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Impacts of Irrigation and Nitrogen Fertilization Rates on Soil Water-stable Aggregates in Hetao I Rrigation District

Fan Zhang[1], Liming Lai[1,2,*], Zhenghan Cui[1], Man Wang[1], Pengju Ji[1]

[1]Department of Agronomy, Hetao College, Bayannur 015000, Inner Mongolia, China.
[2]Research Center of Soil Resource Comprehensive Utilization and Ecological Environment in Western Inner Mongolia, Hetao College, Bayannur 015000, Inner Mongolia, China.

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*__Corresponding author:__ Liming Lai, Department of Agronomy, Hetao College, Bayannur 015000, Inner Mongolia, China; Research Center of Soil Resource Comprehensive Utilization and Ecological Environment in Western Inner Mongolia, Hetao College, Bayannur 015000, Inner Mongolia, China.

Abstract

Soil water-stable aggregate is a key indicator of soil structural integrity. However, little is known about the impacts of irrigation and nitrogen fertilization rates on it in the Hetao Irrigation District. In this study, a split plot experimental design with two factors (irrigation and nitrogen fertilization rate) and three replicates was built on the sunflower land in the Hetao Irrigation District. Main treatment was the irrigation rate, which includes three levels: I1, I2, and I3 (5110, 4050, and 2985 m^3/ha). The sub-treatment was the nitrogen fertilization rate, which has four levels: N1, N2, N3, and N0 (750, 600, 450, and 0 kg/ha). The results indicated that applying nitrogen fertilizer could increase the soil electrical conductivity value of the 0~30 cm soil layer. The application of nitrogen fertilizer could maximize the content of water-stable aggregates at the N2. The interaction between irrigation rate and nitrogen fertilization rate had a significant influence on soil electrical conductivity and soil water-stable aggregate. Under a high irrigation rate, nitrogen fertilization rate significantly increased soil water-stable aggregate. At a medium irrigation rate, the content of water-stable aggregates in soil with medium nitrogen fertilization rate was the highest.

Keywords

Irrigation rate; Nitrogen fertilization rate; Soil water-stable aggregate; pH; Soil electrical conductivity; Hetao Irrigation District

The Hetao Irrigation District is located in Bayannur City, western Inner Mongolia Autonomous Region. It extends north to the Langshan and Wula Mountains of the Yinshan Mountains, south to the Yellow River, east to Baotou, and west to the Ulan Buh Desert. The Hetao Irrigation District has a temperate continental climate, characterized by cold, snowless winters and hot, dry summers, making it a cold and arid region. Therefore, soil irrigation is essential for agriculture. Irrigation in the Hetao Irrigation District of Inner Mongolia has a long history, with irrigation from the Yellow River being the key method for agricultural production. The amount of irrigation water is crucial for increasing agricultural yields. Due to widespread soil salinization, annual irrigation to leach salt is necessary to ensure seedling emergence. Previous irrigation efforts were excessive, resulting in the leaching of large amounts of soil nutrients. Long-term application of large amounts of nitrogen fertilizer has led to the significant leaching of nitrate nitrogen from the soil, causing serious pollution of groundwater and increasing emissions of the greenhouse gas nitrous oxide. Water-stable aggregates are the foundation of soil fertility. Due to the high salt content and high pH of

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saline-alkali soil, soil particle aggregation is weak. Water-stable aggregates are not only few in number, but also mostly small (Sahin & Kiziloglu, 2008), which is not conducive to the formation of well-developed capillary pores. On the one hand, it will cause salt to accumulate on the surface, and on the other hand, it will inhibit salt leaching (Daliakopoulos et al., 2016). Obviously, strengthening soil particle aggregation and increasing the number of large aggregates is the key to improving saline-alkali soil (Franzluebbers, Wright, & Stuedemann, 2000). Therefore, exploring the water-stable aggregates of soil in this region is of great significance for improving the soil fertility of cultivated land in the Hetao Irrigation Area of Inner Mongolia.

Therefore, the purpose of this study is to evaluate the effects of irrigation and nitrogen application on soil pH, electrical conductivity, and water-stable aggregates in the Hetao Irrigation District, so as to provide a theoretical basis for irrigation and fertilization in crop production, improving soil quality, and maintaining sustainable soil development.

