# EFFECT OF SOIL SALINITY ON NITROGEN TRANSFORMATION IN SOIL WITH NITROGEN FERTILIZER APPLICATION

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**Abstract.** In order to study the effect of soil salinity on fertilizer nitrogen transformation, a laboratory culture experiment was conducted with six salinity levels (soil salt content was: 0.17%, 0.99%, 1.64%, 2.32%, 2.91%, 3.79%, respectively) and 6 fertilizer treatments (no fertilizer (CK), low ($UP_L$), medium ($UP_M$) and high three urea phosphate doses (150 kg N/hm$^2$, 300 kg N/hm$^2$ and 600 kg N/hm$^2$), low ($UR_L$) and high urea doses ($UR_H$) (300 kg N/hm$^2$ and 789 kg N/hm$^2$)). With the increase of soil salinity, the average ammonia volatilization loss rate increased from 1.07% to 9.17%. The average of cumulative ammonia volatilization under different fertilization treatments basically followed the order: $UR_H > UR_L > UP_H > UP_M > UP_L > C_K$. With the increase of soil salinity, the average net nitrated nitrogen under different fertilizer treatment was 52.66, 43.06, 68.86, 43.18, 31.10, 22.66 mg/kg in order. Soil inorganic nitrogen transformation increased with the increase of fertilizer application. The net nitrated nitrogen and inorganic nitrogen transformation of soils with different salinity under $UP_M$ treatment were higher than those under $UR_L$ treatment.
**Keywords:** *Xinjiang saline soil, urea, ammonia volatilization, nitrogen hydrolysis, nitration*

## Introduction

Soil salinization is one of the typical problems of global land degradation (Rath and Rousk, 2015). Over 830 million hm$^2$ (about 10% of land area) of soil resources globally are affected by varying degrees of salinization (Wicke et al., 2011). China is a country with a large area of saline soil (about 36 million hm$^2$), mostly distributed in arid and semi-arid ecosystems (Li et al., 2014). Saline soil inhibits the normal growth of crops due to its high salt content, which seriously affects the stability of agricultural ecosystem and the development of agricultural economy (Qadir et al., 2014). Affected by factors such as special climate, soil characteristics and human activities, the problem of soil salinization is prominent in the arid regions of northwest China, and the saline soil area accounts for 69% of the total area of the country (Yang et al., 2022). With the continuous reduction of cultivated land area, the exploitation and utilization of saline soil has drawn more and more attention. As nitrogen is an essential nutrient element for plant growth and development, nitrogen application is one of the important ways to improve soil quality and obtain high crop yield. In order to improve and utilize saline


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soil reasonably, it is very important to understand the effect of soil salt on soil nitrogen cycle.

Soil nitrogen is mainly increased by chemical fertilizer, and a series of reactions such as hydrolysis, volatilization, nitrification, denitrification and crop absorption will occur after the application, and the mineralization of soil organic nitrogen is mixed with them. In saline soil, salt is the main factor affecting nitrogen conversion. Soil salt causes osmotic stress to crop roots, limits nitrogen uptake and utilization (Hagemann, 2011), inhibits microbial activity and reduces soil enzyme secretion. The characteristics of saline soil, such as high salt content and poor physical and chemical properties, determine its unique microbial community structure and diversity (Rath et al., 2019; Zhang et al., 2019a), also will change the process of nitrogen transformation driven by microorganisms (Duan et al., 2018; Elmajdoub et al., 2014), which further affected soil nitrogen transformation and cycle. The main controlling factors and driving mechanisms of each nitrogen conversion process are also different with different soil salinization degree (Zhang et al., 2019b), which seriously limits efficient nitrogen management.

Nitrate nitrogen and ammonium nitrogen are the main effective forms for plants to absorb nitrogen from soil. The effectiveness of fertilizer refers to whether its form is suitable for plants to obtain when they need it, which depends on its own chemical characteristics and the physical and chemical characteristics of the soil tested (Habteselassie et al., 2006). In salt-stressed soil, the change of normal nitrogen transformation mode has a great impact on the effectiveness of fertilizer (Walpola et al., 2008). A large number of studies have shown that the available nitrogen content of saline farmland is usually lower than that of normal soil, and high salt content is often accompanied by low available nitrogen content, also, the average nitrogen utilization rate of farmland crops in saline area was lower than that of conventional farmland (Li et al., 2020a; Sun et al., 2021; Walpola et al., 2008). The loss of nitrogen fertilizer on salinized soil is usually more serious than that on non-salinized soil. Ammonia volatilization is one of the important ways of nitrogen loss in farmland soil (Sigurdarson et al., 2018). The increase of salt will increase the ammonia volatilization intensity and prolong the duration of ammonia volatilization, and the total ammonia volatilization will increase (Li et al., 2020b). Akhtar et al. (2012) and Reddy and Crohn (2014) both found that the mineralization process of soil nitrogen was more inhibited with the increase of salinity. Dendooven et al. (2010) found that there was a significant negative correlation between nitrification rate and soil salinization degree. However, Li and Huang (2008) concluded that low salinization would promote soil ammonification and mineralization, while high salinization would inhibit soil ammonification. Zeng et al. (2013) showed that when soil salt $EC_{1:5}$ was below 1.13 $dS.m^{-1}$, the nitrification rate of soil increased with the increase of soil salinity, and above this threshold, the nitrification rate of soil decreased with the increase of soil salinity. Zhou et al. (2017) found that sediment salinity in the range of 0-15% could increase the nitrification rate. In addition, since fertilization also has an effect on soil microbial community structure, nitrogen fertilizer application and its morphology also affect nitrogen transformation characteristics in soil (Hao et al., 2020; Li et al., 2016, 2019; Wang et al., 2015). It is an important way to improve nitrogen availability to regulate the nitrogen release process under different soil salinity through reasonable fertilization mode. Understanding nitrogen release patterns of different types of fertilizers is important to maximize nitrogen use efficiency and prevent nitrogen loss from causing unnecessary harm to the environment.


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The above reviews show that both soil salinity and fertilization affect nitrogen transformation. However, there are relatively few studies on the effect of soil salinization degree on fertilizer nitrogen transformation characteristics. In order to further explore the nitrogen transformation characteristics of saline soil under the condition of chemical nitrogen fertilizer application, the typical soil in Xinjiang province, China was chose as the research object, and urea and its derivative - urea phosphate, which is widely used in agricultural production, were selected as the fertilizers. The characteristics of ammonia volatilization, hydrolysis and nitrification of two types of nitrogen fertilizer under different salinity gradients were studied, and the transformation forms and loss rules of nitrogen nutrients under different soil salinity conditions were discussed, in order to provide theoretical basis for improving the utilization rate of nitrogen fertilizer in saline soil and reduce the negative impact of nitrogen loss on the environment.

## Materials and methods

### *Test soil and nitrogen fertilizer*

The test soils were typical saline soil (chloride-sulfate soil) and cultivated gray desert soil, collected from Fukang Desert Ecological Experimental Station, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, among which, the saline soil is collected from the saline botanical garden, and the cultivated grey desert soil is collected from the local cotton field. This station is located in Fukang City, Changji Hui Autonomous Prefecture, Xinjiang Uygur Autonomous Region (44° 17’N, 87° 56’E), with a temperate desert climate, and contains both ancient oases and new oases, as well as well-protected natural vegetation. The basic properties of the tested soil are shown in *Table 1*.

