Soil Science and Agricultural Sustainability, 2026, 1(1), 27-34
https://www.hillpublisher.com/Journals/ssas/
ISSN Online:

Effects of Different Planting Methods on Soil Properties of Salinity in Hetao Irrigation District

Sheng Jin[1], Liming Lai[1,2,*], Chao Zhang[1], Leping Bai[1], Kaijuan Li[1], Jianting Wei[1]

[1]Department of Agronomy, Hetao College, Bayannur 015000, Inner Mongolia, China.
[2]Academician and Expert Workstation, Hetao College, Bayannur 015000, Inner Mongolia, China.

How to cite this paper: Sheng Jin, Liming Lai, Chao Zhang, Leping Bai, Kaijuan Li, Jianting Wei. (2026). Effects of Different Planting Methods on Soil Properties of Salinity in Hetao Irrigation District. *Soil Science and Agricultural Sustainability*, 1(1), 27-34.
DOI: 10.26855/ssas.2026.06.005

Received: January 22, 2026
Accepted: February 16, 2026
Published: March 23, 2026

[*]**Corresponding author:** Liming Lai, Department of Agronomy, Hetao College, Bayannur 015000, Inner Mongolia, China; Academician and Expert Workstation, Hetao College, Bayannur 015000, Inner Mongolia, China.

Abstract

This study selected two lands with different cultivating methods (Corn-Sunflower Rotation (CS) and Sunflower continuous crop (SS)) in the HID. Results showed that the soil pH and exchange sodium percentage (ESP) had an increasing trend over time under the SS land, and total water-soluble salts had a decreasing trend over time. Under the CS land, the soil pH, ESP, and total water-soluble salts decreased with time; The changes in soil salinity and pH and ESP over time under the CS land were more stable than those under the SS land. These findings indicated that the overall soil salt content in the HID gradually decreased with time, and the soil pH and ESP increased with time under the SS land. Soil pH and ESP decreased with time under the CS land.

Keywords

Saline-alkali property; Different cultivating method; Temporal trend; Hetao Irrigation District

The Hetao Irrigation District in Inner Mongolia is one of the three major irrigation districts in China. It is located in the upper reaches of the Yellow River Basin and has unique agricultural advantages. It is one of the most important grain production areas in China. The Hetao Irrigation District has 10.2 million mu of cultivated land (Lai, Meili, & Yang, 2022), of which 4.84 million mu are saline-alkali land of varying degrees. Due to the severe mineralization of the deep parent material in the Hetao area, the area is located in an inland rift basin with a low elevation. Long-term flood irrigation and drainage systems are not well matched, which has led to the rise of groundwater level. At the same time, it is located in a cold and arid area with little rainfall. Evaporation is greater than rainfall, which leads to the rise of groundwater and interannual periodic secondary soil salinization (Yang et al., 2016; Sang, 1996; Wei, Atengge, & Zhai, 2001). Therefore, salinization is the main reason for restricting crop production in the Hetao Irrigation District (Li et al., 2021; Yang, 2008). How to reduce soil salinity and saline-alkali land area is of great significance to the agricultural development of the Hetao Irrigation District.

Many studies have reported on the research results of saline-alkali land in the Hetao Irrigation District. The first is the results on the methods of improving saline-alkali soil. From 1991 to 2014, the saline-alkali land in the Hetao Irrigation District showed an overall shrinking trend (Yu et al., 2010; Guo et al., 2016). Different improvement measures were proposed based on different types of saline-alkali soil. Humic acid, organic fertilizer, desulfurized gypsum and other agents were applied to the saline-alkali soil conditioner in the Hetao Irrigation District, which can effectively reduce the salinity of the soil (Yan et al., 2021). Different planting patterns, such as crop rotation and turning in legume green manure, can reduce soil pH, EC and total salt content (Guo et al., 2018). The use of underground drainage technology to control the depth of groundwater can prevent secondary salinization (Dou et al., 2021; Yuan et al., 2011; Han et al., 2012; Chen et al., 2020). The second is the basic research results on saline-alkali land.