1. Materials and Methods

1.1 Overview of the Study Area

The experimental site is located in Shuanghe Town, Linhe District, Bayannur City, Inner Mongolia (latitude and longitude: 40°43′23.65″N, 107°28′53.68″E; altitude: 1050 m), situated in the middle reaches of the Hetao Irrigation District. From 1986 to 2023, the average daily maximum temperature was 15℃ and the average daily minimum temperature was 2.02℃. In 2023, the average daily maximum temperature was 17.9℃ and the average daily minimum temperature was 1.84℃. The average annual precipitation from 1986 to 2023 was 143.94 mm, and the average annual precipitation in 2023 was 290 mm. The soil type in the experimental field is alluvial soil, with clay accounting for 37.13% of the 0-40 cm soil layer, silt accounting for 44.69%, and sand accounting for 18.18%. The pH was 8.23, the salt content was 1.32 g/kg, the organic matter content was 10.08 g/kg, the cation exchange capacity was 10.72 cmol(+)/kg, the total nitrogen was 0.66 g/kg, the nitrate nitrogen content was 4.18 mg/kg, the available potassium content was 144.96 mg/kg, the available phosphorus content was 15.75 mg/kg, the alkalinity was 21.33%, and the sodium ion exchange capacity was 2.04 cmol(+)/kg (Gao, 2022).

1.2 Experimental Design

The experiment was designed as a two-factor split-plot field experiment with three replicates. The tested crop was sunflower (SH363). The main treatment was irrigation amount, with Yellow River water as the irrigation source. It included three levels: 5110, 4050, and 2985 m^3 / hm^2. The actual average irrigation amount for salt leaching in the Hetao Irrigation District was 4050 m^3 / hm^2. The recommended ideal irrigation amount was 2985 m^3 / hm^2, approximately 26% lower than the actual irrigation amount of 4050 m^3/hm^2. 5100 m^3 / hm^2 was 26 % higher than the actual average irrigation amount. The subtreatment was nitrogen application rate, with four levels: 750, 600, 450, and 0 kg/hm^2 (no fertilizer application, serving as a control). 600 kg/hm^2 was the local average nitrogen application rate. There are 36 plots in total (each plot is 9×9 m2, with a seedling density of 23,800 plants/hm2 and a row spacing of 60 cm×70 cm). To eliminate lateral movement of water and fertilizer between plots, 0.5 to 1 m high earthen ridges are set up between plots and separated by plastic film.

The fertilizers used were urea (46% N), potassium sulfate (40% K_2O), and superphosphate (46% P_2O_5). Phosphate fertilizer (300 kg/hm^2) and potash fertilizer (75 kg/hm^2) were applied as base fertilizer in a single application, following the farmers' actual fertilization methods. Nitrogen fertilizer was applied as top dressing at the experimental design rates of 750, 600, 450, and 0 kg/hm^2, applied when the sunflowers reached approximately 20 cm in height. Other aspects of sunflower production management were carried out according to the actual producers' practices.

1.3 Soil Sample Collection and Laboratory Testing

The initial soil samples were collected in October 2020 in Shuanghe Town, Linhe District, Bayannur City, Inner Mongolia Autonomous Region, serving as the initial soil data for this study. On October 14, 2023, topsoil was collected using a shovel at the same location as the initial soil samples, ideally when the soil did not stick to the shovel and did not deform upon contact. Representative undisturbed soil samples were collected from multiple points in the field, removing any deformed portions that came into contact with the shovel surface. The sample size was 1.5-2.0 kg. The samples were placed in tin or aluminum containers to preserve the soil's structure. Collection was conducted within three weeks after the autumn harvest. Soil samples were collected at a depth of 0-30 cm. Following a randomized, multi-point pooling principle, two sampling points were collected from each plot, resulting in a total of 36 soil samples (plots × depth × year) = 36 samples.