***Table 1.*** *Main properties of desert salt soil and irrigated grey desert soil*

| Soil type | pH | Ec (ms/cm) | Total salt (g/kg) | Organic C (g/kg) | Total N (g/kg) | Total P (g/kg) | Total K (g/kg) | Available N (mg/kg) | Available K (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| Cultivated gray desert soil | 8.06 | 0.48 | 1.66 | 5.57 | 0.534 | 1.01 | 9.97 | 42.7 | 264.7 |
| Saline soil | 7.97 | 8.36 | 37.9 | 7.42 | 0.647 | 1.25 | 9.40 | 177.0 | 511.8 |

The nitrogen fertilizers used in the experiment were urea phosphate and urea, of which urea phosphate ($CO(NH_2)_2$-$H_3PO_4$) contained 17.7% N and 44.9% $P_2O_5$, with pH 1.89 in a 1% aqueous solution, and urea ($CO(NH_2)_2$) contained 46.0% N.

### *Experiment design*

A laboratory culture experiment was conducted with six salinity levels and 6 fertilizer treatments. For salinity, the cultivated grey desert soil and saline soil were mixed evenly according to 5:0, 4:1, 3:2, 2:3, 1:4 and 0:5, respectively, which were recorded as salinity I, II, III, IV, V and VI (soil salt content was: 0.17%, 0.99%, 1.64%, 2.32%, 2.91%, 3.79%, respectively); and for fertilization treatments, which were no fertilization (CK), low, medium and high urea phosphate (denoted as $UP_L$, $UP_M$ and $UP_H$), and low and high urea (denoted as $UR_L$ and $UR_H$). Among them, the medium amount of urea phosphate was calculated according to the weight of 20 cm topsoil ($3\times10^6$kg) and nitrogen application doses (300 kg/hm$^2$). In this experiment, the total amount of each soil sample was 3.5 kg, so the medium amount of urea phosphate was


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2 g, and the low amount and high amount of urea phosphate were 1/2 and 2 times of the medium amount, respectively. The nitrogen content of $UR_L$ and $UP_M$ was equal, so $UR_L$ was about 0.8 g urea; $UR_H$ was the same weight as $UP_M$, which was 2 g urea. Among of the total soil samples (3.5 kg) in each treatment, 2 kg was used for ammonia volatilization experiment, and the other 1.5 kg was divided into ten parts for nitrification culture experiment, with 3 replicates for each treatment.

### *Determination items and methods*

#### *Ammonia volatilization*

The ammonia volatilization was measured by glycerin phospho-sponge ventilation method. A PVC pipe (diameter = 15 cm, height = 30 cm) was used as the ammonia volatilization chamber, and its bottom was sealed with PVC plate. The test soil was filled into the pipe, a layer of wire mesh was added 10 cm away from the pipe orifice, and then a sponge (diameter = 16 cm) uniformly soaked with 20 ml glycerin phosphate (50 ml phosphoric acid mixed with 40 ml glycerol and fixed volume to 1000 ml) was placed on the wire mesh to absorb volatilized ammonia from the soil. A sponge (diameter = 20 cm) was placed above the pipe orifice and evenly soaked with 40 ml glycerin phosphate to prevent ammonia in the air from being absorbed by the lower sponge.

The test soil was air-dried and then sieved through 3-mm mesh screen. 2 kg soil sample and fertilizer were mixed evenly according to the experiment design, then put into the test device, 200 ml deionized water was added, barbed wire was installed, and the lower layer and the upper layer sponge were respectively put into the device. To keep the upper sponge moist, evenly 20 ml glycerin phosphate was added to the upper sponge daily. The sponge was replaced every 3 days, and the sponge was extracted with 0.01 mol/L $CaCl_2$ solution. The temperature of the laboratory was controlled at 21 ± 2°C, and the experiment lasted for 30 days.

#### *Nitrification*

The nitrification reaction chamber was a PVC pipe (diameter = 5 cm, height = 20 cm), and its bottom was also sealed with a PVC plate. After the test soil was filled into the pipe, a sponge evenly soaked with 10 ml glycerol phosphate (diameter = 7 cm) was placed above the pipe orifice on the wire mesh to prevent ammonia in the air from entering into the test soil.

The test soil was air-dried and then sieved through 3-mm mesh screen. Each 150 g of soil sample and fertilizer were evenly mixed according to the experiment design and then loaded into each test device. 15 ml of deionized water was added and the sponge was placed above the device. To keep the sponge moist, evenly add 10 ml glycerin phosphate to the upper sponge daily. The temperature of the laboratory was controlled at 21 ± 2°C, and the experiment lasted for 30 days. Three test devices in each treatment were randomly selected every 3 days, and soil samples were taken out for the determination of ammonium nitrogen ($NH_4^+$-N) and nitrate nitrogen ($NO_3^-$-N).

### *Soil and nitrogen content analysis*

Soil EC and pH of 1:5 soil: water extracted were measured using a pH meter (PHSJ-5T, Shanghai, China) and a conductivity meter (DDS-307, Shanghai, China). Automatic discontinuous chemical analyzer SMART-CHEM 450 (Italy) was used to determine


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$NH_4^+$-N and $NO_3^-$-N in the liquid. The Kjeldahl method was used for soil total nitrogen determination, and the alkaline hydrolysis diffusion method was used for soil available nitrogen. Soil organic matter was determined by potassium dichromate volume - external heating method.

The calculation formulas of each index used in this paper are as follows (Tao et al., 2020; Zhang et al., 2018):

Ammonia volatilization:

$$w(NH_3) = \rho \times V \times T / m \quad \text{(Eq.1)}$$

where $w(NH_3)$ is the amount of $NH_3$ volatilization losses (unit: mg/kg); $\rho$ is the concentration of ammonium nitrogen measured by the chemical analyzer (unit: mg/L); *V* is the volume of extraction liquid (unit: L); *T* is the dilution ratio; *m* is the mass of soil sample (unit: kg). The cumulative amount of $NH_3$ volatilization ($\sum_{n}^{i=1} w(NH_3)_i$) is the sum of the measurements over time, where *i* is the *i*th time of soil sampling in each group, *n* is the total number of sampling, *n* = 10 in this study.

Nitrogen loss rate caused by $NH_3$ volatilization:

$$(NH_3)_{Loss}(\%) = \frac{\left(\sum_{n}^{i=1} w(NH_3)_i - \sum_{n}^{i=1} w_{CK}(NH_3)_i\right)}{w(N)} \times 100 \quad \text{(Eq.2)}$$

where $\sum_{n}^{i=1} w_{CK}(NH_3)_i$ is the cumulative $NH_3$ volatilization in CK group under the same salt content, mg/kg; $w(N)$ is the nitrogen fertilizer application amount in each group, mg/kg.

