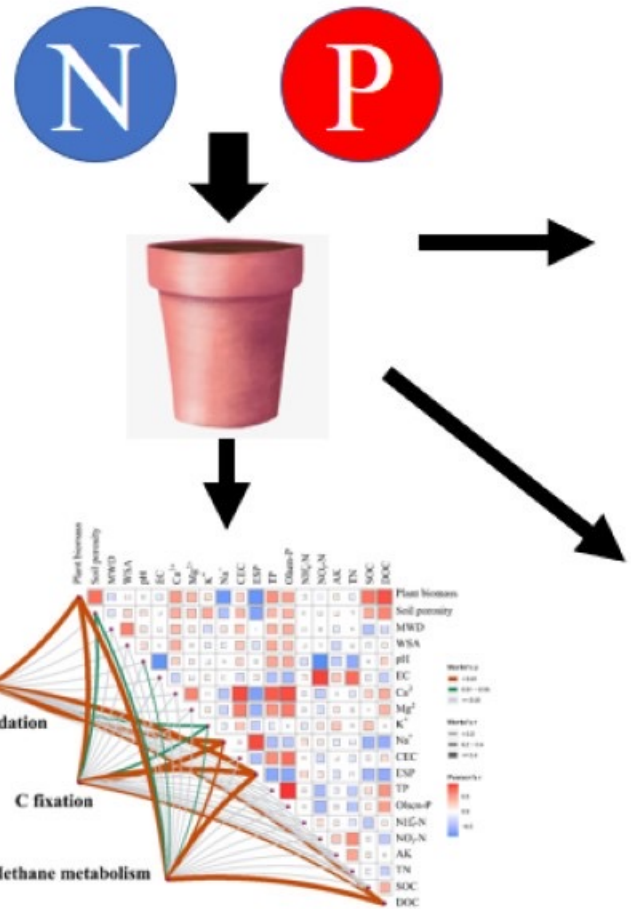


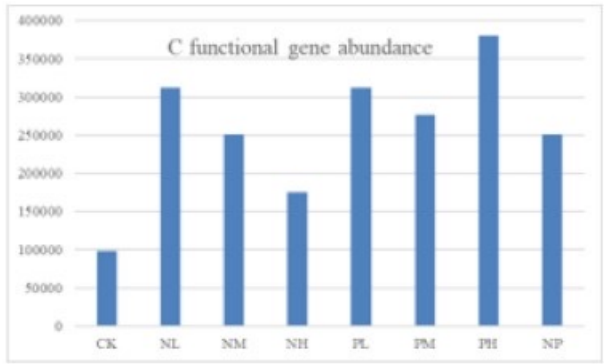
Structural equation modelling revealed crucial driving factors for improving SOC sequestration in saline-sodic soils.

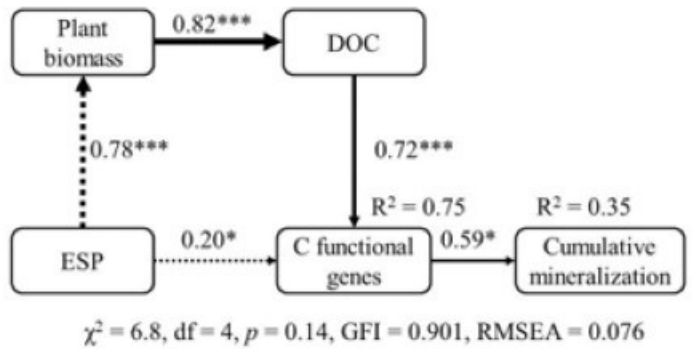
- With the increase of rice planting years, the microbial biomass of soil bacteria and fungi increased gradually, and the bacterial biomass was much larger than the fungal biomass
- The contribution of plant residues to soil organic carbon was greater than that of microbial residues, and the contribution of fungal residues to soil organic carbon was greater than that of bacteria

Du, Geoderma Regional, 2022

Effects of fertilization on organic carbon and carbon cycle functional genes in saline-alkali soil







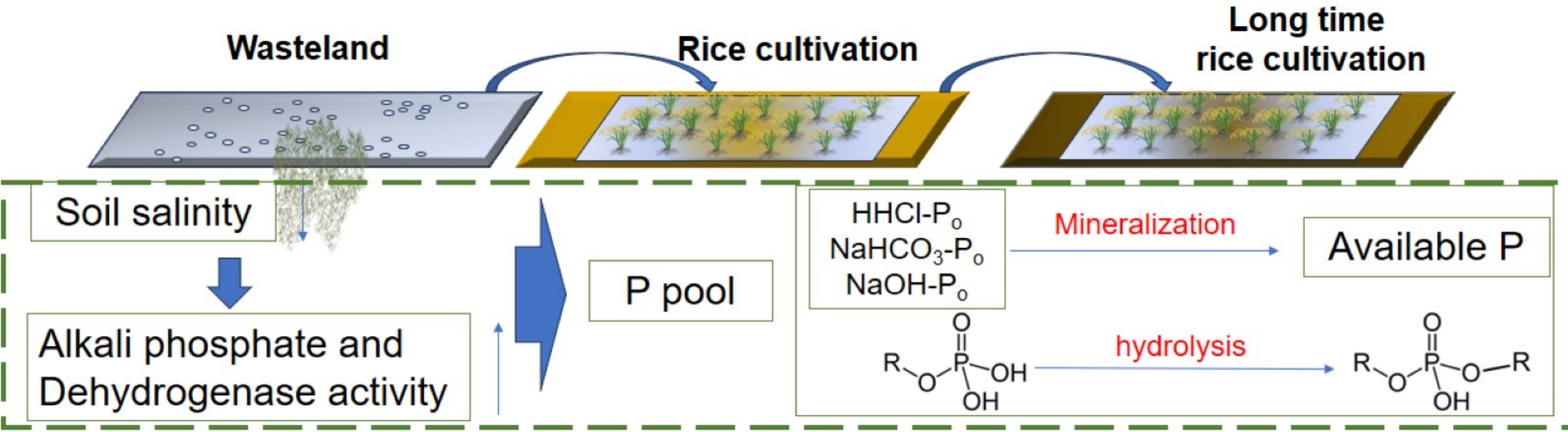
- Low nitrogen fertilizer（ NL ）and high phosphorus fertilizer （ PH ） help to increase the abundance of carbon cycle functional genes