The collected samples were transported back to the laboratory and gently peeled along the natural structure of the soil to break the original soil into small soil clods with a diameter of less than 1 cm. At the same time, the soil was prevented from deforming due to external forces, and coarse roots and small stones were removed. The soil sample was spread out and placed in a well-ventilated place to air dry naturally before the experiment was conducted. The improved Yoder method (Elliott, 1986) was used to determine the water-stable aggregates of the soil sample in the laboratory (soil aggregate structure analyzer model: TPF-100). 500 g of air-dried soil sample was weighed. The sieves with apertures of 5 mm, 3 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm were stacked in sequence, with the larger aperture on top. The weighed soil sample was poured into the sieves and dry sieved. After sieving, the aggregates of each level were weighed and the percentage content of each level of aggregates was calculated. The sample was weighed according to the dry sieve percentage ratio and prepared into 50 g for wet sieve use. Place another set of sieves on the shaking rack of the aggregate analyzer, put it in a container, and place the weighed sample on the sieves. Add water to the upper edge of the top sieve. Shake the sample at 30 times/min for 3 minutes and shake for 8 minutes. Then slowly remove the shaking rack to lift the sieves out of the water. After the water has drained, gently rinse the water-stable aggregates on the sieves into a petri dish. The percentage content of a certain order of water-stable aggregates is:

$$\text{某级团聚体百分数} = \frac{\text{该级团聚体的烘干重}}{\text{烘干土样重}} \times 100\%$$

$$\text{总团聚体百分数} = \text{各级团聚体的和}$$

After the soil sample was crushed, it was used with 2 After sieving through a mm sieve, the soil pH and electrical conductivity were analyzed in the laboratory. All testing methods used in this study were nationally standardized methods: HJ 962-2018 " Determination of Soil pH by Potentiometric Method ", with a pH instrument model of [model number missing]; and HJ 802-2016 " Determination of Soil Electrical Conductivity by Electrode Method", with a conductivity instrument model of DDS-307A.

1.4 Statistical Analysis

The PROC GLIMMIX method (mixed model method) in SAS 9.4 statistical software was used to compare the differences in soil pH, electrical conductivity and water-stable aggregates under different irrigation and nitrogen application treatments. The significance level was set at α=0.05.

2. Results and Analysis

2.1 Soil pH

The results of soil pH values in the 0–30 cm depth under different irrigation amounts (I1, I2, I3) and nitrogen application amounts (N0, N1, N2, N3) are shown in Table 1 and Figure 1. In 2023, there were no significant differences in the average soil pH values and their comparisons in the experimental fields at a depth of 0–30 cm in the Hetao Irrigation District under different irrigation amounts and nitrogen application amounts. Soil pH values tended to decrease with increasing irrigation amount; overall, soil pH values also tended to decrease with increasing nitrogen application amount.

At a depth of 0–30 cm, the mean soil pH values under different irrigation amounts, in ascending order, were: I1 (8.11) < I2 (8.225) < I3 (8.230); the mean soil pH values under different nitrogen application amounts, in ascending order, were: N0 (8.01) < N2 (8.15) < N1 (8.21) < N3 (8.38) (Table 1 and Figure 1). The p-value of the F-test corresponding to the interaction term (I×N) between irrigation amount and nitrogen application amount was >0.05 (Table 1), indicating that this interaction term has no significant effect on soil pH.

2.2 Soil electrical conductivity

Significant differences were observed in soil electrical conductivity at depths of 0–30 cm under different irrigation amounts (I1, I2, I3) and nitrogen application rates (N0, N1, N2, N3) (Table 1 and Figure 2). However, soil electrical conductivity tended to decrease with increasing irrigation amount and increase with increasing nitrogen application rate. At depths of 0–30 cm, the average soil electrical conductivity at different irrigation amounts, from smallest to largest, was: I2 (0.95 ms/cm) < I1 (1.04 ms/cm) < I3 (1.18 ms/cm); the average soil electrical conductivity at different nitrogen application rates, from smallest to largest, was: N2 (0.73 ms/cm) < N3 (0.95 ms/cm) < N1 (1.26 ms/cm) < N0 (1.29 ms/cm). The interaction term between irrigation amount and nitrogen application rate (I × N) significantly affected soil electrical conductivity (Table 2). In the 0–30 cm soil layer, under high irrigation (I ₁) and high nitrogen application (N₁), the soil electrical conductivity was 0.71 % . The soil electrical conductivity under high nitrogen application (N1) was significantly lower than that under no nitrogen application (N0) (1.39 ms / cm). Under medium irrigation (I2), the soil electrical conductivity under high nitrogen application (N1) (1.69 ms/cm) was significantly higher than that under medium nitrogen application (N2), low nitrogen application (N3), and no nitrogen application (N0) (0.53 ms/cm, 0.76 ms/cm, 0.80 ms/cm, respectively).