Net nitrogen mineralization rate, mg/(kg.d):

$$NR_{\min} = \frac{m_{CK}(NH_4^+ - N + NO_3^- - \mathrm{N})_t - m_{CK}(NH_4^+ - N + NO_3^- - \mathrm{N})_{t_0}}{t - t_0} \quad \text{(Eq.3)}$$

Inorganic nitrogen transformation, mg/kg:

$$NC_{\min} = m(NH_4^+ - N + NO_3^- - \mathrm{N})_t - m(NH_4^+ - N + NO_3^- - \mathrm{N})_{t_0} \quad \text{(Eq.4)}$$

Net hydrolysis rate, mg/(kg.d):

$$NR_{amm} = \frac{\left[m(NH_4^+ - N)_t - m(NH_4^+ - N)_{t_0}\right] - \left[m_{CK}(NH_4^+ - N)_t - m_{CK}(NH_4^+ - N)_{t_0}\right]}{t - t_0} \quad \text{(Eq.5)}$$

Net nitrated nitrogen, mg/kg:

$$NR_{nit} = m(NO_3^- - N)_t - m(NO_3^- - N)_{t_0} \quad \text{(Eq.6)}$$

where m is mass, mg/kg; *t* is culture time, d; $t_0$ is the initial time, day 0.


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### *Data processing*

SPSS 25.0 and Excel 2017 were used to analyze the data and make the charts. The least significant difference method (LSD) was used for multiple comparison of the differences among the treatments.

## Results

### *Effect of soil salinity on ammonia volatilization*

The dynamic variation of $NH_3$ volatilization in different treatments over time is shown in *Figure 1*. The $NH_3$ volatilization in different treatments increased first and then decreased, and the peak value appeared between the period of 3rd to 15d. Under the same fertilization treatment, $NH_3$ volatilization in soil increased with the increase of soil salinity, and the peak value of $NH_3$ volatilization under the maximum salinity (VI) was more than 3 times higher than that under the minimum salinity (I). After about 15 days of culture experiment, the difference of $NH_3$ volatilization between different salinities gradually decreased.

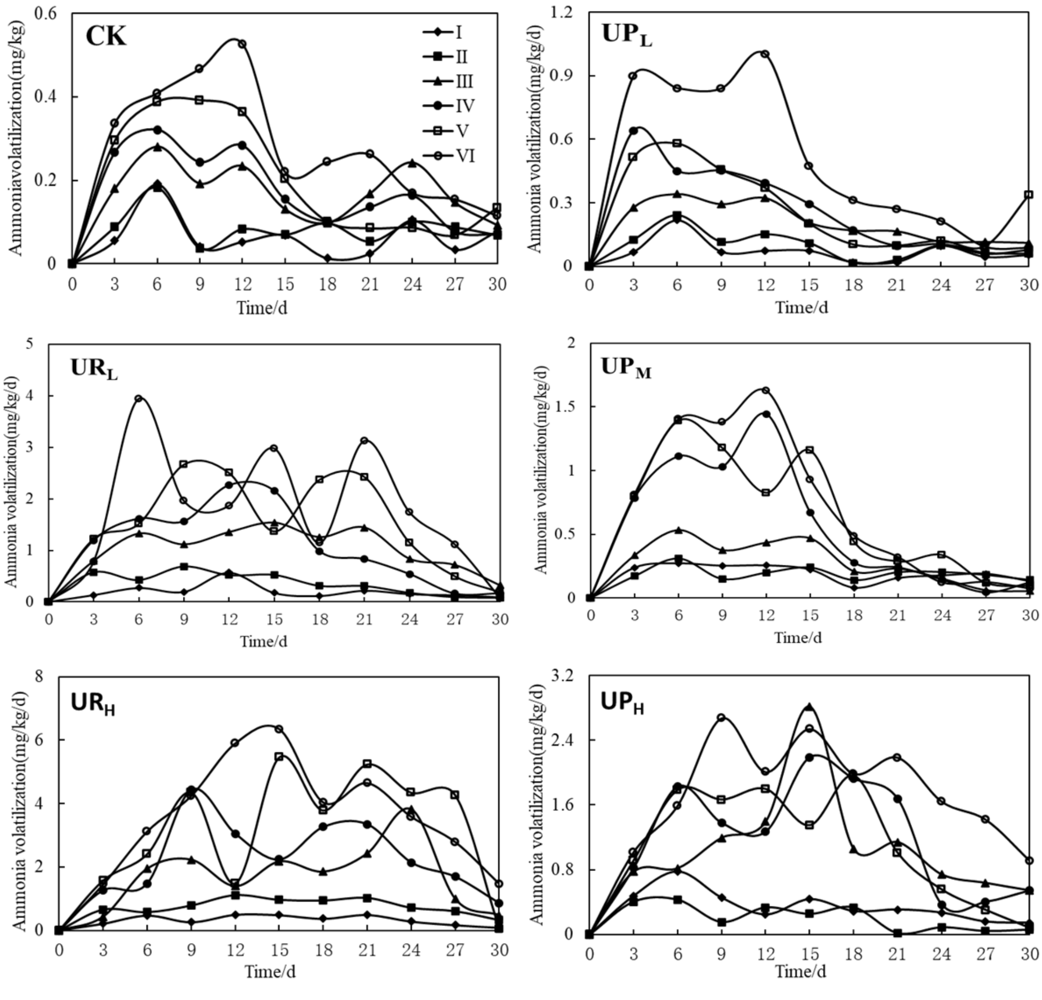


***Figure 1.*** *Variation of $NH_3$ volatilization in experimental soil with time. Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ and Ⅵ means soil salinity explained in experiment design. The same abbreviation will not be repeated in other figures in this article*


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The cumulative $NH_3$ volatilization of soils with different salinity under each treatment is shown in *Figure 2*. Under any fertilization application, the cumulative $NH_3$ volatilization of soil increased almost all with the increase of soil salinity, except for $UP_H$, which may be due to experimental error. Under $UR_H$ treatment, cumulative $NH_3$ volatilization in saline soil Ⅵ (37.6 mg/kg) was more than 10 times higher than that in saline soil Ⅰ (3.3 mg/kg), a was about 4 times higher than that in saline soil Ⅱ (7.7 mg/kg). In CK, $NH_3$ volatilization accumulation in saline soil Ⅵ (2.9 mg/kg) was about 5 times that of saline soil Ⅰ (0.66 mg/kg). With the increase of soil salinity, the average values of cumulative $NH_3$ volatilization under different fertilization treatments were 2.05, 2.90, 7.72, 9.68, 11.99, 14.91 mg/kg, respectively. The results of LSD analysis showed that there were significant differences in cumulative $NH_3$ volatilization between soils with different salinity, e.g., data for salinity I, II (salt content less than 1%) and salinity IV, V, VI (salt content more than 2%) ($P < 0.05$), and data for salinity VI (salt content greater than 3%) and I, II, III (salt content less than 2%) ($P < 0.05$). The cumulative $NH_3$ volatilization in soil with the same salinity all increased with the increase of fertilization level, but there were some differences between different fertilizer types. The average of cumulative $NH_3$ volatilization under different fertilization treatments basically followed the following order: $UR_H > UR_L > UP_H > UP_M > UP_L >$ CK. Under iso-nitrogen treatment, the cumulative ammonia volatilization in soil with the same salinity under $UR_L$ treatment was all bigger than $UP_M$ treatment, e.g., for salinity Ⅰ, cumulative $NH_3$ volatilization under $UR_L$ and $UP_M$ treatment were 2.06 mg/kg and 1.99 mg/kg, and for salinity Ⅱ, the corresponding values were 3.72 and 1.96 mg/kg, for salinity Ⅲ, Ⅳ, Ⅴ and Ⅵ, the corresponding data were 10.69 mg/kg and 2.87 mg/kg, 11.48 mg/kg and 5.87 mg/kg, 15.91 mg/kg and 6.64 mg/kg, 18.71 mg/kg and 7.28 mg/kg, respectively. The above results show that the increase in soil salt content will promote $NH_3$ volatilization, and the amount of fertilizer application and the type of fertilizer will also affect the accumulation of $NH_3$ volatilization under the same soil salt content.