- The changes in the abundance of carbon cycle functional genes were mainly related to the changes of soil exchangeable Na^+, ESP, DOC, microbial diversity and plant biomass after nitrogen and phosphorus addition

Du, Plant & Soils, 2023

Mechanism of long-term reclamation of paddy fields on phosphorus transformation in salt-affected soil

Long-term cultivation of rice promoted the transformation of available phosphorus, and increased the supply of soil phosphorus to plants in soil



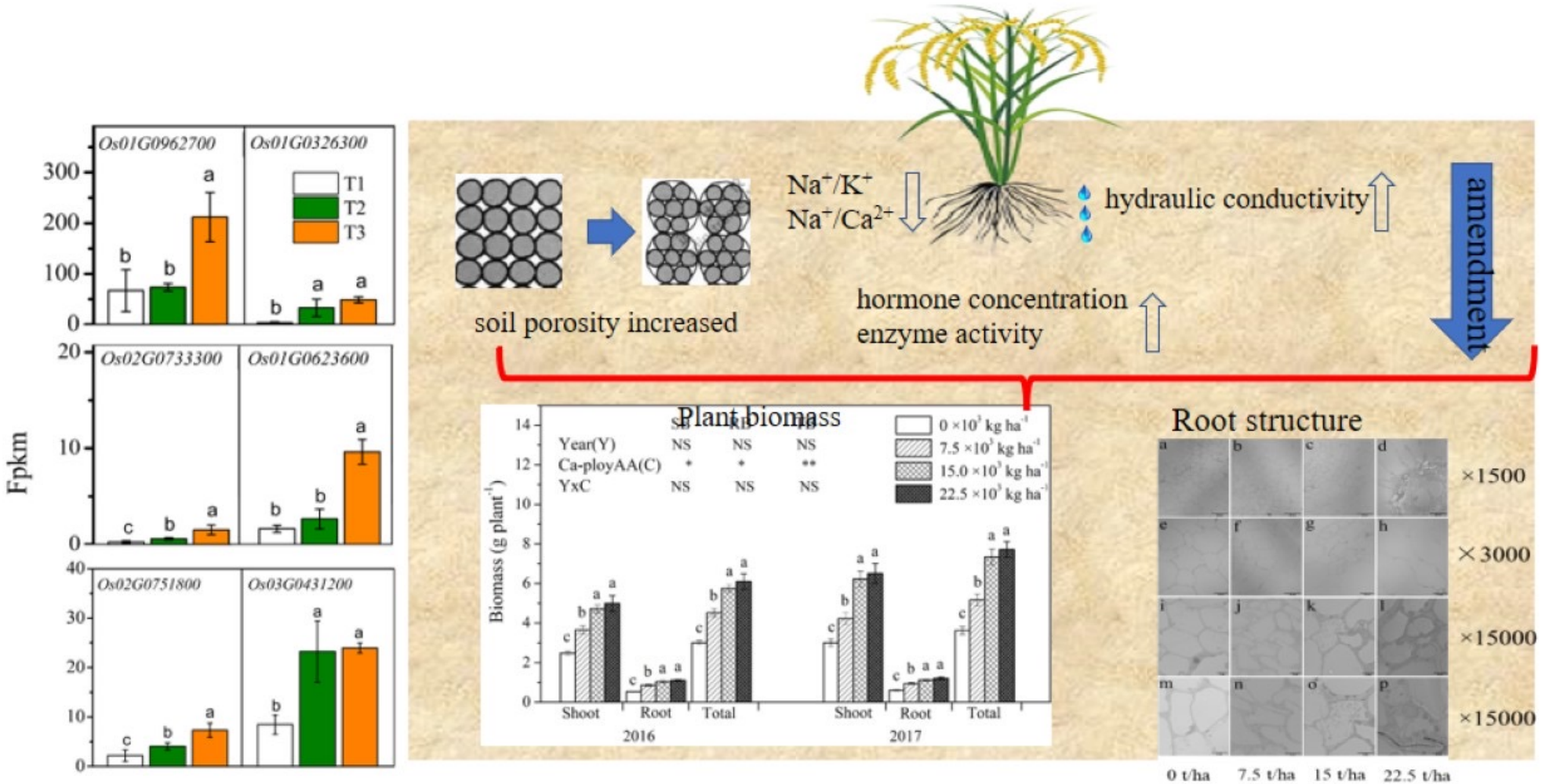
Soil salinity and sodicity

Alkali phosphate and Dehydrogenase activity

Soil pH

Soil bioavailability of P

Explored the promoting effect of saline alkali soil improvement on rice root system



