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Effects of Saline Water Drip Irrigation on Salt Ion Distribution and Quality in the Cistanche deserticola Parasitic System Postprint

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Abstract

To investigate the effects of saline water drip irrigation on salt ion distribution within the artificially cultivated Cistanche deserticola parasitic system and the quality of C. deserticola, several sample plots with substantially different irrigation water salinities were selected at the margin of the Taklamakan Desert in the Tarim Basin. Soil, Haloxylon ammodendron, and C. deserticola samples were collected to analyze salt ion contents in soil and various components of the parasitic system, as well as the contents of primary medicinal constituents in C. deserticola. The results demonstrated that: (1) Under high-salinity drip irrigation, salt ion contents in roots, main stems, and assimilating branches of H. ammodendron inoculated with C. deserticola exhibited the following pattern: assimilating branches > roots > stems, and the salt ion content in C. deserticola was comparable to that in the host root system; (2) Total salt, Na^+, and Cl^- contents in C. deserticola all increased with rising irrigation water salinity; K^+ accounted for one-third of the total salt content in C. deserticola, indicating a strong capacity for K^+ absorption and enrichment, yet K^+ content did not exhibit significant differences in response to variations in irrigation water salt concentration; (3) The content of phenylethanoid glycosides, the principal medicinal components in C. deserticola, increased with elevated irrigation water salinity, and salt stress contributed to stimulating the accumulation of primary medicinal components in C. deserticola. Consequently, higher-salinity saline water drip irrigation can enhance the quality of C. deserticola; however, attention must be devoted to the impacts of long-term high salt stress on the host H. ammodendron, rendering the establishment of a rational irrigation regime essential.

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Full Text

Effects of Saline Water Drip Irrigation on Salt Ion Distribution and Quality in the Haloxylon ammodendron-Cistanche deserticola Parasitic System

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Abstract

To investigate the effects of saline water drip irrigation on salt ion distribution within the Haloxylon ammodendron-Cistanche deserticola parasitic system and on the quality of C. deserticola, we conducted a study at the edge of the Taklimakan Desert in the Tarim Basin. Several sample plots with markedly different irrigation water salinities were selected, and samples of soil, H. ammodendron, and C. deserticola were collected to analyze salt ion content in the soil and various parts of the parasitic system, as well as the main medicinal components of C. deserticola. The results demonstrated three key findings. First, under high-salinity drip irrigation, the salt content in roots, main stems, and assimilating branches of H. ammodendron inoculated with C. deserticola followed the order: assimilating branches > coarse roots > fine roots > stems, while the salt ion content in C. deserticola was similar to that in the host root system. Second, the total salt, Na^+, and Cl^- contents in C. deserticola all increased with rising irrigation water salinity; K^+ accounted for approximately one-third of the total salt content, indicating a strong capacity for K^+ absorption and enrichment, yet K^+ content did not show significant variation with changes in irrigation water salinity. Third, the content of phenylethanol glycosides—the primary medicinal constituents in C. deserticola—increased with irrigation water salinity, suggesting that salt stress stimulates accumulation of these key medicinal components. Consequently, higher-salinity drip irrigation can improve C. deserticola quality, though attention must be paid to the long-term effects of high salt stress on the host H. ammodendron, making the development of a rational irrigation regime essential.

Keywords: saline water drip irrigation; Cistanche deserticola; salt ions; medicinal quality