Under low irrigation (I ₃), the soil electrical conductivity at no nitrogen application (N₀) (1.68 ms/cm) was significantly higher than that at low nitrogen application (N₃) (0.80 ms/cm). In the 0–30 cm soil layer, under high nitrogen application (N1) and high irrigation (I1) conditions, the soil electrical conductivity (0.71 ms/cm) was significantly lower than that under medium irrigation (I2) conditions (1.69 ms/cm).

Under low nitrogen application (N3), the soil electrical conductivity under low irrigation (I3) (0.81 ms/cm) was significantly lower than that under high irrigation (I1) (1.28 ms/cm). Under no nitrogen application (N0), the soil electrical conductivity under medium irrigation (0.80 ms/cm) was significantly lower than that under high irrigation (I1) and low irrigation (I3) (1.39 ms/cm, 1.68 ms/cm, respectively) (Table 2).

2.3 Soil water-stable aggregates

Significant differences were observed in the soil water-stable aggregate content at depths of 0–30 cm under different irrigation amounts (I1, I2, I3) and nitrogen application amounts (N0, N1, N2, N3) (Table 1 and Figure 3). However, the content of soil water-stable aggregates tended to decrease with increasing irrigation amount; similarly, the content of soil water-stable aggregates tended to decrease with increasing nitrogen application amount. At depths of 0–30 cm, the average content of soil water-stable aggregates under different irrigation amounts, from smallest to largest, was: I1 (13.13%) < I3 (13.39%) < I2 (13.78%); the average content of soil water-stable aggregates under different nitrogen application amounts, from smallest to largest, was: N1 (12.97%) < N3 (13.28%) < N0 (13.71%) < N2 (13.77%). The cross term of irrigation amount and nitrogen application amount (I × N) has a significant effect on soil water-stable aggregates (Table 3).

In the 0–30 cm soil layer, under medium irrigation (I2), the soil water-stable aggregate content under high nitrogen application (N1) (11.58%) was significantly lower than that under medium nitrogen application (N2) (16.41%). In the 0–30 cm soil layer, under medium nitrogen application (N2), the soil water-stable aggregate content under high irrigation (I1) (12.70%) was significantly lower than that under medium irrigation (I2) (16.41%) (Table 3).

Table 1. Average soil pH, electrical conductivity, and number of water-stable aggregates in experimental fields at a depth of 0-30 cm under different irrigation and nitrogen application rates in 2023, and their comparison results

deal with	Soil pH	Soil electrical conductivity (ms/cm)	Soil water-stable aggregates %
Irrigation volume (I)			
I1	8.11 ^{a†}	1.04 ^{a}	13.13 ^{a}
I2	8.225 ^{a}	0.95 ^{a}	13.78 ^{a}
I3	8.230 ^{a}	1.18 ^{a}	13.39 ^{a}
施氮量（N）			
N1	8.21 ^{a}	1.26 ^{a}	12.97 ^{a}
N2	8.15 ^{a}	0.73 ^{b}	13.77 ^{a}
N3	8.38 ^{a}	0.95 ^{a}	13.28 ^{a}
N0	8.01 ^{a}	1.29 ^{a}	13.71 ^{a}
	Analysis of variance (P>F)		
I	0.86	0.61	0.72
N	0.50	0.02	0.74
I×N	0.72	0.01	0.07

Note †: Different lowercase letters corresponding to the mean values of indicators under different irrigation and nitrogen application rates indicate that their mean values are significantly different.

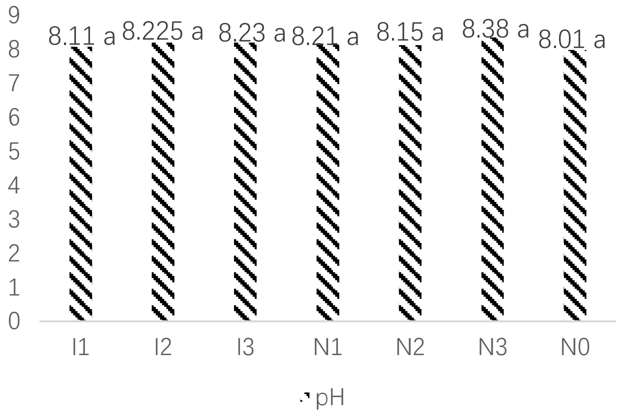

Figure 1. pH values under different irrigation and nitrogen application rates.