Note: The article was originally published in *Journal of Agriculture and Food Science*, and this is an authorized translation of it.

In the Hetao Irrigation District of Inner Mongolia, severe surface salt accumulation occurs in heavily saline soils during freezing and thawing, while moderate and mild soils show a slightly smaller increase in salt content (Li et al., 2007). Evaporation, irrigation water, rainfall, evaporation, and soil freezing are the basic causes of soil salinization in the Hetao Irrigation District (Kang, 1982). Irrigation water washes away soil salts to reduce soil salinity, following the rule of "salt comes with water and salt goes with water" (Dou et al., 2021; Yuan et al., 2011; Han et al., 2012; Chen et al., 2020). However, there is very little research on the specific characteristics of soil salinity changes over time.

Therefore, this study addresses the above-mentioned issues by combining different planting methods in the Hetao Irrigation District of Inner Mongolia to investigate the impact of different planting methods on the changes in soil salinity and alkalinity over time. This research aims to explore the changes in soil pH, alkalinity, and total water-soluble salts in the Hetao Irrigation District over time, providing theoretical guidance for soil improvement in the Hetao Irrigation District.

1. Materials and Methods

1.1 Experimental Zone Selection and Overview

The experimental soil was taken from cultivated soils of different planting methods, namely corn-sunflower rotation (CS) and sunflower continuous cropping (SS), in Machangdi Village, Shuanghe Town, Hetao Irrigation District, Inner Mongolia. (CS: 40°43'23.65" N, 107°28'36.67" E; SS: 40°43'33.73" N, 107°28'53.68" E, altitude 1001 m). Both experimental fields were reclaimed land. CS has been planted for 33 years and covers an area of 0.22 hectares. SS has been planted for 8 years and covers an area of 0.67 hectares. The experimental fields belong to the mid-temperate continental climate zone. The average temperature from 1982 to 2021 was 9.37℃ and the average annual precipitation was 143.94 mm. The irrigation method was irrigation from the Yellow River. The soil in the experimental site was irrigated soil. In the CS soil, the proportion of clay was 46.5%, silt was 45.7%, and sand was 7.8%. In the SS soil, the proportion of clay was 33.52%, silt was 54.64%, and sand was 11.84%.

1.2 Soil Sample Collection and Testing

This experiment used a random sampling method (Li & Fan, 2020) to collect soil samples over two years, on June 11, August 6, and October 7, 2019; and on June 8, August 7, and October 8, 2020. Four soil samples were collected from each experimental plot, and each sample was a mixture of four sub-samples. Two sub-samples were collected at 20 cm from the crop roots (without mulch), and two sub-samples were collected in the middle of the mulched area (the experimental field was partially mulched). The sampling depths were 0–20 cm and 20–40 cm, respectively. A total of 96 topsoil samples were collected over the two years.

Soil pH was measured using a pH meter (soil-to-water ratio of 2.5:1) (Ministry of Agriculture of the People's Republic of China, 2007). Cation exchange capacity was determined using the ammonium chloride-ammonium acetate exchange method (F-HZ-DZ-TR-0030) (Forest Soil Research Laboratory, Institute of Forestry, Chinese Academy of Forestry, 1999). Exchangeable sodium was determined using atomic emission spectrometry (F-HZ-DZ-TR-0035) (Sun & Liu, 1999; Lu, 1999). Soil alkalinity was calculated as the ratio of exchangeable sodium to cation exchange capacity × 100%. Soil water-soluble total salts were determined using the laboratory gravimetric method.

1.3 Statistical Analysis

The experimental data were organized using Microsoft Excel 2019 and subjected to one-way ANOVA with a significance level set at $\alpha=0.05$.