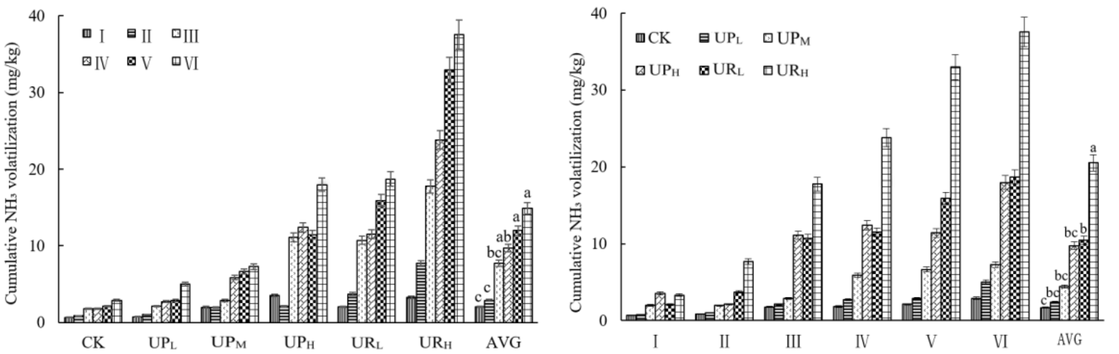


***Figure 2.*** *The cumulative $NH_3$ volatilization of soils with different salinity and different fertilization treatments during the whole culture period. Different lowercase letters in the figure indicate significant differences in ammonia volatilization accumulations under different salinity gradients ($P < 0.05$). The same abbreviation will not be repeated in other figures in this article*

$NH_3$ volatilization loss rate can reflect the degree of nitrogen fertilizer loss in soil. The loss rate of nitrogen fertilizer under different salinity gradients and fertilizer treatment is shown in *Figure 3*. Under different nitrogen fertilizer treatments, the


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change of nitrogen fertilizer loss rate with soil salinity were basically the same (*Fig. 3a*), that is, with the increase of soil salinity, the nitrogen fertilizer loss rate caused by $NH_3$ volatilization increased, and the mean value increased from 1.07% to 9.17%. Among them, nitrogen fertilizer loss rate of soils with salinity VI under $UR_L$ treatment was highest, 15.81%. Through the significance test, it was found that the ammonia volatilization loss rate of salinity V, VI soil was significantly different from that of salinity I, II soil. Under the same soil salt content, the nitrogen fertilizer loss rate basically increased with the increase in urea phosphate application, whereas, the nitrogen fertilizer loss rate was higher when urea application was low ($UR_L$) than high ($UR_H$) (*Fig. 3b*). On the whole, the nitrogen fertilizer loss rate under different fertilization treatments basically followed the following order: $UR_L > UR_H > UP_H > UP_M > UP_L$, the rate under $UR_L$ treatment was 3 to 10 times higher than that under $UP_L$ treatment, and 2 to 3 times higher than that under $UP_M$ and $UP_H$ treatment. Thus, compared with conventional urea, the application of urea phosphate fertilizer can effectively reduce the loss of $NH_3$ volatilization.

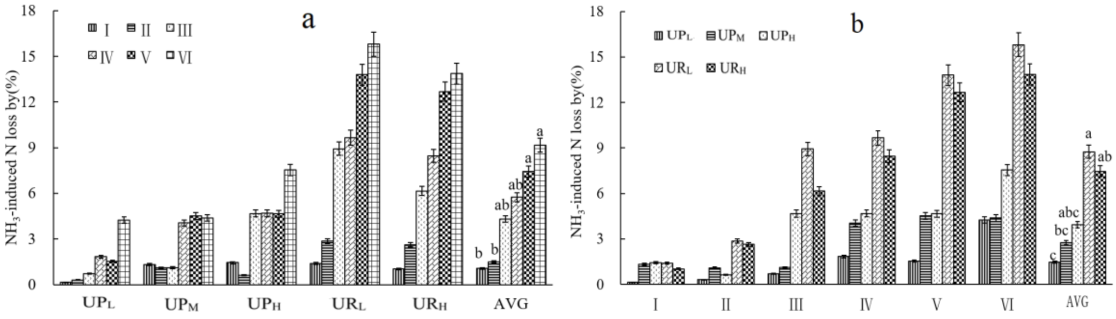


***Figure 3.*** *Nitrogen loss rate under different soil salinity and fertilizer treatments*

### *Effects of soil salinity on mineralization, nitrogen hydrolysis and nitrification processes*

The changes of net mineralization rate and net hydrolysis rate of nitrogen fertilizer under different fertilizer treatments over time are shown in *Figure 4*. The trend of net mineralization rate of soil with different salinity under CK treatment was generally consistent, and the net mineralization rate of soil in the first 4d was negative and decreased with the increase of salinity, reaching the lowest value at the third day of culture. The net mineralization rates of salinity soils I, II, III and IV reached their peak values on the 6th day, which were 2.558, 4.055, 5.412 and 7.531 mg/(kg.d), respectively, and then fluctuated. The net mineralization rates of salinity soils V and VI reached their peak values on the 18th day, 2.656 and -0.142 mg/(kg.d), respectively. Under CK treatment, the net mineralization rate of soil with different salinity was gradually stable and negative after 21 days of culture, and the net mineralization rate of soil with the highest salinity was negative during the whole test period. The above results showed that the effect of soil salt increase on net mineralization rate was first promotion and then inhibition, and the effect of excessive salt on the inhibition of mineralization was stronger.

Under fertilization application, the net nitrogen hydrolysis rate peaked on days 3 to 6, and the peak value increased with the increase of soil salinity, followed by 8.65, 11.15, 8.79, 13.89, 12.02, 10.73 mg/(kg.d) under $UP_L$ treatment, and 38.26, 33.17, 17.62,


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21.51, 12.23, 7.69 mg/(kg.d) under $UP_M$ treatment, and 43.95, 38.91, 37.58, 19.21, 15.35, 9.37 mg/(kg.d) under $UP_H$ treatment, 32.82, 22.88, 16.31, 16.93, 13.02, 10.64 mg/(kg.d) under $UR_L$ treatment, and 94.33, 41.10, 53.25, 23.295, 8.97, 7.47 mg/(kg.d) under $UR_H$ treatment. It can be seen that except $UP_L$ treatment, the net hydrolysis rate of nitrogen fertilizer under other fertilization treatments decreased with the increase of soil salinity. Under $UP_L$ treatment, although the peak of net nitrogen hydrolysis rate increased with the increase of soil salinity, there was little difference among different salinity soils, and with the increase of salinity, the time when the net nitrogen hydrolysis rate peaked was delayed. The results indicated that soil salinity inhibited the hydrolysis of nitrogen fertilizer. In the same salinity soil, the net hydrolysis rate of nitrogen fertilizer increased with the increase of fertilizer application amount. The net hydrolysis rates in the period of 0 to 3d under $UR_L$ treatment were higher than those for $UP_M$ treatment under iso-nitrogen application. The net hydrolysis rates on the 3rd under $UR_L$ treatment were 34.12, 20.07, 16.05, 10.02, 7.76, -3.48 mg/(kg.d) day with the increase of salinity, and the data were 18.27, 18.46, 15.98, 9.68, 5.21, -12.65 mg/(kg.d) with the increase of salinity under $UP_M$ treatment. However, on the 6th day of culture experiment, the net hydrolysis rates under $UP_M$ treatment were almost all higher than those under $UP_L$ treatment, indicating that urea hydrolyzed earlier than urea phosphate and formed ammonium ions faster.