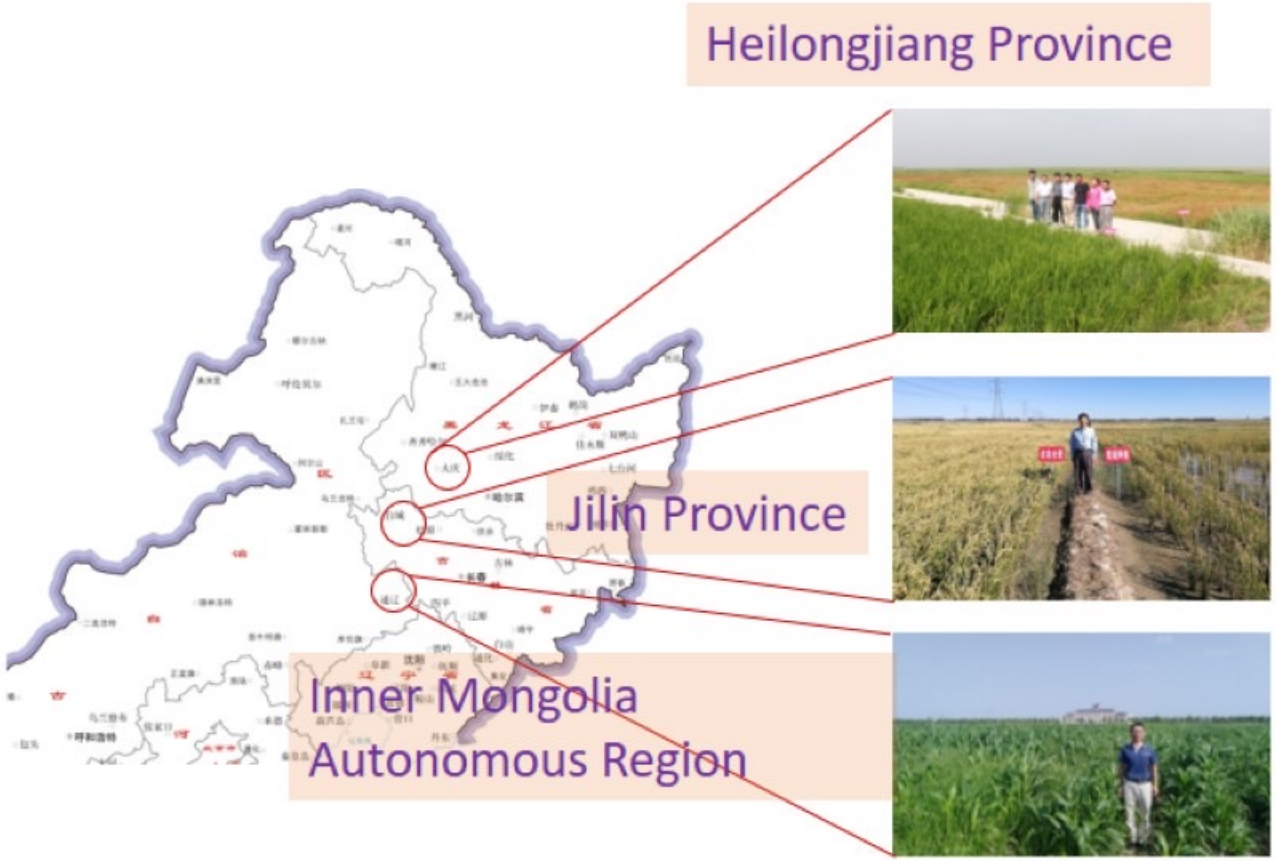
Promoting the accumulation of rice root biomass by increasing root hydraulic conductivity, carbon metabolism enzyme activity, hormone concentration, especially by reducing Na^+/K^+ and Na^+/Ca^{2+} ratios

Du, Arch. Agron. & Soil Sci., 2022

- 133 testing points
- 315 soil profiles
- 100 plots
- 32,245 soil samples
- Build database
- 36 demonstration bases
- Encompassing all global types of SAS

Feng, Land Degr. Dev., 2019, 2021
Du, Plant & soil, 2023
Du, Geoderma Regional, 2022
Du, Sci. Total Environ., 2023
Du, Arch. Agron. & Soil Sci., 2021, 2022