2. Result

2.1 pH changes over time under different planting methods

Trends in soil pH over time under different planting methods

Under the maize-sunflower rotation system, the pH values in the 0–20 cm and 20–40 cm soil layers showed an overall decreasing trend over time between 2019 and 2020. Under the sunflower continuous cropping system, the pH values in the 0–20 cm and 20－40 cm soil layers showed an overall increasing trend over time between 2019 and

2020. The pH values in the 0–20 cm and 20 – 40 cm soil layers were generally higher in the sunflower continuous cropping system than in the maize-sunflower rotation system (see Figure 1).

Comparison of the difference in soil pH value over time in the 0-20 cm and 20-40 cm soil layers under different planting methods

In the 0–20 cm and 20–40 cm soil layers, there were no significant changes in soil pH values for maize-sunflower rotation during June, August, and October 2019 and June, August, and October 2020 (P > 0.05) (see Table 1) .

2.2 Changes in alkalinity over time under different tillage methods

(1) Trends in soil alkalinity over time under different farming practices

Under the maize-sunflower rotation system, the soil alkalinity in the 0 – 20 cm and 20 – 40 cm soil layers showed an overall decreasing trend over time between 2019 and 2020. Under the sunflower continuous cropping system, the soil alkalinity in the 0 – 20 cm and 20 – 40 cm soil layers showed an overall increasing trend over time between 2019 and 2020. The soil alkalinity in the sunflower continuous cropping system was significantly higher than that in the maize-sunflower rotation system in the 0–20 cm and 20–40 cm soil layers (see Figure 2).

Comparison of the difference in soil alkalinity over time in the 0-20 cm and 20-40 cm soil layers under different planting methods

In fields with continuous sunflower cropping, the alkalinity of the soil layers (0–20 cm and 20–40 cm) generally showed an increasing trend, with the increasing trend in the 0–20 cm layer being less pronounced than that in the 20–40 cm layer. In fields with corn-sunflower rotation, the alkalinity of the soil layers (0–20 cm and 20–40 cm) generally showed a decreasing trend, with the decreasing trend in the 0–20 cm layer being greater than that in the 20–40 cm layer. Under continuous sunflower cropping, the alkalinity in the 20–40 cm layer was higher than that in the 0–20 cm layer, while under corn-sunflower rotation, the alkalinity in the 0–20 cm layer was higher than that in the 20–40 cm layer.

2.3 Changes in total water-soluble salts over time under different farming practices

(1) Trends in total water-soluble salt content in soil over time under different farming practices

Under different planting methods, namely maize-sunflower rotation and continuous sunflower field cropping, the total water-soluble salt content in the 0–20 cm and 20–40 cm soil layers generally showed a decreasing trend over time between 2019 and 2020. The total water-soluble salt content in the soil of continuous sunflower field cropping was significantly higher than that of maize-sunflower rotation in the 0–20 cm and 20–40 cm soil layers. (See Figure 3)

Comparison of the differences in total water-soluble salt content in soil layers 0 – 20 cm and 20 – 40 cm under different planting methods over time

In the 0–20 cm and 20–40 cm soil layers, there were no significant differences in the total water-soluble salt content of the soil during the maize-sunflower rotation in June, August, and October 2019 and June, August, and October 2020 (P > 0.05). (See Table 3)

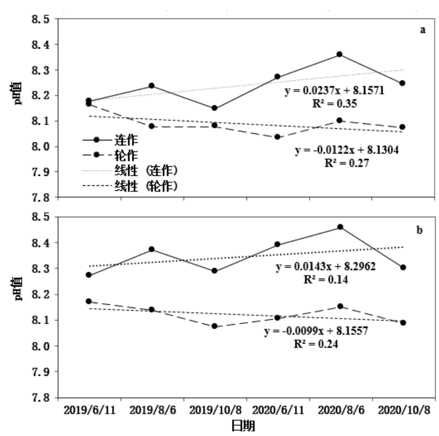

Figure 1. pH value variation over time at different planting depths (0–20 cm (a) and 20–40 cm (b)) in Shuanghe Town, Hetao Irrigation District (2019-2020).