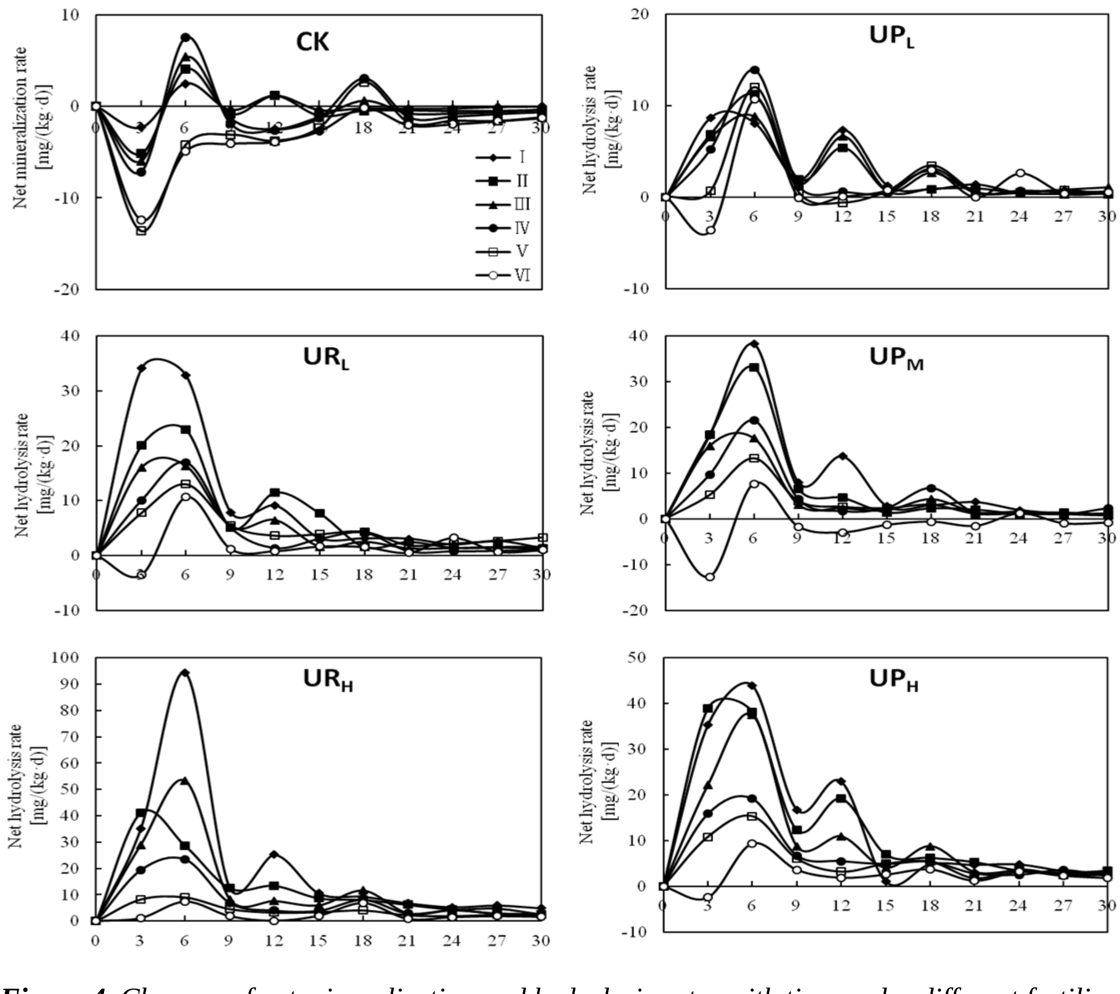


***Figure 4.*** *Changes of net mineralization and hydrolysis rates with time under different fertilizer treatments*


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At the end of culture experiment, the net nitrated nitrogen of soil under different fertilization methods was shown in *Figure 5a*, and the heat map (*Fig 5b*) was given based on the horizontal and vertical coordinates of soil type and fertilizer treatment respectively. The cumulative net nitrated nitrogen of the soil with fertilizer application was almost all higher than the control group (CK). The cumulative net nitrated nitrogen content in all fertilizer treatments roughly increased first and then decreased with the increase of soil salinity. The average net nitrated nitrogen under each fertilizer treatment was 52.66, 43.06, 68.86, 43.18, 31.10, 22.66 mg/kg with the increase of soil salinity. The cumulative net nitrated nitrogen of the soil with salinity III was almost all significantly higher than that of other soil salinity, the data was 107.16 mg/kg and 87.56 mg/kg for isonitrogen treatment ($UP_M$ and $UR_L$, respectively), and the cumulative net nitrated nitrogen of soils with different salinity under $UP_M$ treatment was higher than that under $UR_L$ treatment. For the same salinity soil, the net nitrated nitrogen increased first and then decreased with the increase in urea phosphate application, and the value of high urea content was lower than that of low urea application.

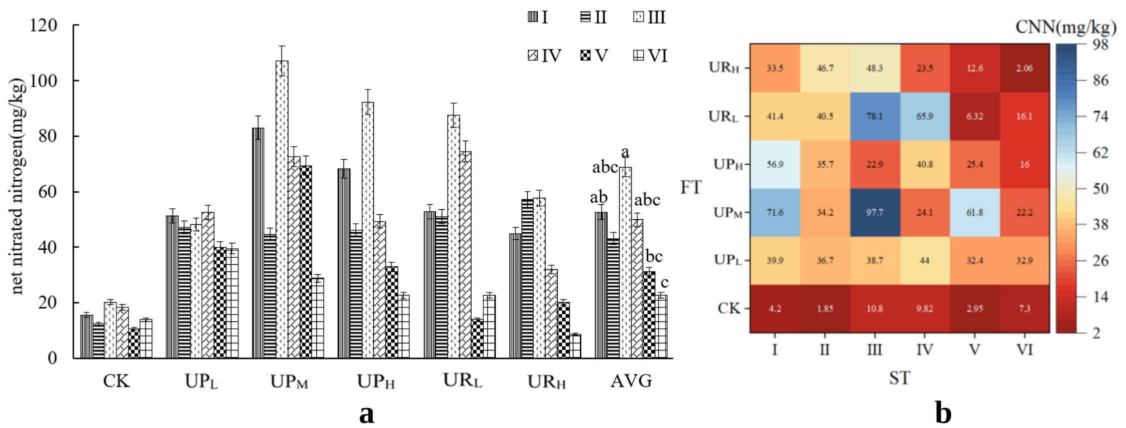


***Figure 5.*** *(a) Histogram of net nitrated nitrogen content in soil under different fertilization methods at the end of culture. (b) Heat map of net nitrated nitrogen of soils with different salinity under different fertilization. ST - Soil type; FT - Fertilizer treatment; CNN - Cumulative nitrifying nitrogen*