Cistanche deserticola Ma is a perennial root-parasitic herb belonging to the family Orobanchaceae. It is a traditional and valuable medicinal material primarily distributed in the arid regions of northwestern China. With increasing market demand, wild resources are 濒临枯竭 (approaching depletion), and artificial cultivation has become the main source. Currently, the contradiction between ecological and agricultural water use is prominent in arid regions, making the exploitation of saline groundwater resources for C. deserticola cultivation increasingly common. However, high-salinity irrigation water can cause ion toxicity, inhibiting crop growth and reducing yields. *Haloxylon ammodendron*, the host plant of C. deserticola, is a typical euhalophyte with strong salt tolerance. Studies have shown that H. ammodendron can continue growing under saline water irrigation and can even be inoculated with C. deserticola at salinities up to 28–50 $g \cdot L^{-1}$. As a holoparasite, C. deserticola obtains all nutrients from its host through haustoria that tightly connect the two organisms, effectively functioning as an organ of the host. The source-sink relationship between them facilitates material and information exchange. However, few studies have examined the H. ammodendron-C. deserticola parasitic system as an integrated whole, particularly regarding salt ion dynamics under high-salinity irrigation. The effects of high-salinity environments on salt content and medicinal quality in C. deserticola remain unclear. This study, conducted in southern Xinjiang—the primary cultivation region—analyzes salt ions in the parasitic system and medicinal components of C. deserticola under varying salinity levels. The findings are significant for developing saline water resources for C. deserticola cultivation.

1. Materials and Methods

1.1 Study Sites

The study was conducted at three C. deserticola cultivation bases located on the edge of the Taklimakan Desert: the Second Division 34th Branch (area: 2 hm^2), the First Division Alar (area: 15 hm^2), and Hotan Cele (area: 65 hm^2). All sites experience a warm temperate extreme arid continental climate with scarce precipitation, high evaporation potential, long sunshine hours, and strong wind-sand activity. Annual rainfall is generally below 50 mm, while evaporation exceeds 3000 mm. The soil at the Second Division site is sandy loam, while Alar and Cele have mobile aeolian sandy soil. Haloxylon ammodendron was planted in 2012 at the Second Division and Cele sites, and in 2013 at Alar, all using a row spacing configuration of 1 m $\times$ 3 m with drip irrigation and no fertilizer application.

The irrigation regimes were as follows: the Second Division site used high-salinity groundwater (45.08 $g \cdot L^{-1}$); Alar employed an alternating irrigation mode with mixed channel water and freshwater from May to October (mineralization 12.3 $g \cdot L^{-1}$); and Cele used groundwater (13.92 $g \cdot L^{-1}$) with freshwater irrigation as a control (1.73 $g \cdot L^{-1}$). The irrigation schedule was uniform across sites, with a quota of 30 $L \cdot plant^{-1} \cdot application^{-1}$ and 22–24 applications annually. The salt ion composition of irrigation water is presented in .

1.2 Sample Collection and Analysis

Soil samples were collected in early October during the late growth season. At each site, random sampling points (at drip emitters) were selected to collect rhizosphere soil from the inoculation layer at 40–45 cm depth. Soil total soluble salts were determined by the residue drying method, while K^+, Na^+, Ca^{2+}, and Mg^{2+} were measured by ion chromatography and Cl^- by potentiometric titration.

Haloxylon ammodendron samples were collected in early October. At each site, one H. ammodendron plant inoculated with C. deserticola was selected, and four organs were sampled: main root, fine roots (diameter < 2 mm), main stem, and assimilating branches (middle portion). After drying, salt ions were measured by ion chromatography and total salt by the residue drying method.

Cistanche deserticola samples were collected in early April during the emergence period. All samples were one-year-old plants. At each site, five plants at the soil-emergence stage were randomly selected, air-dried, and ground into powder for homogeneous mixing. Salt ion content was determined using the same methods as for H. ammodendron. The contents of primary medicinal components —phenylethanol glycosides including echinacoside, verbascoside, and acetylverbascoside—were measured by HPLC (Thermo Ultimate 3000).

1.3 Data Processing

Data were analyzed using SPSS 26 software for one-way ANOVA, with Duncan' s multiple range test for post-hoc comparisons. Differences were considered statistically significant at $P < 0.05$. Figures were generated using Origin 2018.