Table 1. Comparison of soil pH differences at different time points under different planting methods in the 0–20 cm and 20–40 cm soil layers of the Hetao Irrigation District

deal with	pH value					
	2019			2020		
	8/6-6/11	10/7-8/6	10/7-6/11	August 7 - June 8	10/8-8/7	10/8-6/8
				0～20 cm		
Difference						
Sunflower continuous cropping	-0.06 [a]	0.09 [a]	0.03 [a]	-0.09 [a]	0.05 [a]	0.03 [a]
Corn-sunflower rotation	0.09 [a]	0.01 [a]	0.09 [a]	-0.08 [a]	0.04 [a]	-0.04 [a]
				Analysis of variance ($P > F$)		
	0.08	0.42	0.73	0.93	0.75	0.08
				20–40 cm		
Difference						
Sunflower continuous cropping	-0.10 [a]	0.08 [a]	-0.02 [a]	-0.06 [a]	0.06 [a]	0.01 [a]
Corn-sunflower rotation	0.03 [a]	0.07 [a]	0.10 [a]	-0.04 [a]	0.06 [a]	0.02 [a]
				Analysis of variance ($P > F$)		
	0.1	0.85	0.18	0.67	0.99	0.73

Note: Different lowercase letters in the table indicate that the soil pH difference at different time points under the same planting method in the same layer has significant differences (α=0.05).

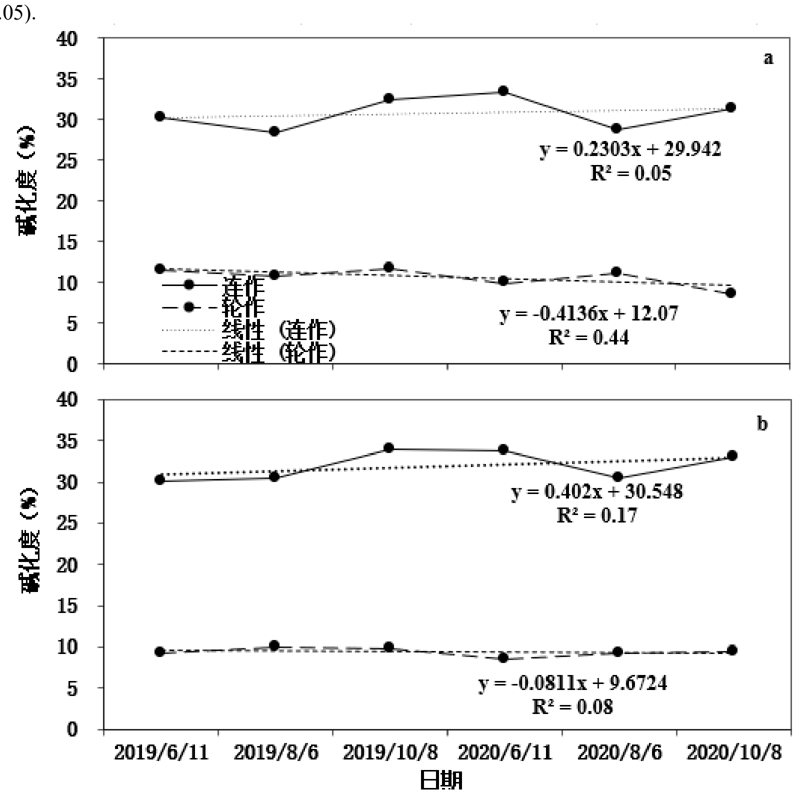

Figure 2. Changes in alkalinity over time at different planting depths (0–20 cm (a) and 20–40 cm (b)) in Shuanghe Town, Hetao Irrigation District (2019 − 2020) under different planting methods.