The amount of soil inorganic nitrogen transformation under different fertilizer treatments at the end of the experiment decreased with the increase of salinity (*Fig. 6*). There was significant difference in the amount of inorganic nitrogen transformation between soils with the highest salinity VI and the other salinity (I, II, III, IV, V). Inorganic nitrogen transformation of soil with salinity III was almost the highest in all saline soils under different fertilizer treatments, this was similar to the amount of net nitrated nitrogen. There was also significant difference in the amount of inorganic nitrogen transformation between fertilization and no fertilization application. Under CK treatment, all soil inorganic nitrogen transformation amount was negative, and with the increase of salinity, it was -0.42, -11.28, -9.565, -19.14, -35.595, -37.845 mg/kg, respectively. Under the same fertilizer treatment, inorganic nitrogen transformation increased with the increase in fertilizer application. After 30 days of culture, the average inorganic nitrogen transformation under $UP_M$ treatment was slightly higher than that under $UR_L$ treatment (64.61 and 62.93 mg/kg, respectively).


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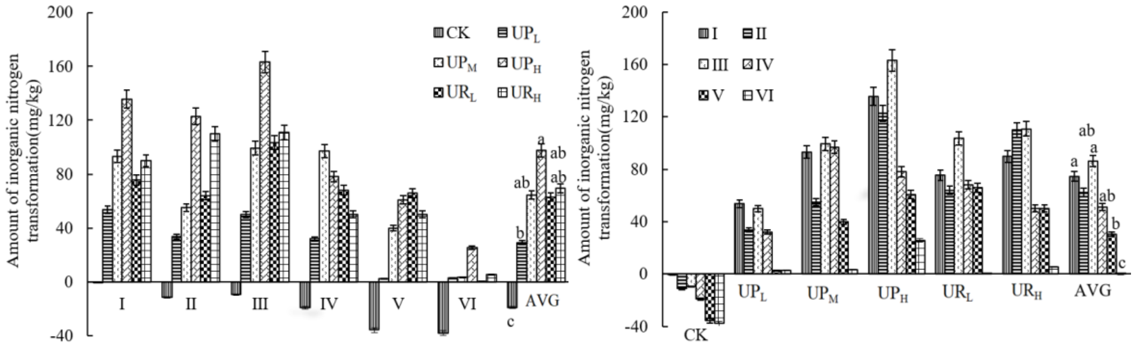

***Figure 6.*** *Soil inorganic nitrogen transformation under different treatments*

### *Analysis of influencing factors of ammonia volatilization, mineralization, hydrolysis and nitrification*

The correlation analysis results of various factors involved in nitrogen conversion are shown in *Table A1*. The cumulative ammonia volatilization (CAV) in soil was positively correlated with the soil type (ST, means different salinity), fertilizer treatment (FT), pH, electrical conductivity (EC), organic matter (OM), water-soluble potassium (WSP), water-soluble sodium (WSS), $Na^+$, $Cl^-$, $SO_4^{2-}$ and total salt content (TDS) significantly ($P < 0.01$). It was positively correlated with total nitrogen (TN) and total phosphorus (TP) ($P < 0.05$).

The cumulative net nitrated nitrogen (CNN) and inorganic nitrogen conversion (CMN) were significantly positively correlated ($P < 0.01$), and CNN was significantly negatively correlated with ST, EC, WSP, WSS, $Na^+$, $Cl^-$, $SO_4^{2-}$ ($P < 0.05$). CMN was positively correlated with FT ($P < 0.01$), positively correlated with OM, WSS and $Na^+$ ($P < 0.01$), and negatively correlated with EC, WSP, $Cl^-$, $SO_4^{2-}$ and TDS ($P < 0.05$).

## Discussion

### *Ammonia volatilization in soils with different salinities*

Ammonia volatilization is one of the main ways of nitrogen loss during fertilizer nitrogen application. In this study, the total soil salt content ranged from 0.17% to 3.79%, and $NH_3$ volatilization loss rates of urea and urea phosphate range from 0.15% to 15.81%, which is consistent with the study of Sun et al. (2017), ammonia volatilization accounts for 9.5-14.5% of nitrogen fertilizer in saline-alkali soil. After the application of urea phosphate and urea, the accumulation and loss rate of $NH_3$ volatilization were significantly different under different soil salinity, and both showed an increasing trend with the increase in soil salinity, which was consistent with the study of Shi et al. (2021). Li et al. (2020) also believed that soil salinization in a certain salinity range exacerbated nitrogen loss due to ammonia volatilization. The content of $NH_4^+$-N is the main factor affecting $NH_3$ volatilization. In this study, $NH_4^+$-N content reached its peak within 3-6 days after nitrogen fertilizer application, while $NH_3$ volatilization peaked later (3-15 d after fertilization). Relevant studies suggest that ammonia volatilization is significantly positively correlated with soil $NH_4^+$-N concentration (Rochette et al., 2013). With the increase of soil salt content, high salt content will inhibit the activity of nitrifying microorganisms such as nitrosifying bacteria and nitrifying bacteria (Elgharably and Marschner, 2011) and slow down the


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nitrification process of nitrogen in soil. The higher the soil salt content, the stronger the inhibiting effect on nitrification (Zhou et al., 2016), resulting in an increase in the accumulation of $NH_4^+$-N in soil, thus aggravating the accumulation of ammonia volatilization in soil. In addition, high salinity also reduces the adsorption capacity of soil for $NH_4^+$-N, increases the concentration of $NH_4^+$-N in soil solution, and promotes the conversion of $NH_4^+$ to $NH_3$, so the $NH_3$ volatilization rate increases significantly (Venterea et al., 2015).

Correlation analysis showed that soil ammonia volatilization accumulation was positively correlated with pH, EC, OM, WSP, WSS, $Na^+$, $Cl^-$, $SO_4^{2-}$ and TDS ($P < 0.01$). Sun et al. (2017) showed that pH was positively correlated with $NH_3$ volatilization in soil. EC generally increases with the increase of soil salinity (Yang et al., 2020), so the cumulative amount of ammonia volatilization in soil is significantly positively correlated with EC. Organic matter mineralization is an important source of $NH_4^+$-N. The standard method for $NH_4^+$-N analysis in soil, using KCl or NaCl solution as the medium for extracting $NH_4^+$-N, can reduce the adsorption capacity of soil for $NH_4^+$-N, which is consistent with the research results of Murtaza et al. (2017), which showed that $Na^+$ and $NH_4^+$-N competed for adsorption sites. The increase of $Na^+$ concentration in soil will reduce the adsorption of $NH_4^+$-N in soil, thus promoting $NH_3$ volatilization, which can also explain the positive correlation between the cumulative amount of $NH_3$ volatilization in soil and $K^+$, $Na^+$, $Cl^-$ and total salt content.