2. Results

2.1 Salt Ion Distribution in the Parasitic System

The distribution of salt ions across different organs of the parasitic system revealed several notable patterns. In the host H. ammodendron, both total salt and individual salt ion contents followed the order: assimilating branches > coarse roots > fine roots > stems. Specifically, Ca^{2+} showed a different pattern, with the highest content in fine roots and lowest in stems. Assimilating branches accumulated 3.1 times more total salt than main roots and fine roots, while stems contained only one-third of the salt in assimilating branches. The similar salt content between main and fine roots indicates that H. ammodendron concentrates most salt in its assimilating branches.

The K^+ distribution pattern resembled that of total salt, while Na^+ distribution was opposite, with higher content in assimilating branches than in fine roots. In the parasite C. deserticola, total salt content was comparable to that in host fine roots and significantly higher than in host stems. The K^+ content in C. deserticola was similar to that in host assimilating branches and substantially higher than in fine roots, whereas Na^+ and Cl^- contents were lower than in fine roots and similar to stem levels.

The K^+/Na^+ ratio varied among organs, with relatively high values in fine roots, main stems, and C. deserticola, all exceeding 1.5. In contrast, assimilating branches showed the lowest ratios. Fine roots and main stems had ratios of 1.885 and 1.502, respectively, while C. deserticola maintained a ratio of 1.885.

2.2 Salt Ion Content in Cistanche deserticola Across Sampling Sites

As shown in [Figure 2: see original paper], the total salt and individual salt ion contents in C. deserticola increased with irrigation water mineralization and soil salinity across the three sampling sites. The proportion of K^+ in total salt reached 84-88%, demonstrating a clear trend of increasing with irrigation and soil salinity. However, K^+ content did not exhibit significant differences among sites.

The K^+/Na^+ ratio showed an inverse relationship to soil salt content, decreasing as soil salinity increased. Significant differences in K^+/Na^+ ratio were observed for C. deserticola grown in the same soil type under different saline water irrigation conditions. In sandy loam soil, the K^+/Na^+ ratio was lower at the higher-salinity site compared to the lower-salinity site, while the opposite pattern was observed in mobile aeolian sandy soil.

2.3 Biochemical Active Substance Content in Cistanche deserticola

The total phenylethanol glycoside content (total glycosides) in C. deserticola increased with irrigation water mineralization and soil total salt content. In sandy loam soil, the total glycoside content at the high-salinity site was 2.8 times that at the low-salinity site. Among the three constituent compounds, verbascoside and echinacoside showed similar increasing trends with irrigation and soil salinity, while cistanoside A showed no significant differences. In mobile aeolian sandy soil, C. deserticola exhibited consistent patterns, with total glycosides and the three individual compounds all increasing under saline irrigation. The total glycoside content under saline irrigation was 2.2 times that under freshwater irrigation. Specifically, acetylverbascoside, echinacoside, and cistanoside A contents were 2.2, 2.3, and 2.1 times higher, respectively, under saline compared to freshwater irrigation.

3. Discussion

3.1 Effects of Saline Water Drip Irrigation on Salt Ion Distribution in the Parasitic System

Saline water drip irrigation increases soil salinity, which negatively affects plant growth. However, plants have evolved tolerance mechanisms during long-term environmental adaptation. Euhalophytes like H. ammodendron possess unique protective mechanisms, such as compartmentalizing salts into vacuoles or storage organs to avoid damage to growing tissues. Our results show that within the host H. ammodendron, salt ion content decreased sequentially from assimilating branches to main roots, fine roots, and stems, consistent with findings from Cui et al. The highest salt content in assimilating branches reflects their succulent nature and well-developed vacuoles, enabling effective Na^+ compartmentalization to maintain cellular osmotic potential. Roots serve as the primary organ for nutrient and mineral absorption but maintain low salt content (only 17% of that in assimilating branches), indicating a protective mechanism for root physiological function. Stems function primarily as transport rather than storage organs, explaining their lowest salt content. This distribution pattern likely represents an adaptive advantage for H. ammodendron in high-salinity environments.