(1) Restoration of northeast Songnen plains–sodic (mainly Na_2CO_3) type soils



Issues

Poor soil structure, sticky

Low water permeability

Difficulties of surface salt removal

Crops are hard to grow

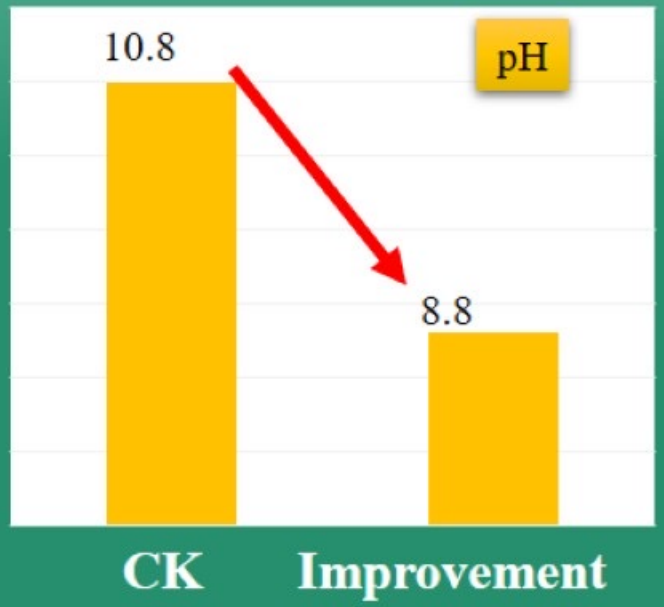
Strategy

Reshaping soil structure

Improving water permeability

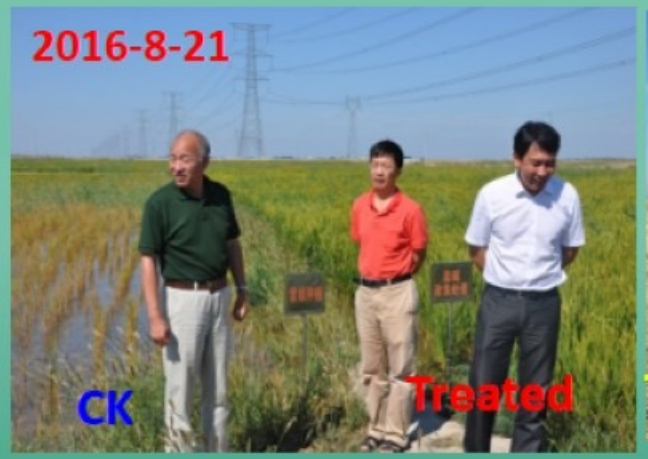
Removing soil salt quickly

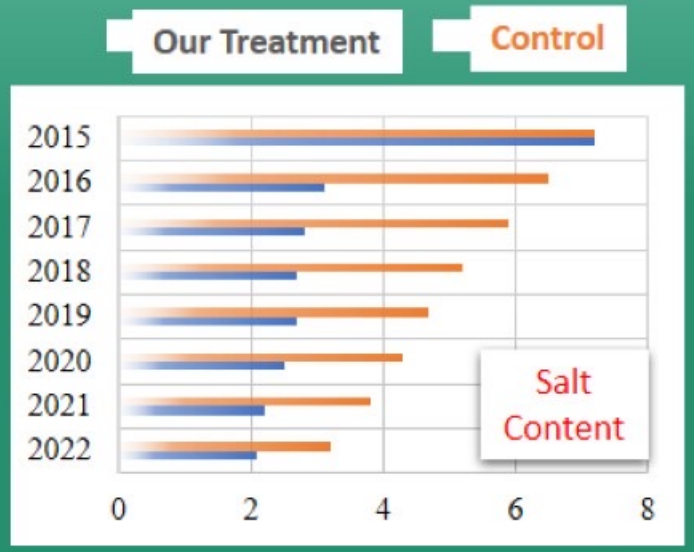
Case 1: 100 hectares of extremely sticky saline-alkali land were reclaimed within one season in Songyuan, Jilin Province



100 hectares of extremely sticky saline-alkali land were transformed into fertile land, with high yields achieved in the same year of reclamation

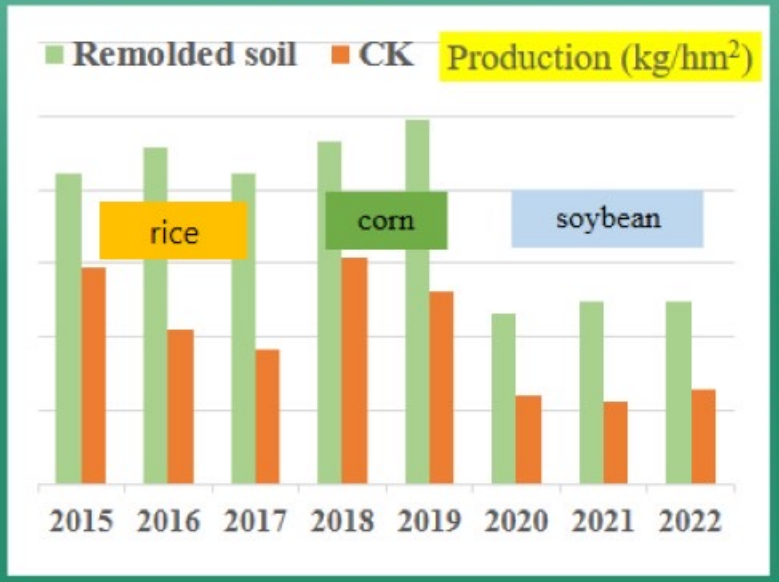
Case 2: Restoration of 300 hectares extremely heavy saline-alkali wasteland into fertile land in Da'an, Jilin Province