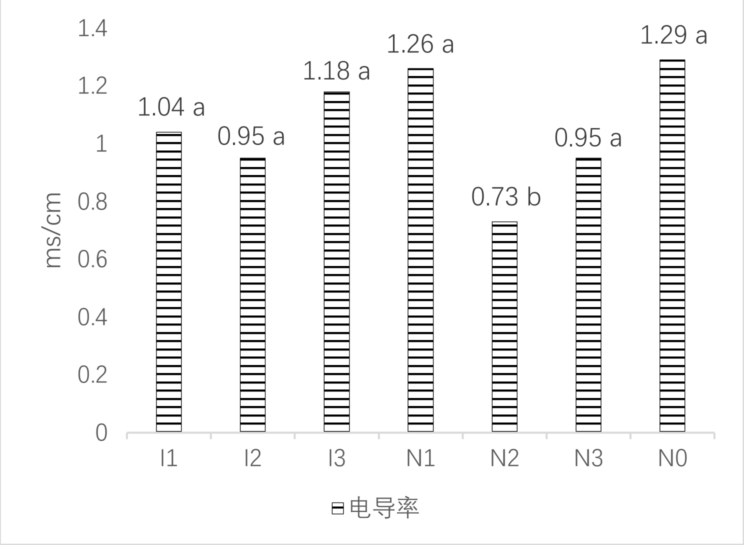

Figure 2. Mean soil electrical conductivity under different irrigation and nitrogen application rates.

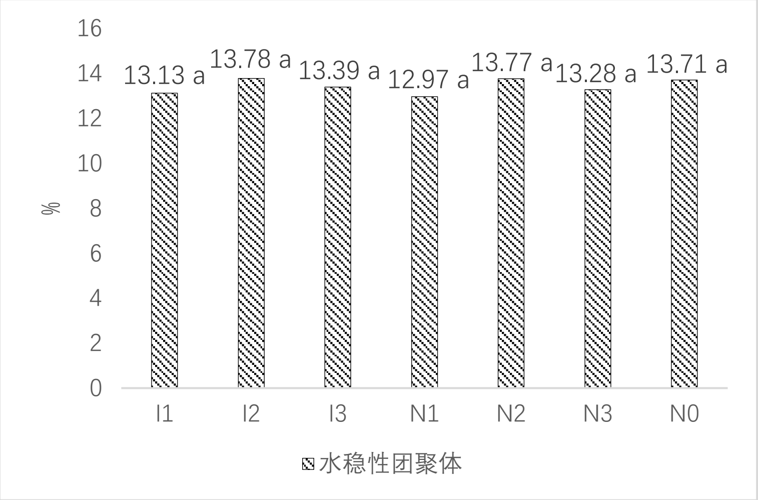

Figure 3. Mean values of soil water-stable aggregates under different irrigation and nitrogen application rates.

Table 2. Average and comparative results of soil electrical conductivity under the cross term of irrigation amount and nitrogen application amount in experimental plots at a depth of 0-30 cm in 2023

	N1	N2	N3	N0
I1	0.71 $^{\text{bB}\dagger}$	0.78 $^{\text{aB}}$	1.28 $^{\text{aA}}$	1.39 $^{\text{aA}}$
I2	1.69 $^{\text{aA}}$	0.53 $^{\text{aB}}$	0.76 $^{\text{bB}}$	0.80 $^{\text{bB}}$
I3	1.37 $^{\text{abAB}}$	0.88 $^{\text{aB}}$	0.80 $^{\text{bB}}$	1.68 $^{\text{aA}}$

Note [†]: Different lowercase letters indicate significant differences in the mean soil electrical conductivity under different irrigation amounts and different nitrogen application rates; different uppercase letters indicate significant differences in the mean soil electrical conductivity under different nitrogen application rates and different irrigation amounts.

Table 3. Mean number and comparison results of soil water-stable aggregates under the cross term of irrigation amount and nitrogen application amount in experimental plots at a depth of 0-30 cm in 2023

	N1	N2	N3	N0
I1	14.73 $^{\text{aA}\dagger}$	12.70 $^{\text{bA}}$	13.95 $^{\text{aA}}$	12.82 $^{\text{aA}}$
I2	11.58 $^{\text{bA}}$	16.41 $^{\text{aA}}$	12.88 $^{\text{aA}}$	14.27 $^{\text{aA}}$
I3	12.59 $^{\text{abA}}$	13.90 $^{\text{aA}}$	13.00 $^{\text{aA}}$	14.06 $^{\text{aA}}$

Note [†]: Different lowercase letters indicate significant differences in the mean soil water-stable aggregates under different irrigation amounts and different nitrogen application rates; different uppercase letters indicate significant differences in the mean soil water-stable aggregates under different nitrogen application rates and different irrigation amounts.