Table 2. Comparison of soil alkalinity changes over time in the 0 – 20 cm and 20 – 40 cm soil layers under different planting methods in the Hetao Irrigation District.

deal with	alkalinity					
	2019			2020		
	8/6-6/11	10/7-8/6	10/7-6/11	8/7-6/8	10/8-8/7	10/8-6/8
	%					
	0 ~ 20 cm					
Difference						
Sunflower continuous cropping	1.79 [a]	-4.02 [a]	-2.24 [a]	3.09 [a]	-2.68 [b]	1.99 [a]
Corn - sunflower rotation	0.68 [a]	-0.97 [a]	-0.28 [a]	-1.28 [b]	2.61 [a]	1.32 [a]
	Analysis of variance ($P > F$)					
	0.52	0.45	0.48	0.01	0.03	0.71
	20-40 cm					
Difference						
Sunflower continuous cropping	-0.33 [a]	-3.57 [a]	-3.90 [a]	3.36 [a]	-2.63 [b]	0.74 [a]
Corn - sunflower rotation	-0.65 [a]	-2.39 [a]	-5.21 [a]	-0.72 [b]	-0.23 [a]	-0.95 [a]
	Analysis of variance ($P > F$)					
	0.93	0.76	0.74	0.02	0.04	0.12

Note: Different lowercase letters in the table indicate that the difference in soil alkalinity at different time points under the same planting method in the same layer is significant (α =0.05).

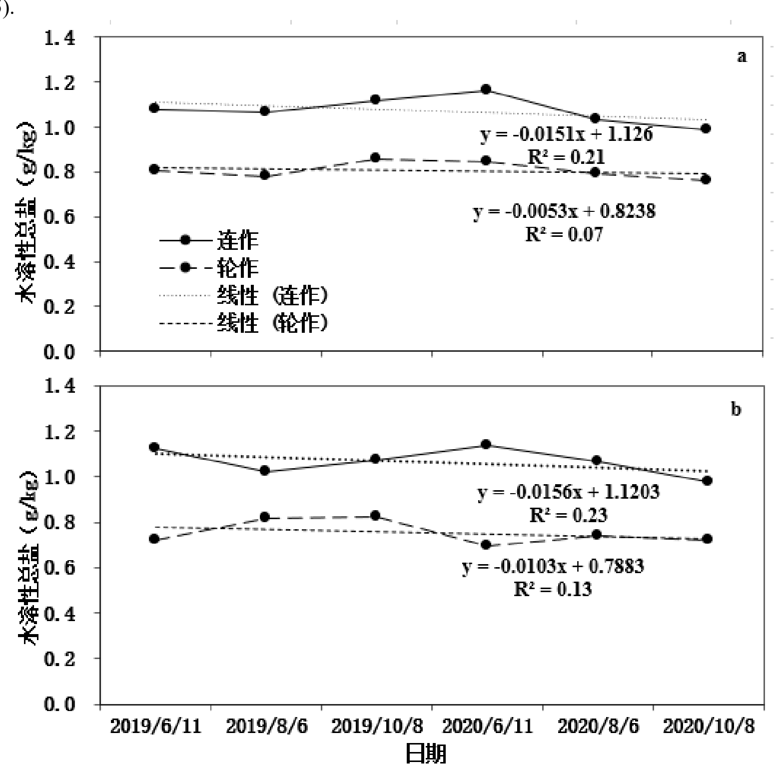

Figure 3. Trends of total water-soluble salt content over time at different planting depths (0–20 cm (a) and 20–40 cm (b)) in the Shuanghe Town experimental site of the Hetao Irrigation District (2019–2020) under different planting methods.