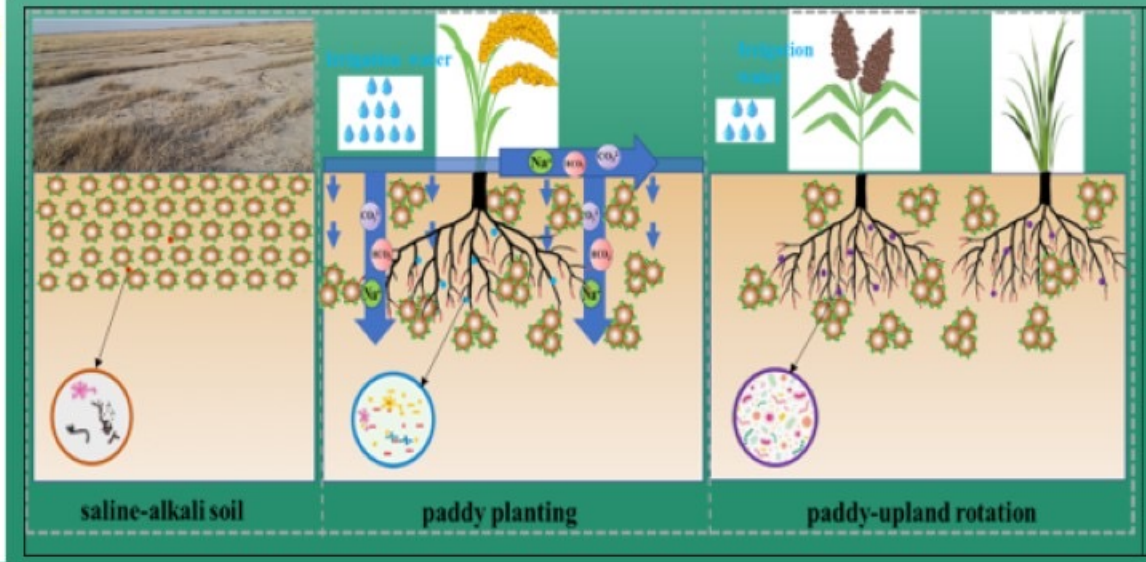




With just a season's reclamation, up to 8 years of stable high yields were achieved

Classic case 3: Ecological restoration saline-alkali land with "rotate paddy field into upland model" in Daqing, Heilongjiang





Reclaimed sodic land as a rice field for 3 years, swiftly removing salt from the topsoil, and rotate paddy field into upland under rain-fed condition, sustainable utilization of water resource was achieved

(2) System restoration of the Eastern coastal - saline soils (mainly NaCl)

Dongying
Shandong Province

Hebei Province,
Tianjin, etc

Yancheng, Jiangsu

Issues

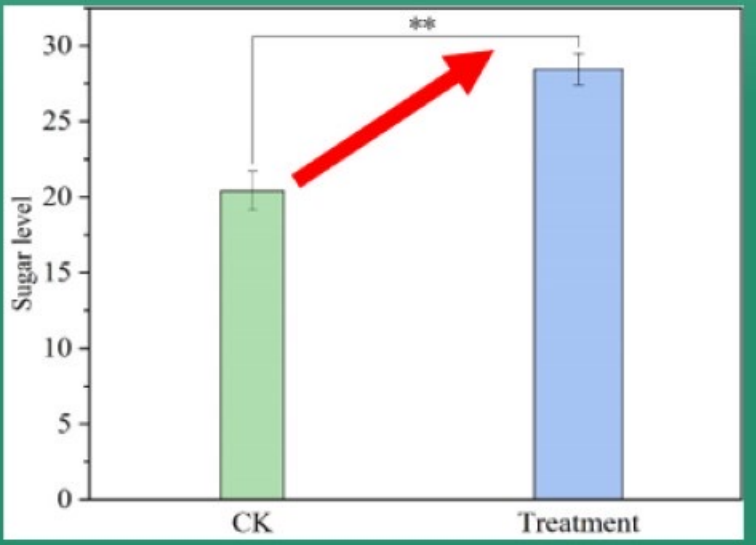
1. The water table is shallow and prone to seawater erosion
2. Saline soil has a poor structure and low water permeability

