Effects of Irrigation on the Selective Transport of Na$^+$ and K$^+$ in Corn

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Abstract. Due to its special climate and geological reasons, Tianjin Binhai area has formed a large area of saline-alkali land. It is of great significance to explore the distribution of salt ions in crops under drip irrigation conditions. In this paper, maize was used as the research object, and different irrigation amount treatment was set up to study the distribution of Na$^+$ and K$^+$ in corn under drip irrigation conditions, and the transport selectivity of corn to Na$^+$ and K$^+$ was analyzed. The results show that the Na$^+$ absorbed by corn is mainly distributed in roots and K$^+$ is mainly distributed in stems and leaves; the transport selectivity coefficient decreases with the increase of irrigation amount, and the increase of Na$^+$/K$^+$ value is the improvement of salt tolerance of corn when irrigation amount is small. Corn can inhibit the transport of Na$^+$ to the ground by enhancing the transport of K$^+$ and reduce the damage to corn.

1. Introduction
The total area of saline-alkali land in China is 99.13 million hm$^2$[1]. It is distributed in the northwest, north, northeastern of China and coastal areas. The saline-alkali land in Tianjin is mainly distributed in the coastal area and inland low-lying areas, with a total area of 49.3×10$^3$ hm$^2$, accounting for 41.4% of the total land area of Tianjin. Soil salinization is a major obstacle to agricultural production. Crops grow in saline-alkali soil. When the concentration of salt ion in the soil exceeds a certain amount, the salt ion absorbed by the crops accumulates in the crop body, which will cause ion toxicity to the crops [2]. Drip irrigation technology is one of the successful techniques to improve saline-alkali soil. It slowly irrigates crops through the dripper and forms a water-salt environment that is conducive to crop growth around the crop roots [3].

The main ion toxicity in salinized soil is Na$^+$, which will destroy the membrane structure, leading to membrane permeability loss, and the nutrient absorption function of crops will be inhibited, which will affect the growth and development of crops. Corn is one of the main crops in Tianjin. Exploring the distribution of salt ions in corn, revealing the salt tolerance mechanism of corn, and effectively utilizing the considerable reserve resources of saline-alkali land in Tianjin coastal area is of great significance for increasing corn yield. At present, domestic and foreign research mainly focuses on the comparison of salt tolerance between different crop varieties under salt stress [2], but there is lack of research on the transport selectivity of salt ions in drip irrigation saline-alkali soil. In this paper, the selectivity transportation of corn for Na$^+$ and K$^+$ was explored through studying the distribution characteristics of Na$^+$ and K$^+$ in various organs of corn, in order to improve the effective utilization of saline-alkali land, which is of great significance for promoting the sustainable development of agricultural production.
2. Materials and methods

2.1. Test area
The test was carried out in the experimental field of Gegu Town, Jinnan District, Tianjin. The area of the test field is 50.0 m × 9.3 m. This area belongs to the warm temperate semi-humid monsoon continental climate with sufficient sunshine, significant monsoon and distinct four seasons. The irrigation water of farmland is mainly groundwater. The basic chemical properties of the experimental soil are: in the 0-20 cm soil layer, salt content 1.19 g/kg, soil available phosphorus 18.33 mg/kg, soil nitrate nitrogen 7.18 mg/kg, soil bulk density 1.62 g/cm³.

2.2. Test design
The tested corn variety is Zhengdan 958. The corn was planted on April 22, 2017 and harvested on August 14. The whole growth period was 115 days, the plant spacing was 25 cm, and the row spacing was 60 cm. The drip irrigation is set up with a pipe in a row. The distance between the drip irrigation pipes is 60 cm, the diameter of the pipe is 1.6 cm, the distance between the dripper is 30 cm, the working pressure is 0.1 MPa, and the flow rate of the dripper is 1.38 L/h. This experiment sets two treatments of LI₁₀ and LI₂₀. The irrigation quotas for LI₁₀ and LI₂₀ treatment are 10 mm and 20 mm respectively, and each treatment has 3 repetitions. The irrigation time and irrigation quota of corn during the whole growth period are shown in Table 1.