Table 3. Comparison of changes in total water-soluble salt content in soil layers 0–20 cm and 20–40 cm under different planting methods in the Hetao Irrigation District over time

deal with	Water-soluble total salts					
	2019			2020		
	8/6-6/11	10/7-8/6	10/7-6/11	8/7-6/8	10/8-8/7	10/8-6/8
	g/kg					
	0 ~ 20 cm					
Difference						
Sunflower continuous cropping	-0.03 [a]	-0.05 [a]	-0.07 [a]	0.13 [a]	0.04 [a]	0.18 [a]
Corn - sunflower rotation	0.03 [a]	-0.08 [a]	-0.05 [a]	0.15 [a]	-0.24 [a]	0.32 [a]
	Analysis of variance ($P > F$)					
	0.7	0.72	0.91	0.95	0.11	0.46
	20-40 cm					
Difference						
Sunflower continuous cropping	0.39 [a]	-0.10 [a]	0.05 [a]	0.07 [a]	0.09 [a]	0.16 [a]
Corn - sunflower rotation	-0.10 [a]	-0.01 [a]	-0.10 [a]	-0.05 [a]	0.02 [a]	-0.02 [a]
	Analysis of variance ($P > F$)					
	0.07	0.39	0.09	0.21	0.49	0.15

Note: Different lowercase letters in the table indicate that the difference in total water-soluble salt content in the soil at different time points under the same planting method in the same layer is significant (α=0.05).

3. Discussion

3.1 Analysis of the trend of soil salinity and alkalinity over time

The soil pH value changes over time under different planting methods in the Hetao Irrigation District. Under the corn-sunflower rotation planting method, the soil salinity and alkalinity of the Hetao Irrigation District generally show a downward trend over time. Under the sunflower continuous planting method, the soil salinity of the Hetao Irrigation District generally shows a downward trend, while the pH value and alkalinity show an upward trend. The soil pH value and alkalinity increase under the sunflower continuous planting method because the continuous planting of sunflowers causes the soil microorganisms to develop into fungi. The continuous planting of sunflowers will also spread sunflower parasitic weeds such as broomrape, which absorb the soil fertility and reduce the soil fertility (Wang, 1987). The decrease in nutrients reduces the number of soil microorganisms, thereby affecting the transformation of ion availability in the soil, increasing the water-soluble base ions in the soil, and the soil alkalinity also increases accordingly. Corn has lower salt tolerance than sunflower (Geilfus, Zörb, & Mühling, 2010). Under salt stress, sunflowers can absorb and utilize some of the salt in the soil and accumulate it in the sunflower stems (Marcum, 1999). Two years of sunflower planting leads to a downward trend in soil salinity. The corn-sunflower rotation planting method can effectively preserve soil nutrient balance and nutrient activity, and promote the reduction of soil salinity.

The Hetao region has soil parent material with high salt content, groundwater mineralization is serious, and the Hetao irrigation area has a large evaporation rate during drought, and the salt content increases with the evaporation of groundwater (Yang et al., 2016; Sang, 1996). Therefore, with the increase of temperature, the soil salt content under different planting methods increased to varying degrees between August and October. As time changes, the salt in the 20-40 cm layer evaporates upward, so the salt-alkali change in the 20-40 cm layer is larger than that in the 0-20 cm layer, which is consistent with the results of previous studies (Li et al., 2019; Zhou et al., 2021). As time changes, the salt evaporates upward, resulting in the total water-soluble salt content in the 0-20 cm layer being greater than that in the 20-40 cm soil layer, which is consistent with previous studies (Yan, 2020) and shows a surface accumulation type.

3.2 Comparative Analysis of Differences in Soil Salinity and Alkalinity Parameters at Different Time Points

The difference in soil alkalinity between June and August 2020 in the 0-20 cm and 20-40 cm soil layers of sunflower continuous cropping was significantly higher than that in maize-sunflower rotation ($P>0.05$) (Table 2). This indicates that the difference in soil alkalinity between June and August in sunflower continuous cropping fields is relatively large because the soil salinity in sunflower continuous cropping fields is high. Under salt stress, the absorption of Na and Fe elements by the stems and leaves of sunflowers is enhanced (Tong, Chen, & Wen, 2014), which affects the change in the amount of exchangeable Na in the soil and thus significantly reduces the alkalinity (Figure 2).