Strategy

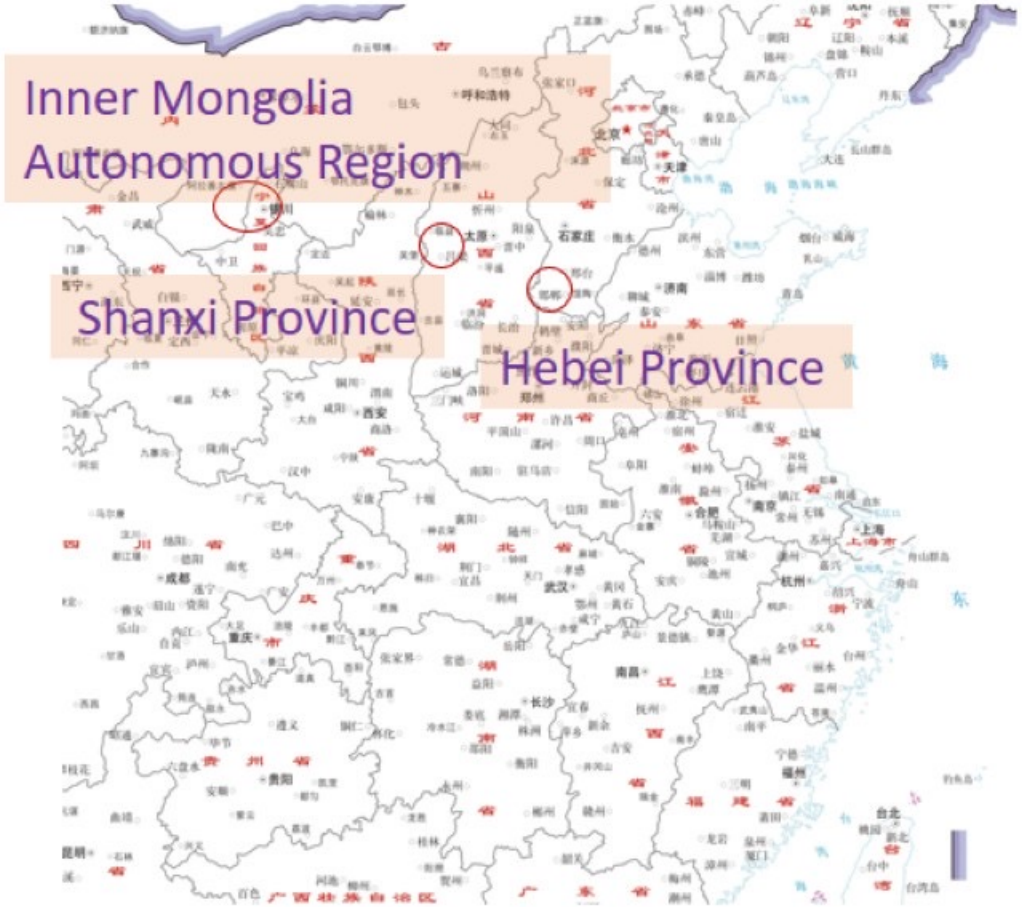
1. Build embankments and dam to control the water table and prevent salt return (Step 1)
2. Reshape soil structure and enhance soil permeability (Step 2)

Case: Sugar content of Chinese dates (Jujube) was increased by 40% after restoration of salinization soil in Zhanhua, Shandong

- After systematic restoration of salinized soil, the shrinkage rate of dates was decreased by 70%
- The average sugar content of dates increased by 8 degrees from 20.4 to 28.4, i. e. 40% increment
- After treatment, dates tasted crispy, sweet, which meet high quality standard



(2) Systematic restoration of mixed saline-alkali soils in arid regions (mainly NaCl, Na_2SO_4 and Na_2CO_3)



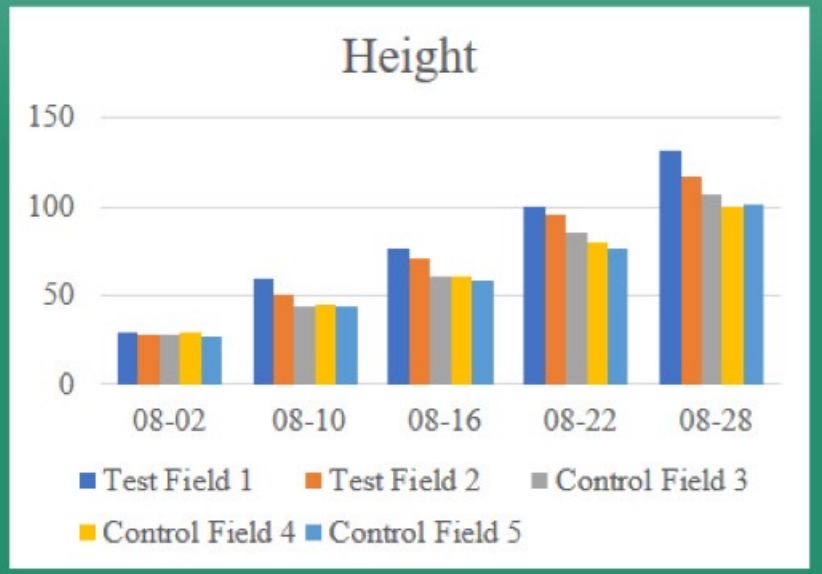
Issues

1. Irrigation with mineralized water leads to salinization
2. Channel leakage raises the water table, resulting in saline soil zones

Strategy

1. Set up irrigation and drainage system, control the water table
2. Remold soil structure and apply water saving drip irrigation complex