3. Discuss

3.1 Effects of irrigation amount on soil pH, electrical conductivity, and water-stable aggregates

The data results of this study show that the soil pH value tends to decrease with the increase of irrigation amount (Table 1 and Figure 1). Irrigation itself allows cations such as sodium and calcium ions in the soil to exchange with hydrogen ions in the water, which reduces the alkaline cations in the soil, increases the relative concentration of hydrogen ions, and lowers the soil pH value. This is consistent with previous research results (Lai, Meili, & Yang, 2022). This has an effect on improving the soil fertility of saline-alkali soil and is beneficial to crop growth.

The observations in this study indicate that soil electrical conductivity tends to decrease with increasing irrigation volume (Table 1 and Figure 2). This is because soil salts dissolve in water and move with the water. As irrigation volume increases, soil salts are leached downwards with the water, reducing salt concentration. As salt content decreases in the topsoil, electrical conductivity decreases. This is consistent with the research findings of Zhang Meitao (Zhang et al., 2022). The decrease in soil electrical conductivity is beneficial to improving soil fertility in the experimental field of this study. The decrease in topsoil electrical conductivity and salt content is conducive to crop growth.

This study found that soil water-stable aggregates decreased with increasing irrigation (Table 1 and Figure 3). Organic matter is one of the cementing substances of soil aggregates (Lu, 2022), and soil organic matter is a factor affecting the content of water-stable aggregates. Studies have shown that with increasing irrigation, a small amount of organic matter may be leached away (Lai, Meili, & Yang, 2022), leading to a decrease in the content of soil water-stable aggregates. In summary, soil water-stable aggregates decrease with increasing irrigation. The decrease in the content of soil water-stable aggregates will reduce the fertility of the topsoil and have a negative impact on crop growth.

3.2 Effects of nitrogen application rate on soil pH, electrical conductivity, and water-stable aggregates

The soil pH value of sunflower fields in the Hetao Irrigation District decreased with increasing nitrogen application under four different treatments (N0, N1, N2, N3) (Table 1 and Figure 1). This is because urea applied to the soil releases H + during the nitrogen cycle, which accelerates soil acidification (Zhou et al., 2015; Meng, 2013). This is consistent with the research results of Tian Muyu et al. (Tian et al., 2020). Nitrogen application reduces the pH of saline-alkali land, improves soil fertility, and has a positive impact on crop growth.

The results of this study indicate that the soil electrical conductivity of sunflower fields in the Hetao Irrigation District under four different treatments (N0, N1, N2, N3) tends to increase with the increase of nitrogen application (Table 1 and Figure 2). This is because the applied nitrogen fertilizer is converted into nitrate nitrogen and ammonium nitrogen in the soil, which are salts, resulting in an increase in the salt content of the soil and thus an increase in electrical conductivity. This is consistent with the research results of Wang Liying et al. (Wang et al., 2015). Nitrogen application makes saline-alkali land more susceptible to salinity, and the increased electrical conductivity will also increase the salt content, which will reduce soil fertility and be detrimental to crop growth.

The results of this study predict that in sunflower fields in the Hetao Irrigation District, the content of water-stable aggregates tends to decrease with increasing nitrogen application under four different treatments (N0, N1, N2, N3) (Table 1 and Figure 3). This is because increasing nitrogen application leads to higher soil salinity, disrupting the cementing material between soil particles. Organic matter is the cementing material for water-stable aggregates, thus reducing the content of water-stable aggregates in the soil, and decreasing both the number and particle size of soil aggregates. The impact on soil fertility and crop growth is similar to the impact of irrigation amount on water-stable aggregates.