Table 1. Water irrigation time and irrigation quota during the whole growth period of corn

| Treatments | Jointing stage | Big bell stage | Irrigation quota |
|------------|----------------|----------------|------------------|
| LI₁₀       | 20 mm          | 20 mm          | 40 mm            |
| LI₂₀       | 40 mm          | 40 mm          | 80 mm            |

2.3. Sample collection and determination
Corn samples were collected is May 23 (seedling stage), June 10 (jointing stage), July 13 (big bell stage), July 28 (filling stage), August 14 (mature stage). 3 uniform corns were selected and bring back to the laboratory each time, the roots, stems and leaves of corn were washed separately, then they were killed at 108 °C for 30 min, dried at 80 °C to constant weight, then they were grinded with a grinder and screened through a 50 mesh sieve, stored in a sealed bag. The tested liquid was prepared by digesting with nitric acid-perchloric acid, and the concentrations of Na⁺ and K⁺ were determined by flame atomic absorption spectrophotometry (AA-6300C, Japan).

3. Results and analysis

3.1. Distribution of Na⁺ in roots, stems and leaves
Figure 1 shows the distribution of Na⁺ in corn roots, stems and leaves treated with LI₁₀ and LI₂₀. It can be seen from Figure 1 that the Na⁺ concentration in corn roots is the highest under different irrigation treatments, and the Na⁺ concentration in stems and leaves is small, indicating that Na⁺ absorbed by corn is mainly accumulated in roots. The Na⁺ concentration in the roots from the seedling stage to the jointing stage decreased with different irrigation amount, and the Na⁺ concentration in the roots from the jointing stage to the big bell stage showed an upward trend. During this period, there was no irrigation, the soil salinity was higher, and the absorption of Na⁺ in corn roots also increased. Under different irrigation doses, the change of Na⁺ concentration in stems and leaves during the whole growth period was consistent, showing a decreasing-increasing-decreasing-increasing trend with a small change range.
3.2. Distribution of K\textsuperscript{+} in roots, stems and leaves

Figure 2 shows the distribution of K\textsuperscript{+} in roots, stems and leaves of corn. It can be seen from Figure 2 that the K\textsuperscript{+} concentration in the roots and stems of corn under different irrigation conditions is larger, and the K\textsuperscript{+} concentration in the roots is smaller, indicating that K\textsuperscript{+} mainly accumulates in stems and leaves. The K\textsuperscript{+} concentration in the roots of LI\textsubscript{20} showed a downward trend, and the concentration of K\textsuperscript{+} in the roots of LI\textsubscript{10} treatment increased from the seedling stage to the jointing stage. It is due to the irrigation amount of LI\textsubscript{20} treatment was larger, and the effect of soil salinity was better. The K\textsuperscript{+} concentration in the roots from the jointing stage to the maturity stage decreased with different irrigation amount. The K\textsuperscript{+} concentration in stems and leaves decreased during the whole growth period under different irrigation conditions, which may be due to the mature harvest of corn and the decrease of K\textsuperscript{+} demand. The K\textsuperscript{+} concentrations in all three organs decreased.

3.3. Selectivity of Na\textsuperscript{+} and K\textsuperscript{+} during root-to-stem transportation

The transport selectivity coefficient (TS) indicates that the salt ion entered to the corn root is transported to the aerial part with water metabolism, and the upper part of the organ is selective to ions, and which is selectively distributed to various organs. The calculation formula is:

$$TS_{K,Na} = \frac{\text{root Na}^+/\text{K}^+}{\text{stem Na}^+/\text{K}^+}$$

The larger TS\textsubscript{K,Na}, the greater the selectivity of corn for K\textsuperscript{+} transport to stems, and the more Na\textsuperscript{+} remains in the roots.

Table 2 shows the TS\textsubscript{K,Na} of the root-to-stem transport process under LI\textsubscript{10} and LI\textsubscript{20} treatments. It can be seen from Table 2 that TS\textsubscript{K,Na} of LI\textsubscript{20} was less than LI\textsubscript{10} treatment during the whole growth period. The TS\textsubscript{K,Na} of the root-to-stem transportation process was larger at the seedling stage and the jointing stage under different irrigation rates. The main reason was that the corn in the seedling stage
and jointing stage grew vigorously, and the corn needs a large amount of K\(^+\) to maintain its normal physiological metabolic function. K\(^+\) transportation was enhanced, and Na\(^+\) transportation was inhibited, Na\(^+\) was accumulated in the root system, in order to reduce the damage of Na\(^+\) to the aboveground part. Under the different irrigation amount, the TS\(_{K,Na}\) in the big bell stage and the filling stage are small. At this time, the corn grows slowly, and does not need a lot of K\(^+\). At maturity, TS\(_{K,Na}\) increased, and reached the highest value. There was no irrigation at this stage. The soil salinity of both treatments was higher. The corn absorbed more Na\(^+\), also absorbed more K\(^+\), and TS\(_{K,Na}\) increased.