Case 1: Xinjiang Hetian reclaimed saline-alkali arid land



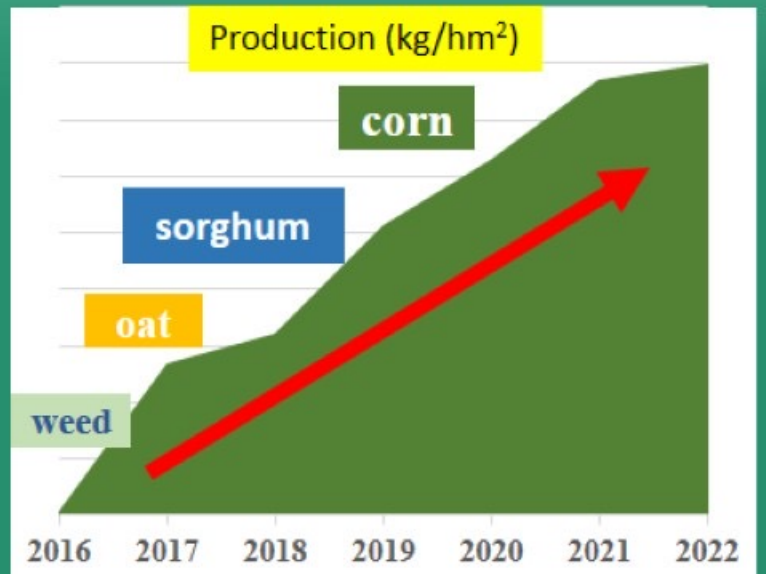
By ***fertigation*** of novel water-soluble amendment, the biomass and fresh weight of stored corn increased by 60%

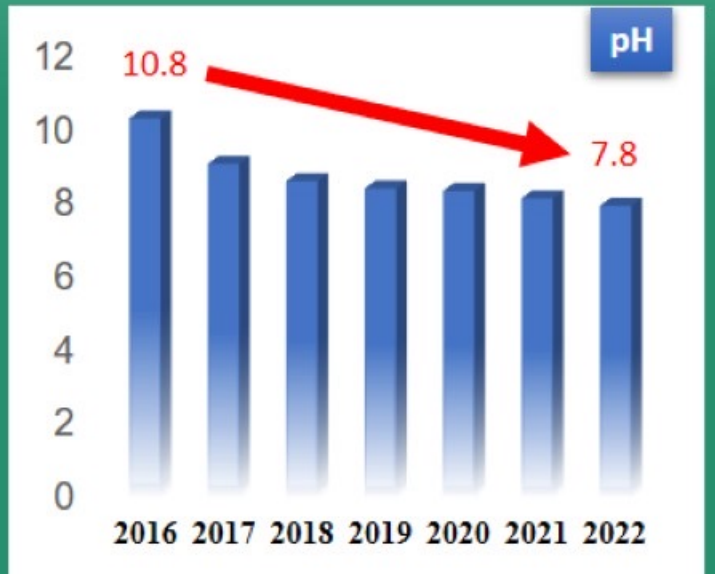
Case 2: Xinjiang Bayinguoleng reclaimed saline-alkali arid land

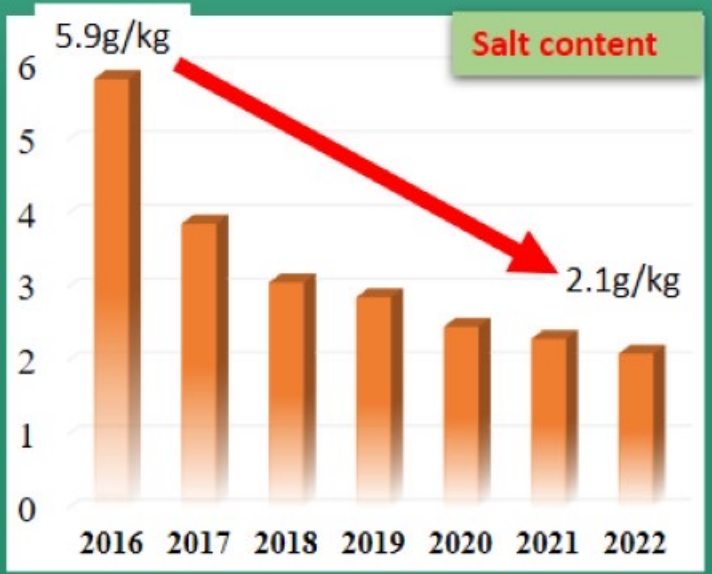
By ***fertigation*** of novel water-soluble amendment, the biomass and fresh weight of stored corn increased by 32%

Case 3: The saline-alkali arid land in Tongliao, Inner Mongolia turned into high-quality grassland via soil restoration