3.3 Effects of the cross term of irrigation amount and nitrogen application amount on soil electrical conductivity and water-stable aggregates

The cross term of irrigation amount and nitrogen application amount has a significant effect on soil electrical conductivity. In the 0-30 cm soil layer, under high nitrogen application (N1), the soil electrical conductivity under high irrigation amount (I1) is significantly lower than that under medium irrigation amount (I2) (Table 2). This is because after nitrogen fertilizer is applied to the soil, in addition to being absorbed by crops, a large amount of nitrogen exists in the soil in the form of nitrate nitrogen (Zhang, Bai, & Yan, 2020). Nitrate nitrogen in the soil mainly exists in the form of nitrate ions. Nitrate and soil colloids are both negatively charged and repel each other, making them easy to be washed into the deeper soil layers by irrigation water. Under low nitrogen application (N3), the soil electrical conductivity under high irrigation amount (I1) is significantly higher than that under low irrigation amount (I3) (Table 2). This is because irrigation water has a leaching effect on soil salts, and the greater the irrigation amount, the more obvious the leaching effect (Liu et al., 2020). Under no nitrogen application (N0), the soil electrical conductivity under medium irrigation levels was significantly lower than that under high and low irrigation levels (Table 2). This is because, with limited irrigation, subsoil salts will return to the surface, but the amount of salt carried to the surface is also limited. Alternatively, high irrigation levels can fill soil pores, reducing aeration and slowing salt movement, leading to salt accumulation. (0-30) In the cm soil layer, under high irrigation (I1), the soil electrical conductivity under high nitrogen application (N1) was significantly lower than that under no nitrogen application (N0) (Table 2). After nitrogen application, the amounts of ammonium and nitrate ions in the soil increased. These ions adsorbed with sodium ions in the soil, resulting in the partial replacement of ions causing soil salinization and thus a decrease in electrical conductivity. Under low irrigation (I3), the soil electrical conductivity under no nitrogen application (N0) was significantly higher than that under low nitrogen application (N3) (Table 2). This may be because the soil samples were taken after the sunflower maturity period, and due to the arid climate in the Hetao Irrigation Area, soil moisture rose to the surface via capillary action, leading to soil salinization. Under medium irrigation (I2), the soil electrical conductivity under high nitrogen application (N1) was significantly higher than that under medium nitrogen application (N2), low nitrogen application (N3), and no nitrogen application (N0) (Table 2). This is because the amount of nitrogen applied can increase the content of nitrate nitrogen in the soil. The salt content in the soil is directly proportional to the soil electrical conductivity, so the salt content in the soil increases (Zhang, Bai, & Yan, 2020). The changes in the amount of irrigation water and nitrogen applied will cause the electrical conductivity to increase or decrease, and the salt content of the topsoil will also change accordingly. For the saline-alkali land in the Hetao Irrigation District, the increase in salt content will reduce soil fertility and also be detrimental to crop growth. The decrease in salt content will have the opposite effect.

Stable aggregates. In the 0-30 cm soil layer, the soil water-stable aggregates under medium nitrogen application (N2) and high irrigation amount (I1) are significantly lower than those under medium irrigation amount (I2) (Table 3). This may be because high irrigation amount will disperse soil water-stable aggregates, or it may be that under high irrigation amount conditions, soil aeration is affected, soil microbial activity is reduced, soil organic matter content is reduced, and the stability of water-stable aggregates is reduced. Under medium irrigation amount (I2), the soil water-stable aggregates under high nitrogen application (N1) are significantly lower than those under medium nitrogen application (N2) (Table 3). This is because excessive nitrogen application and high salt content enhance particle dispersion (Li et al., 2002), which destroys soil structure and water stability of aggregates (Xu, 2015). Increased soil salinity inhibits soil microbial activity and reduces soil aggregate content. In this study, as nitrogen application increased, the content of water-stable aggregates with a particle size greater than 0.25 mm decreased, which is consistent with other research results (Zhu et al., 2019). The higher the content of water-stable aggregates in the soil, the more vigorous the soil fertility and the more conducive it is to crop growth. The opposite is true for low water-stable aggregate content.

4. Conclusion

(1) With increasing irrigation amount, soil pH, electrical conductivity and water-stable aggregates all tend to decrease; with increasing nitrogen application, soil water-stable aggregates and pH both tend to decrease, while soil electrical conductivity tends to increase. (2) The interaction between irrigation amount and nitrogen application has a significant effect on soil electrical conductivity. Under high irrigation amount, nitrogen application significantly reduces soil electrical conductivity; under medium irrigation amount, nitrogen application significantly increases electrical conductivity. (3) The interaction between irrigation amount and nitrogen application has a significant effect on soil water-stable aggregates. Under high irrigation amount, nitrogen application significantly increases soil water-stable aggregates; under medium irrigation amount, the content of soil water-stable aggregates is the highest with medium nitrogen application.