The difference in soil alkalinity between August and October 2020 in the 0–20 cm and 20–40 cm soil layers of the corn-sunflower rotation was significantly higher than that in the sunflower continuous cropping ($P > 0.05$) (Table 2). This indicates that the large difference in soil alkalinity between August and October in the corn-sunflower rotation fields is due to the infiltration of salt and alkalinity from the 0–20 cm soil layer during the multiple large-scale irrigations from August to October, with the alkalinity content increasing in the 20 – 40 cm layer (Figure 2). At the 20–40 cm layer, sunflowers absorb some of the salt (Figure 3).

4. Conclusion

This experiment shows that in the Hetao Irrigation District, under the continuous sunflower cropping system, soil pH and alkalinity both increased over time, while total water-soluble salt content decreased over time. Under the corn-sunflower rotation system, soil pH, alkalinity, and total water-soluble salt all decreased over time. The soil salinity and alkalinity characteristics under the corn-sunflower rotation system in the Hetao Irrigation District showed a more stable decreasing trend over time compared to continuous sunflower cropping.

References

Chen, M. Y., Huang, J. S., Zeng, W. Z., et al. (2020). Water and salt transport patterns under geotextile-covered concealed pipe salt drainage conditions. *Transactions of the Chinese Society of Agricultural Engineering*, *36*(2), 130-139.

Dou, X., Shi, H. B., Li, R. P., et al. (2020). Evaluation of the effectiveness of subsurface drainage in controlling salt concentration and leaching salt in saline irrigation areas. *Journal of Irrigation and Drainage*, *39*(8), 102-110.

Forest Soil Research Laboratory, Institute of Forestry, Chinese Academy of Forestry. (1999). Determination of Cation Exchange Capacity in Forest Soils (Forestry Industry Standard).

Forestry Industry Standard. (1999). Calculation of Soil Alkalinity.

Geilfus, C. M., Zörb, C., & Mühling, K. (2010). Salt stress differentially affects growth-mediating β-expansins in resistant and sensitive maize (Zea mays L.). *Plant Physiology & Biochemistry*, *48*(12), 993-998.

Guo, S. S., Ruan, B. Q., Guan, X. Y., et al. (2016). Spatiotemporal evolution and driving factors of salinization in the Hetao Irrigation Area of Inner Mongolia over the past 30 years. *China Rural Water Resources and Hydropower*, (9), 159-162, 167.

Guo, Y. D., Cheng, M., Zhao, X. F., et al. (2018). Effects of green manure rotation on soil properties, yield and quality of subsequent silage maize in saline-alkali land. *Chinese Journal of Eco-Agriculture*, *26*(6), 856-864.

Han, L. P., Ma, F. J., Yu, S. H., et al. (2012). Principles and practices of farmland ecological engineering based on buried pipes for the improvement of saline-alkali land in Yundong coastal area. *Chinese Journal of Eco-Agriculture*, *20*(12), 1680-1686.

Jing, Y. P., Zhao, P. Y., Zhao, J., et al. (2022). Application of sesbania-sunflower rotation and methods for improving soil quality in saline-alkali soils (CN114190249A) [Patent].

Kang, S. Y. (1982). Dynamic Analysis of Groundwater in the Irrigation Area of Jiefang Gate, Bayannur League. *Inner Mongolia Water Resources Science and Technology*, (1), 78-97.

Lai, L. M., Meili, & Yang, Y. (2022). Analysis of agricultural soil characteristics and development in the Hetao Irrigation District of Inner Mongolia. *Jiangsu Agricultural Sciences*, *50*(2), 213-218.

Li, J., & Fan, X. Z. (2020). Layout of soil sampling points in agricultural product production environment sampling.

Modern Agricultural Science and Technology, (1), 175, 180.