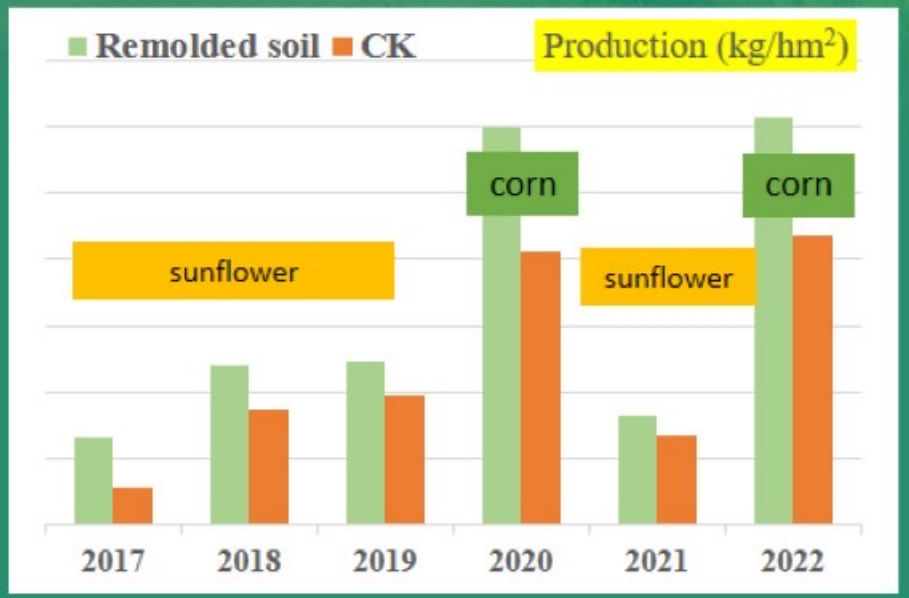
Just a season's reclamation, up to 7 years of stable high yield under natural rain-fed condition

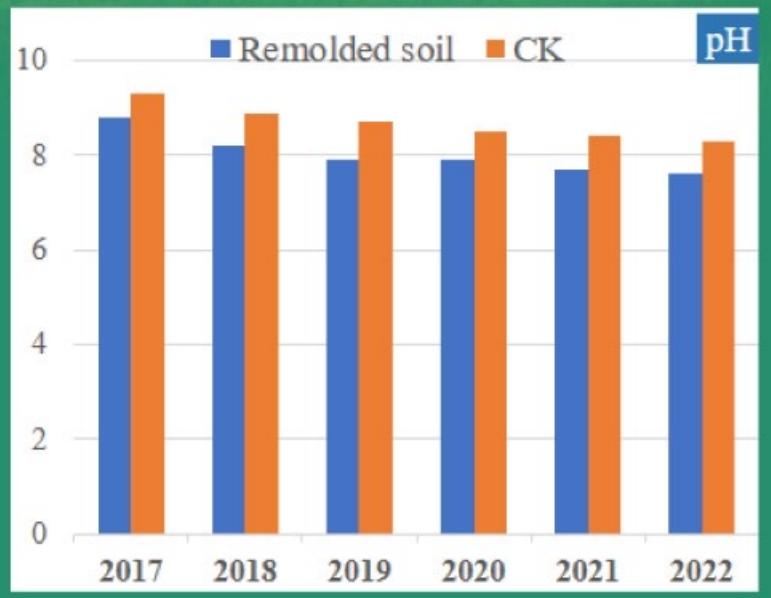


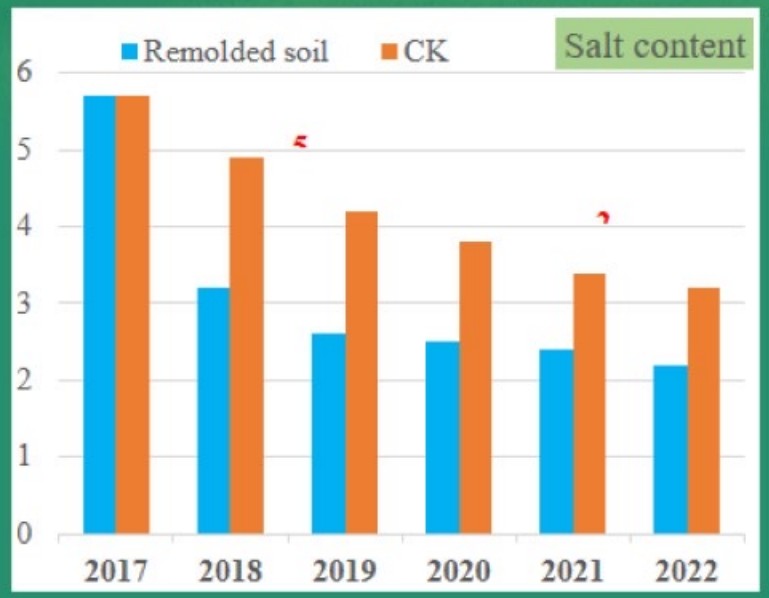




Case 4: Restoration of saline sodic land of irrigated area in Bayannur, with only one season's restoration, up to 7 years of stable high yield







Conclusions

- We have created the systemic technical model of "**remodeling soil structure, efficient desalting, combining dredging and cultivating good farmland**" for restoration of salt-affected soils.
- **(1) A series of new eco-friendly bio-based soil amendments have been developed, which can promote the formation of soil granular structure, increase soil permeability, and greatly improve the infiltration and desalination efficiency.**
- (2) **Adopt the "combination of dredging and blocking" strategy to manage groundwater, prevent brine evapotranspiration, and export regional salt.**
- Reclamation practices on various type of salt affected soils have been carried out over 14 years in massive areas. The results showed that **soil salt and alkali content decreased and soil structure improved year by year. Crops achieved higher quality and yield, and the productivity is increased year by year, and the restoration effect is very stable in all regions without recurrence.**

Food and Agriculture Organization of the United Nations

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GLOBAL SOIL PARTNERSHIP