Postprint: Characteristics of Soil Nutrients and Enzyme Activities in Salinized Soils of the Qaidam Basin

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Abstract

To investigate the characteristics of soil nutrients and enzyme activities in soils with varying degrees of salinization in the Qaidam Basin, five sampling sites were sequentially selected along the direction from the Qarhan Salt Lake to the Kunlun Mountains to analyze the characteristics of soil nutrients and enzyme activities and their correlations. The results showed that: except for soil total potassium, the effects of soil salinization degree, soil depth, and their interaction on soil nutrient contents and soil enzyme activities were all significant ($P<0.05$). In soils with lower salinization degrees, nutrient availability (except for available potassium) and enzyme activities were higher, and decreased with increasing soil depth. Taking organic carbon and sucrase as examples, their contents in the S5 plot with the lowest salinization degree were 13.83 g · kg-1 and 21.01 mg · g-1 · d-1 (0~5 cm), 12.85 g · kg-1 and 19.29 mg · g-1 · d-1 (5~10 cm), 9.83 g · kg-1 and 12.19 mg · g-1 · d-1 (10~20 cm), significantly higher than those in S1 with the highest salinization degree: 8.56 g · kg-1 and 1.41 mg · g-1 · d-1 (0~5 cm), 8.40 g · kg-1 and 1.30 mg · g-1 · d-1 (5~10 cm), 8.33 g · kg-1 and 1.26 mg · g-1 · d-1 (10~20 cm). Correlation analysis showed that in plots with lower salinization degrees, soil enzyme activities showed significant or extremely significant positive correlations with most soil nutrients ($P<0.05$). Therefore, there were significant differences in the characteristics of soil nutrients and enzyme activities among soils with different salinization degrees in the Qaidam Basin; soil salinization reduces the availability of soil nutrients, inhibits soil enzyme activities, and decreases the decomposition rate of organic matter in soils.

Full Text

Characteristics of Nutrient and Enzyme Activity in Salt-Affected Soils of the Qaidam Basin

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Abstract

To explore the characteristics of nutrient and enzyme activity in salt-affected soils of varying degrees in the Qaidam Basin, five sampling points were selected along a transect from the Chahan Salt Lake to the Kunlun Mountains. Soil nutrient and enzyme activity characteristics and their interrelationships were analyzed. The results showed that soil salinization degree, soil depth, and their interactions significantly affected soil nutrient content and enzyme activity ($P<0.05$), with the exception of soil total potassium. In soils with lower salinity, nutrient availability (except for available potassium) and enzyme activity were higher and decreased with increasing soil depth. Taking organic carbon and invertase as examples, the contents in the S5 site with the lowest salinity degree were 13.83 g·kg^{-1} and 21.01 mg·g^{-1}·d^{-1} (0–5 cm), 12.85 g·kg^{-1} and 19.29 mg·g^{-1}·d^{-1} (5–10 cm), and 9.83 g·kg^{-1} and 12.19 mg·g^{-1}·d^{-1} (10–20 cm), respectively—significantly higher than those in the S1 site with the highest salinity degree, which had 8.56 g·kg^{-1} and 1.41 mg·g^{-1}·d^{-1} (0–5 cm), 8.40 g·kg^{-1} and 1.30 mg·g^{-1}·d^{-1} (5–10 cm), and 8.33 g·kg^{-1} and 1.26 mg·g^{-1}·d^{-1} (10–20 cm). Correlation analysis indicated that in sites with lower salinity, soil enzyme activity showed significant or extremely significant positive correlations with most soil nutrients ($P<0.05$). Therefore, distinct differences exist in the characteristics of soil nutrients and enzyme activity across different salinization degrees in the Qaidam Basin. Soil salinization reduces nutrient effectiveness, inhibits soil enzyme activity, and decreases the decomposition rate of soil organic matter.

Keywords: salinization; soil enzyme activity; soil nutrient; correlation analysis; Qaidam Basin

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1 Introduction

Soil salinization is a critical global environmental issue affecting ecological security and agricultural sustainability, severely constraining economic development worldwide, particularly in arid and semi-arid regions. Currently, global salt-affected soil area totals approximately 1.1$\times10^{9}$ hm^2, accounting for about 7% of total land area. China's salt-affected soil area reaches approximately 0.99×10^{8} hm^2, representing 6.62% of the nation's cultivated land. Soil salinization directly influences soil physical, chemical, and biological properties. While numerous studies have documented its impact on soil physicochemical characteristics, soil biological attributes are equally important indicators for evaluating soil quality and health. Soil enzymes, as products of microbial activity, participate in soil biochemical processes and are highly sensitive to environmental changes. Their activity correlates with soil physical and chemical properties and microbial characteristics, reflecting nutrient transformation status and comprehensive soil fertility to some extent.