In the H. ammodendron-C. deserticola parasitic system, C. deserticola salt ion content (including total salt, Na^+, and Cl^-) was comparable to host root levels and substantially lower than in assimilating branches, suggesting limited salt transfer to the parasite. The mechanism underlying this pattern requires further investigation.

The K^+/Na^+ ratio serves as an indicator of plant salt tolerance. Appropriate K^+ levels promote growth and drought resistance in the xerophyte H. ammodendron, while excessive Na^+ becomes inhibitory. In this study, irrigation water K^+ concentrations reached 14.0 $mg \cdot g^{-1}$ and 3.8 $mg \cdot g^{-1}$, both exceeding reported thresholds. Haloxylon ammodendron accumulated K^+ in vacuoles to adapt to environmental stress rather than excluding Na^+. Within the parasitic system, H. ammodendron fine roots and C. deserticola maintained high K^+/Na^+ ratios, with C. deserticola showing even higher values than fine roots. This indicates that C. deserticola selectively absorbs and enriches K^+ while restricting Na^+ influx, forming a self-protection mechanism against high-salinity stress.

3.2 Effects of Saline Water Drip Irrigation on Salt Content in Cistanche deserticola

The host root system serves as the connection point between C. deserticola and its host, forming an integrated whole through source-sink relationships. As the "source," H. ammodendron continuously transfers required substances to the C. deserticola "sink," making the host' s physiological state critical for parasite development. Our results show that higher irrigation salinity increased salt content in host roots, leading to corresponding increases in total salt and Na^+, Cl^- contents in C. deserticola, demonstrating that the parasite responds to changes in host growing conditions.

Unlike Na^+ and Cl^-, K^+ content in C. deserticola showed no significant differences among sampling sites and did not increase with soil salt content. Previous studies indicate that C. deserticola possesses strong K^+ absorption capacity and exhibits significant K^+ enrichment at different growth stages. Our findings support this conclusion, revealing that C. deserticola maintains selective K^+ uptake even under high salinity.

3.3 Effects of Saline Water Drip Irrigation on Main Medicinal Active Components in Cistanche deserticola

Cistanche deserticola contains various active constituents including phenylethanol glycosides, iridoids, lignans, and polysaccharides, with phenylethanol glycoside content serving as a primary quality indicator. These glycosides and terpenoids are secondary metabolites produced through long-term adaptation to environmental stress. Previous research demonstrated that drought stress promotes accumulation of echinacoside and verbascoside in C. tubulosa suspension cells. Our results similarly show that increased irrigation water mineralization and soil salinity significantly enhanced phenylethanol glycoside content in C. deserticola across different soil types. Clearly, salt stress promotes secondary metabolite production, benefiting accumulation of medicinal components.

However, long-term high-salinity stress can inhibit host H. ammodendron growth. Therefore, in practical applications of saline water irrigation for C. deserticola cultivation, balancing host health and biomass accumulation with parasite quality improvement is crucial. Determining appropriate saline irrigation thresholds and developing rational irrigation schedules are key to sustainable industry development.

Conclusions

Based on analysis of soil, parasitic system salt ions, and C. deserticola medicinal components across sites with varying irrigation salinity, we conclude:

1. Under high-salinity drip irrigation, C. deserticola salt ion content in the H. ammodendron-C. deserticola parasitic system resembles that of host roots and remains far lower than in host assimilating branches. Cistanche deserticola resists high-salinity stress through selective ion absorption.

2. Under high-salinity drip irrigation, total salt, Na^+, and Cl^- contents in C. deserticola increase with irrigation salinity. The parasite exhibits strong K^+ absorption and enrichment capacity, though K^+ content shows no significant variation with irrigation salinity.

3. The content of phenylethanol glycosides—key secondary metabolites—in C. deserticola increases with irrigation salinity. Considering host plant impacts, selecting appropriate saline irrigation thresholds and developing rational irrigation regimes are essential measures for sustainable C. deserticola industry development.

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