Table 2. TS\(_{K,Na}\) in the process of root-to-stem transport under LI\(_{10}\) and LI\(_{20}\) treatments

| Treatments     | LI\(_{10}\) | LI\(_{20}\) |
|----------------|------------|------------|
| Seedling stage | 10.15      | 7.23       |
| Jointing stage | 9.39       | 6.92       |
| Big bell stage | 5.10       | 4.76       |
| Filling stage  | 5.80       | 4.62       |
| Mature stage   | 12.00      | 11.06      |

3.4. Selectivity of Na\(^+\) and K\(^+\) during stem-to-leaf transportation

The TSK and Na formulas for stem-to-leaf transport are:

\[
TS_{K,Na} = \frac{\text{stem Na}^+/K^+}{\text{leaf Na}^+/K^+}
\]

The larger TS\(_{K,Na}\), the greater the selectivity of corn for K\(^+\) transport to leaf, and the more Na\(^+\) leaving in the stem.

Table 3 shows the TS\(_{K,Na}\) of stem-to-leaf transport under LI\(_{10}\) and LI\(_{20}\) treatment. It can be seen from Table 3 that the stem-to-leaf TS\(_{K,Na}\) is much smaller than the root-to-stem TS\(_{K,Na}\), because the root system has intercepted Na\(^+\) resulting in less Na\(^+\) transported into the stem. At the seedling stage, TS\(_{K,Na}\) of LI\(_{20}\) treatment was greater than that of LI\(_{10}\) treatment, and from the jointing stage to the mature stage TS\(_{K,Na}\) of LI\(_{20}\) treatment was less than that of LI\(_{10}\) treatment. The TS\(_{K,Na}\) of the stem-to-leaf transport process under different irrigation rates increased firstly, then decreased, and then increased, and reached the maximum at maturity.

Table 3. TS\(_{K,Na}\) in the process of stem-to-leaf transport under LI\(_{10}\) and LI\(_{20}\) treatments

| Treatments     | LI\(_{10}\) | LI\(_{20}\) |
|----------------|------------|------------|
| Seedling stage | 0.46       | 0.53       |
| Jointing stage | 0.96       | 0.89       |
| Big bell stage | 0.61       | 0.47       |
| Filling stage  | 0.94       | 0.57       |
| Mature stage   | 1.98       | 1.03       |

4. Conclusions and discussion

Khan\(^{[4]}\) research showed that the growth of corn was slow after salt stress, and the dry matter accumulation rate of plants slowed down. In this paper, the concentration of Na\(^+\) and K\(^+\) in corn roots, stems and leaves under saline-alkali drip irrigation was determined, the distribution of Na\(^+\) and K\(^+\) in corn was analyzed, and the effects of irrigation on the transport selectivity of Na\(^+\) and K\(^+\) in corn were discussed. The results showed that the distribution of Na\(^+\) and K\(^+\) in corn under different irrigation rates was basically the same. Na\(^+\) was mainly distributed in roots, and K\(^+\) was mainly distributed in stems and leaves, which was consistent with previous salt stress test results\(^{[5]}\). Na\(^+\) and K\(^+\) have similar ionic radii and hydration energy, and the two will compete with each other for the same
binding site of transporters. K’ has the effect of inhibiting Na⁺. This study found that \( T_{S_{K, Na}} \) of stem-to-leaf transport and root-to-stem transport process was both LI\(_{20}\) treatment less than LI\(_{10}\) treatment. The irrigation amount of LI\(_{20}\) was greater than LI\(_{10}\) treatment, so there was higher salinity concentration in LI\(_{10}\) treatment soil, and corn can selectively transport more K’, using higher K’ concentration, maintaining the balance of Na⁺/K’ for osmotic adjustment and improving the salt tolerance of corn, which is consistent with the salt tolerance mechanism of cotton \([6]\).

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