Recent research on enzyme activity in salt-affected soils has attracted attention from scholars domestically and internationally, focusing primarily on distribution patterns of enzyme activity in different saline soil types and changes during soil amelioration. However, assessments of enzyme activity across varying salinization degrees in China's Qaidam Basin remain relatively scarce. This study investigates soil nutrient content and enzyme activity in salt-affected soils of different salinization degrees in the Qaidam Basin, analyzing their characteristics and correlations to evaluate soil fertility levels and degradation status, thereby providing theoretical support for utilization and restoration of these saline soil resources.

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2 Materials and Methods

2.1 Study Area Overview

The Qaidam Basin, located on the northern edge of the Qinghai-Tibet Plateau (35°00 –39°20 N, 90°16 –99°16 E), covers an area of 2.75×10^{5} km^2 with elevations ranging from 2427 to 6212 m. This important inland mountain basin features an arid climate with scarce rainfall, high evaporation, and extensive desertification, representing a typical plateau continental climate. Annual precipitation decreases from 200 mm in the southeast to 15 mm in the northwest, while mean annual temperature ranges from 1.1 to 5.1 °C. The region experiences large diurnal temperature variations exceeding 28 °C, with annual sunshine duration exceeding 3000 h and annual evaporation of 2200–3500 mm. Due to special climatic and hydrological conditions combined with irrational irrigation practices, soil salinization extent and area are increasingly severe. The Chahan Salt Lake, located in the central-eastern Qaidam Basin, is the largest and most abundant of the four major salt lakes, stretching approximately 168 km east-west and 20–40 km north-south, with an area of 5856 km^2.

2.2 Methods

2.2.1 Sample Site Selection To compare differences in soil enzyme activity across varying salinization degrees, five sampling points (S1–S5) were selected along a transect from Chahan Salt Lake to the Kunlun Mountains based on vegetation coverage, salt crust thickness, and salinity (represented by electrical conductivity). At each site, soil samples were collected using a soil auger at five points, then mixed by layer. Sampling depths were 0–5 cm, 5–10 cm, and 10–20 cm. Samples were divided into two portions: one air-dried and sieved for nutrient analysis, the other stored at 4 °C for enzyme activity measurement.

2.2.2 Measurement Methods Soil pH and electrical conductivity were measured using a pH meter and conductivity meter in a 1:5 soil-water suspension. Soil nutrient content was determined following methods from the Institute of Soil Science, Chinese Academy of Sciences. Soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), available phosphorus (AP), and available potassium (AK) were measured using the potassium dichromate volumetric method (external heating), Kjeldahl method, NaOH fusion-molybdenum antimony colorimetry, $NaHCO_3$ extraction-molybdenum antimony colorimetry, and ammonium acetate extraction-flame photometry, respectively.

Soil enzyme activities were determined following Guan Songyin's methods. Catalase (CAT), urease (UR), invertase (INV), and dehydrogenase (DHA) activities were measured using potassium permanganate titration, indophenol blue colorimetry, 3,5-dinitrosalicylic acid colorimetry, and triphenyltetrazolium chloride (TTC) reduction methods, respectively.

2.2.3 Statistical Analysis All experimental data are presented as means ± standard deviation. SPSS 20.0 software was used for one-way ANOVA to explore significant differences in soil enzyme activity across salinization degrees, with Duncan's method for multiple comparisons ($P<0.05$). Correlations between soil enzyme activity and nutrients were analyzed using Pearson correlation analysis. Two-way ANOVA was employed to test the effects of salinization degree, soil depth, and their interactions on soil nutrients and enzyme activities. Data were log-transformed before analysis to meet normal distribution requirements. Origin 8.6 software was used for graphical presentation.

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3 Results

3.1 Differences in Soil Nutrient Content Across Salinization Degrees

Two-way ANOVA revealed that soil salinization degree, soil depth, and their interactions significantly affected all soil nutrient contents except for the interaction effect on total potassium, with salinization degree showing a stronger effect than the interaction (Table 2). For the same depth, SOC, TN, TP, and AP contents increased significantly with decreasing salinization degree ($P<0.05$), while AK content showed a decreasing trend ($P<0.05$). For the same salinization degree, nutrient contents generally decreased with increasing soil depth (Fig. 2), demonstrating surface accumulation.

3.2 Differences in Soil Enzyme Activity Across Salinization Degrees

Two-way ANOVA showed that soil salinization degree, soil depth, and their interactions significantly affected all four enzyme activities, with salinization degree having a greater inhibitory effect than depth and their interactions (Table 3). In soils of the same depth, enzyme activities decreased significantly with increasing salinization degree, reaching maximum values at the S5 site with lowest salinity (Fig. 3). In soils of the same salinization degree, enzyme activities decreased with depth, showing minimum values in the 10–20 cm layer.