### *Mineralization, hydrolysis and nitrification in different salinity soil*

Comparing the peak values of soil net mineralization rate with different salinity under CK treatment in this study, it was found that when soil salt content increased from 0.17% to 2.32%, the peak value of soil net mineralization rate increased and changed from initial negative value to positive value, indicating that the increase of soil salt from a low content may lead to the biological retention of $NH_4^+$-N gradually weaker than soil mineralization, thus net mineralization rate increased, which is consistent with the results of Zhou et al. (2017). However, high salinity may reduce microbial activity (Yan and Marschner, 2012), thereby inhibiting nitrogen mineralization (Zhou et al., 2020). The net mineralization rate of the soil with the highest salinity (VI) was all negative during the whole experiment period, and the amount of inorganic nitrogen conversion of the soil with different salinity was also negative under the CK treatment. The amount of inorganic nitrogen conversion decreased with the increase of soil salinity, indicating that the excessive salt will enhance the inhibition effect on mineralization, which is consistent with the research conclusion of Reddy et al. (2014). In this study, with the increase of soil salinity, $NH_3$ volatilization loss increased, which may also lead to the decrease of inorganic nitrogen conversion with the increase of salt.

Through the study of the net hydrolysis rates of different fertilizers, it was found that the hydrolysis of urea and urea phosphate was significantly inhibited by the increase of soil salinity, which was consistent with the research results of Li et al. (2020). The net hydrolysis rates of salinity I, II, III, IV and V were all positive during the whole culture experiment, indicating the increase in the content of $NH_4^+$-N in soil, and the formation rate of $NH_4^+$-N was greater than the consumption rate. Under the condition of high salt (VI), $NH_4^+$-N formed by hydrolysis of the two kinds of nitrogen fertilizer began to transform in large quantities after the 4th day of culture, which was delayed by 4 d compared with the other 5 kinds of salinity soils. This indicates that urea takes longer time to fully hydrolyze at very high salinity levels (Akhtar et al., 2012). The lower the


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soil salinity is, the more $NH_4^+$-N is formed through urea and urea phosphate hydrolysis and the faster the conversion happens, which indicates that soil salinity inhibited the hydrolysis of urea and urea phosphate and the conversion of hydrolyzate.

By investigating the net nitrification amount of fertilizer, it can be seen that the net nitrification amount of soil under medium salt treatment was the largest, while that under high salt treatment was the smallest, indicating that the nitrification process under urea and urea phosphate treatment has a promoting effect, which is consistent with the research results of Zeng et al. (2013) and Zhou et al. (2017). Soil salinity can promote nitrification to a certain extent, while high salinity conditions show an inhibitory effect (Patil et al., 2021). However, some scholars found that the nitrification rate was significantly negatively correlated with the degree of soil salinization (Dendooven et al., 2010). As the influence of soil salt on nitrification varies with soil salt ion composition, pH, ratio and content of $NH_4^+$-N and $NO_3^-$-N, microbial abundance and activity, etc., the influence of soil salt on nitrogen conversion in different environments cannot be generalized (Akhtar et al., 2012; Nejidat, 2005).

### *Effect of fertilizer type and fertilizer amount on nitrogen conversion*

The type and amount of nitrogen fertilizer also have important effects on nitrogen conversion process. In this study, the cumulative amount of ammonia volatilization of urea phosphate and the loss rate of nitrogen fertilizer caused by urea phosphate were lower than those of urea, which was due to the concentration of $H^+$ in soil increased after application of urea phosphate, inhibiting the positive reaction of $NH_4^+ \rightarrow NH_3 + H^+$ (Ma et al., 2020). Thus, its $NH_3$ volatilization was reduced (Zhang et al., 2019c). When equal amounts of urea phosphate and urea were applied, the net hydrolysis rate of urea was significantly higher than that of urea on days 0 to 3, and urea hydrolyzed earlier than urea phosphate. This is due to the fact that phosphoric acid produced by decomposition of urea phosphate will reduce soil pH and inhibit urease activity (Tao et al., 2020). Under iso-nitrogen conditions, the contents of inorganic nitrogen and nitrate nitrogen formed by urea phosphate were higher than those of urea treatment, mainly because urea phosphate contained phosphorus, and additional phosphorus would promote nitrogen conversion. Field experiments have been conducted to study the effects of nitrogen and phosphorus interactions, and the results show that the application of phosphorus fertilizer can improve soil fertility and microbial activity, promote nitrogen conversion, and improve nitrogen use efficiency (Dong et al., 2015; Xing et al., 2015).

In this study, under the same soil salt content, the net hydrolysis rate of nitrogen fertilizer increased with the increase of fertilizer application amount. This is because urease plays an important role in the conversion of urea into ammonium nitrogen. Min et al. (2012) concluded that soil urease activity basically increased with the increase of urea application amount. This is because after the addition of high nitrogen, microorganisms obtain enough inorganic nitrogen themselves, their metabolism is enhanced, and the content of inorganic nitrogen released into the soil is also increased (Xu et al., 2021). In this study, with the increase of fertilizer application rate, the difference in the net hydrolysis rate of nitrogen fertilizer in high-salt and low-salt treatments increased, which was similar to the study of Min et al. (2012), and the urea N conversion was significantly affected by soil salinity and urea application rate. The net nitrification capacity of soil with the same salinity first increased and then decreased with the increase of urea phosphate application, while the net nitrification capacity of


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soil with high urea content was smaller than that of soil with low urea content, indicating that nitrification was mainly influenced by the interaction between soil salinity and nitrogen application, which was consistent with the research results of Min et al. (2012). The more urea applied, the more obvious the influence of salt content on nitrification. The smaller the effect on nitrate reductase activity, and the excessive application of inorganic fertilizers will aggravate soil salinization (Ceccoli et al., 2012), and thus have a stronger inhibition on nitrification. The above analysis showed that the net hydrolysis of nitrogen fertilizer and nitrification were influenced by the interaction between fertilization and soil salinity.

Microorganisms are the main biological factors regulating soil nitrogen conversion (Kuypers et al., 2018), and salt affects nitrogen conversion process by inhibiting microbial activity. Studies have shown that high soil salt content can reduce microbial activity and biomass (Rath and Rousk, 2015; Yang et al., 2020), changing microbial community structure (Sun et al., 2016). The analysis results of related factors of nitrogen conversion in this study also confirmed that the cumulative net nitrated nitrogen was significantly negatively correlated with soil type and electrical conductivity. In addition, since fertilization can improve the chemical properties and microbial properties of saline-alkali soil (Yao et al., 2021), the change of accumulated mineral nitrogen content in this study was significantly positively correlated with fertilizer treatment ($P < 0.01$), and significantly negatively correlated with electrical conductivity and total salt content. Therefore, soil salt content, nitrogen source type and application amount all affect the conversion process of nitrogen in soil, which is consistent with the findings of Zhou et al. (2020).

As a vital potential land resource in our country, how to make efficient use of saline-alkali soil is particularly important. Due to the complex physical and chemical properties and microbial community structure of saline-alkali soil, the study of nitrogen loss and transformation characteristics of saline-alkali soil needs to be further studied. The characteristics of ammonia volatilization, mineralization, hydrolysis and nitrification under 6 soil salinity gradients were analyzed in this study. However, the relationship between the difference of nitrogen conversion under different soil salinities and soil microorganisms has not been studied, especially the relationship between the response of dominant microorganisms to salt in different nitrogen conversion processes needs to be further studied. In addition, the research object of this paper is based on the allocation of two different salinity natural soils of Xinjiang in different proportions. Under the treatment of other types of saline soil and different types of nitrogen fertilizer, the influence of soil salinity on nitrogen conversion characteristics also needs to be further studied.