Li, R. P., Shi, H. B., Chijiang, G. F., et al. (2007). Study on the characteristics of air temperature and soil water and salt transport during freeze-thaw period. *Transactions of the Chinese Society of Agricultural Engineering*, *23*(4), 5.

Li, X. X., Jin, K. P., Cao, J. J., et al. (2019). Research progress on the impact of crop rotation on soil ecology. *Modern Agricultural Science and Technology*, (6), 154-155, 159.

Li, X. Y., Cui, J. Q., Shi, H. B., et al. (2021). Analysis of soil salinization risk and groundwater environment based on indicator Kriging. *Transactions of the Chinese Society for Agricultural Machinery*, *52*(8), 297-306.

Lu, R. K. (1999). Methods for Soil Agricultural Chemical Analysis. Beijing: China Agricultural Science and Technology Press.

Marcum, K. B. (1999). Salinity Tolerance Mechanisms of Grasses in the Subfamily Chloridoideae. *Crop Science*, *39*(4), 1153-1160.

Ministry of Agriculture of the People's Republic of China. (2007). Determination of Soil pH: NY/T 1377-2007. Beijing: China Standards Press.

Sang, Y. L. (1996). Causes and characteristics of alkaline soils in the Hetao Irrigation Area of Inner Mongolia. *Acta Pedologica Sinica*, (4), 398-404.

Soil testing, Part 16: Determination of total water-soluble salts in soil. (2006).

Sun, H. L., & Liu, G. S. (1999). Description of soil physicochemical profiles. Beijing: China Standards Press.

Tong, W. J., Chen, F., & Wen, X. Y. (2014). ICP-AES analysis of mineral element absorption and accumulation in sunflowers in saline-alkali land of Hetao Irrigation District. *Spectroscopy and Spectral Analysis*, (1), 231-234.

Wang, D. S. (1987). To avoid continuous cropping of sunflowers. *New Agriculture*, (2), 17.

Wei, J. M., Atengge, & Zhai, Z. Z. (2001). Comprehensive management of saline-alkali land in the Hetao Irrigation District of Bayannur League. *Inner Mongolia Forestry Science and Technology*, (1), 32-35.

Wheata Gas Company - Farmers, Wheat Sprout Big Data Information (Ningbo) Co., Ltd. (2021). WHEATA Gas Company - Farmers, Wheat Sprout Big Data Information. Retrieved December 22, 2021, from http://www.wheata.cn/

Yan, H., Zhong, S. Z., Wen, X. L., et al. (2021). Effects of different soil conditioners on agronomic traits and yield of sunflower in saline-alkali land. *Journal of Northern Agriculture*, *49*(3), 36-40.

Yan, J. W., Shi, H. B., Li, X. Y., et al. (2020). Water-nitrogen coupling effect of maize in saline soil in Hetao Irrigation District. *Arid Zone Agricultural Research*, *38*(4), 103-110.

Yang, J. S. (2008). The Development History and Prospect of Saline Soil Research in China. *Acta Pedologica Sinica*, (5), 837-845.

Yang, J. S., Yao, R. J., Wang, X. P., et al. (2016). Ecological governance and ecological industry development model of saline-alkali land in Hetao Plain. *Acta Ecologica Sinica*, *36*(22), 7059-7063.

Yu, R., Liu, T., Xu, Y., et al. (2010). Analysis of salinization dynamics by remote sensing in Hetao Irrigation District of North China. *Agricultural Water Management*, *97*(12), 1952-1960.

Yuan, N. N., Huang, J. S., Xie, H., et al. (2011). Study on drainage control and nitrogen loss in cotton fields using underground pipes. *Journal of Irrigation and Drainage*, *30*(1), 103-105, 29.

Zhou, L. Y., Li, R. P., Miao, Q. F., et al. (2021). Analysis of soil salinization and fertility characteristics adjacent to drainage ditches in Hetao Irrigation District, Inner Mongolia. *Arid Zone Research*, *38*(1), 114-122.