3.3 Correlation Analysis Between Soil Enzyme Activity and Nutrients

Correlation analysis revealed that in heavily salinized sites (S1–S2), enzyme activities showed significant correlations with only a few nutrients. In moderately salinized sites (S3–S4), urease showed relatively close relationships with nutrients, while catalase and dehydrogenase were more closely related in S3. With decreasing salinization (S5), enzyme activities showed significant or extremely significant positive correlations with most nutrients, including a significant positive correlation with AK content (Table 4). This indicates that these four enzyme activities can effectively reflect nutrient status in lower-salinity soils.

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4 Discussion

4.1 Impact of Salinization Degree on Soil Nutrients

Soil nutrient content is a crucial indicator of soil fertility. This study found significant differences in nutrient contents across salinization degrees in the Qaidam Basin. Except for AK, all nutrient contents increased significantly with decreasing salinization ($P<0.05$), indicating that intensified salinization severely inhibits soil fertility, consistent with previous findings. Salt accumulation reduces microbial quantity and activity, affecting the transformation of carbon, nitrogen, phosphorus, and potassium, thereby decreasing nutrient availability. High salinity causes nitrogen loss through nitrate and ammonium leaching, while also reducing phosphorus availability. Notably, AK content decreased with decreasing salinization, likely because lower salinity sites are farther from the potassium-rich Chahan Salt Lake, China's largest potassium-magnesium salt deposit. Vertically, nutrient contents decreased with depth (Fig. 2), showing surface accumulation consistent with general spatial distribution patterns and related to surface litter and microbial activity.

4.2 Impact of Salinization Degree on Soil Enzyme Activity

Soil enzyme activity is highly sensitive to environmental changes and serves as a catalyst for all biochemical reactions in soil, playing vital roles in material cycling and energy flow. Vegetation composition, soil nutrients, microbial quantity, and activity all influence enzyme activity. This study demonstrated that CAT, UR, INV, and DHA activities increased significantly with decreasing salinization ($P<0.05$), consistent with nutrient content patterns. Soil enzymes primarily originate from microbial secretions, and intensified salinization alters microbial communities, thereby affecting enzyme activity. Previous studies confirm that high salinity is unsuitable for microbial growth, reducing microbial quantity and activity and consequently decreasing enzyme activity. Additionally, enzyme activity decreased with soil depth (Fig. 3), consistent with literature reports. This may be attributed to: (1) litter from shrubs and herbs improving microbial quantity and diversity in surface soils, concentrating enzyme activity in the topsoil; and (2) nutrient surface accumulation enhancing nutrient availability and aeration in surface soils, promoting microbial activity and resulting in higher surface enzyme activity.

4.3 Relationship Between Enzyme Activity and Soil Nutrients

The relationship between enzyme activity and nutrients is complex, with different enzymes constrained by different nutrient types. In heavily salinized soils, enzyme activities showed significant correlations with only a few nutrients (Table 4), likely because high salinity and low organic matter limit CAT, UR, INV, and DHA activities. Other studies have similarly reported that soil organic carbon and organic matter content are the most important factors affecting enzyme activity, with high salinity inhibiting enzyme activity while low organic matter directly reduces nutrient transformation and organic matter decomposition. In lower-salinity soils, the significant correlations between DHA and INV activities with organic carbon content indicate high organic matter degradation and microbial activity. As the primary factor influencing enzyme activity, organic matter can provide energy and nutrients for microbes, promoting microbial growth and activity and thereby increasing enzyme activity. The significant positive correlation between UR activity and TN in lower-salinity soils indicates high nitrogen transformation and utilization capacity. Overall, the significant positive correlations between enzyme activities and most nutrients in lower-salinity soils suggest that these four enzyme activities can effectively reflect nutrient status, likely because reduced salinity increases enzyme activity, thereby enhancing the transformation of carbon, nitrogen, and phosphorus and increasing soil fertility. Meanwhile, increased organic carbon and other nutrients promote CAT, UR, INV, and DHA activities.

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5 Conclusion

Significant differences exist in soil nutrient and enzyme activity characteristics across different salinization degrees in the Qaidam Basin. Except for available potassium, soil nutrient contents and enzyme activities increase with decreasing salinization and decrease with increasing soil depth. Moreover, in lower-salinity sites, soil enzyme activities show significant or extremely significant positive correlations with most soil nutrients (particularly the significant correlations between dehydrogenase and invertase activities with organic matter content), effectively reflecting nutrient status and serving as indicators for evaluating soil fertility and degradation. In summary, soil salinization reduces nutrient availability and utilization efficiency, with high salt concentrations negatively impacting enzyme activity, inhibiting soil enzymes, and decreasing organic matter decomposition rates.

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