## Conclusions

Soil salt content had a great influence on the nitrogen transformation of urea phosphate and urea. With the increase of soil salt content in the range of 1.7-37.9 g/kg, the accumulation and loss rate of ammonia volatilization increased under the same fertilization treatment. The effect of high soil salinity on net mineralization rate was firstly promoted and then inhibited. Soil salinity inhibited the hydrolysis of urea and urea phosphate and the conversion of hydrolyzates, but urea hydrolyzed earlier than urea phosphate and formed ammonium ions faster. Compared with urea, urea phosphate is more beneficial to reduce the volatilization loss of ammonium nitrogen in soil and


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improve the nitrogen utilization rate. The effect of high soil salinity on nitration was firstly promoted and then inhibited. For the same salinity soil, the net nitrogen hydrolysis rate increased with the increase of fertilizer application rate, the net nitrification rate increased first and then decreased with the increase of urea phosphate application, and the net nitrification rate of high urea content was lower than that of low urea content. Under iso-nitrogen treatment, inorganic nitrogen produced by application of urea phosphate was generally higher than that of urea treatment. Soil cumulative ammonia volatilization was positively correlated with pH, EC, total salt content and organic matter, cumulative net nitrification nitrogen was negatively correlated with soil type and conductivity, cumulative mineral nitrogen content was positively correlated with fertilizer treatment, and was negatively correlated with conductivity and total salt content. In summary, soil salt content, nitrogen source type and application amount all affect the conversion characteristics of nitrogen in soil.

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## APPENDIX

***Table A1.*** *Correlation analysis of soil salinization parameters, salt ions, nutrient indexes and nitrogen transform results*

| Index | FT | CAV | CNN | CMN | pH | EC | TN | TP | TK | OM | PAN | WSP | WSS | $Na^+$ | $Cl^-$(%) | $SO_4^{2-}$ (%) | $Ca^{2+}$ (%) | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ST | 0.000 | 0.513$^{**}$ | -0.360$^{*}$ | -0.416$^{*}$ | 0.586$^{**}$ | 0.997$^{**}$ | 0.253 | 0.306 | -0.042 | 0.865$^{**}$ | 0.206 | 0.989$^{**}$ | 0.987$^{**}$ | 0.989$^{**}$ | 0.992$^{**}$ | 0.977$^{**}$ | 0.456$^{**}$ | 0.970$^{**}$ |
| FT | | 0.677$^{**}$ | 0.217 | 0.675$^{**}$ | 0.502$^{**}$ | 0.014 | 0.074 | 0.167 | -0.150 | -0.113 | 0.349$^{*}$ | 0.071 | -0.019 | -0.019 | 0.001 | -0.007 | -0.193 | 0.008 |
| CAV | | | -0.235 | 0.107 | 0.645$^{**}$ | 0.517$^{**}$ | 0.347$^{*}$ | 0.353$^{*}$ | -0.146 | 0.426$^{**}$ | 0.253 | 0.575$^{**}$ | 0.495$^{**}$ | 0.498$^{**}$ | 0.509$^{**}$ | 0.495$^{**}$ | -0.024 | 0.503$^{**}$ |
| CNN | | | | 0.563$^{**}$ | -0.267 | -0.354$^{*}$ | -0.249 | -0.009 | 0.004 | -0.263 | -0.032 | -0.349$^{*}$ | -0.362$^{*}$ | -0.361$^{*}$ | -0.345$^{*}$ | -0.332$^{*}$ | -0.044 | -0.304 |
| CMN | | | | | 0.072 | -0.402$^{*}$ | -0.032 | -0.085 | -0.308 | -0.462$^{**}$ | 0.303 | -0.365$^{*}$ | -0.437$^{**}$ | -0.442$^{**}$ | -0.421$^{*}$ | -0.419$^{*}$ | -0.280 | -0.408$^{*}$ |
| pH | | | | | | 0.566$^{**}$ | 0.410$^{*}$ | 0.106 | -0.282 | 0.360$^{*}$ | 0.283 | 0.605$^{**}$ | 0.602$^{**}$ | 0.580$^{**}$ | 0.587$^{**}$ | 0.518$^{**}$ | 0.289 | 0.514$^{**}$ |
| EC | | | | | | | 0.246 | 0.326 | -0.025 | 0.866$^{**}$ | 0.201 | 0.989$^{**}$ | 0.983$^{**}$ | 0.985$^{**}$ | 0.993$^{**}$ | 0.979$^{**}$ | 0.431$^{**}$ | 0.972$^{**}$ |
| TN | | | | | | | | 0.165 | -0.252 | 0.208 | 0.007 | 0.338$^{*}$ | 0.282 | 0.267 | 0.285 | 0.212 | -0.063 | 0.206 |
| TP | | | | | | | | | 0.001 | 0.375$^{*}$ | 0.138 | 0.339$^{*}$ | 0.288 | 0.306 | 0.310 | 0.322 | -0.062 | 0.320 |
| TK | | | | | | | | | | 0.032 | -0.114 | -0.052 | -0.043 | -0.038 | -0.039 | -0.007 | -0.054 | 0.007 |
| OM | | | | | | | | | | | 0.104 | 0.840$^{**}$ | 0.852$^{**}$ | 0.854$^{**}$ | 0.852$^{**}$ | 0.858$^{**}$ | 0.274 | 0.853$^{**}$ |
| PAN | | | | | | | | | | | | 0.231 | 0.194 | 0.210 | 0.197 | 0.240 | 0.072 | 0.223 |
| WSP | | | | | | | | | | | | | 0.979$^{**}$ | 0.980$^{**}$ | 0.989$^{**}$ | 0.968$^{**}$ | 0.408$^{*}$ | 0.965$^{**}$ |
| WSS | | | | | | | | | | | | | | 0.995$^{**}$ | 0.984$^{**}$ | 0.983$^{**}$ | 0.458$^{**}$ | 0.978$^{**}$ |
| $Na^+$ | | | | | | | | | | | | | | | 0.984$^{**}$ | 0.991$^{**}$ | 0.453$^{**}$ | 0.986$^{**}$ |
| $Cl^-$(%) | | | | | | | | | | | | | | | | 0.973$^{**}$ | 0.439$^{**}$ | 0.968$^{**}$ |
| $SO_4^{2-}$(%) | | | | | | | | | | | | | | | | | 0.400$^{*}$ | 0.996$^{**}$ |
| $Ca^{2+}$(%) | | | | | | | | | | | | | | | | | | 0.383$^{*}$ |

ST - soil type； FT - fertilizer treatment; CAV - cumulative ammonia volatilization; CNN - cumulative net nitrated nitrogen; CMN - cumulative mineralized nitrogen; EC - electrical conductivity; TN - total nitrogen; TP - total phosphorus; TK - total potassium; OM - organic matter; PAN - available nitrogen; WSP - water-soluble potassium; WSS - water soluble nano; TDS - total salt. $^*P < 0.05$; $^{**}P < 0.01$


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