This study provides preliminary insights into the effects of irrigation and nitrogen application rates on soil water-stable aggregates in the Hetao Irrigation District. The unique geographical location and climate conditions of the Hetao Irrigation District have led to soil salinization in the region. Future research should consider the long-term effects of irrigation and nitrogen application on soil microorganisms and nitrogen emissions in order to gain a more comprehensive understanding of the impact of irrigation and nitrogen application rates on soil water-stable aggregates.

References

Daliakopoulos, I., Tsanis, I., Koutroulis, A., Kourgialas, N. N., Varouchakis, A. E., Karatzas, G. P., & Ritsema, C. J. (2016). The threat of soil salinity: A European scale review. *Science of the Total Environment*, *573*, 727-739.

Elliott, E. T. (1986). Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Science Society of America Journal*, *50*, 627-633.

Franzluebbers, A. J., Wright, S. F., & Stuedemann, J. A. (2000). Soil aggregation and glomalin under pastures in the southern Piedmont USA. *Soil Science Society of America Journal*, *64*(3), 1018-1026.

Gao, X. (2022). Effects of the interaction between irrigation amount and nitrogen application rate on soil quality and yield of sunflower fields under the irrigation and salt leaching model in Hetao Irrigation District (Master's thesis, Xinjiang Agricultural University).

Lai, L., Meili, M., & 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, X., Cui, Z., Wang, L., Wang, P., & Zhang, L. (2002). Effects of salinization and organic matter on soil structural stability and Atberg limit. *Acta Pedologica Sinica*, *4*, 550-559.

Liu, X., Ding, B., Bai, Y., Zhang, F., & Fu, J. (2020). Effects of drip irrigation under brackish water film on soil salinity and cotton yield. *Arid Zone Research*, *37*(2), 410-417.

Lu, J. (2002). Study on water stability of soil aggregates and its relationship with soil erodibility (Master's thesis, Northwest A&F University).

Meng, H., Liu, J., Xu, M., Zhang, W., Wen, S., & He, X. (2013). pH evolution of topsoil in typical farmland in my country under long-term fertilization. *Acta Pedologica Sinica*, *50*(6), 1109-1116.

Sahin, U., Angin, I., & Kiziloglu, M. F. (2008). Effect of freezing and thawing processes on some physical properties of saline–sodic soils mixed with sewage sludge or fly ash. *Soil & Tillage Research*, *99*(2), 254-260.

Tian, M., Yu, C., Wang, J., & Liu, X. (2020). Effects of nitrogen addition on soil pH, phosphorus content and phosphatase activity in grassland ecosystems. *Chinese Journal of Applied Ecology*, *31*(9), 2985-2992.

Wang, L., Wu, X., Zhang, Y., Li, S., Liu, H., Wang, H., & Shen, S. (2015). Appropriate nitrogen application rate to ensure cucumber and tomato yield and reduce soil salinity and nitrogen residue in drip-irrigated greenhouses. *Transactions of the Chinese Society of Agricultural Engineering*, *31*(17), 91-98.

Xu, S. (2015). Effects of chemical substances on soil aggregate stability and other physical properties (Master's thesis, Northwest A&F University).

Zhang, M., Yang, P., Ren, S., & Zhou, J. (2022). Effects of irrigation water salinity and irrigation amount on soil water and salt distribution and spring maize growth. *Journal of Soil and Water Conservation*, *36*(4), 290-298.

Zhang, X., Bai, J., & Yan, H. (2020). Effects of irrigation amount and nitrogen application on nitrate transport in different soil types. *Water Saving Irrigation*, *2*, 83-87.

Zhou, X., Xu, M., Zhou, S., Li, D., Zhang, H., Wang, B., & Zhao, Y. (2015). Acidification characteristics of typical farmland soils in southern my country under long-term fertilization. *Journal of Plant Nutrition and Fertilizers*, *21*(6), 1615-1621.

Zhu, M., Kong, F., Li, Y., Li, J., & Liu, G. (2019). Indoor simulation experiment on water-stable aggregates in reed marsh soil in Jiaozhou under different water and salinity conditions. *Wetland Science*, *17*(2), 228-236.