Soil Carbon Distribution Characteristics and Influencing Factors in Typical Desert Areas of Urad Rear Banner (Postprint)

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Date: 2026-01-30T16:53:16+00:00

Abstract

To gain an in-depth understanding of the distribution characteristics of soil carbon in the desert regions of northwestern China, this study takes the typical desert area in western Wulatehou Banner as the research object. Through a combination of profile investigation, sample collection, and laboratory analysis, we examined the distribution patterns of soil organic carbon and inorganic carbon contents in the study area and their influencing factors. The results show that: (1) Overall, soil organic carbon content decreases with increasing soil depth, declining from 1.92 $g \cdot kg^{-1}$ at the 0–20 cm depth to 0.57 $g \cdot kg^{-1}$ below 1 m depth. In contrast, soil inorganic carbon content increases with increasing soil depth, rising from 5.13 $g \cdot kg^{-1}$ at the 0–20 cm depth to 8.71 $g \cdot kg^{-1}$ below 1 m depth. Within the 0–120 cm depth, soil inorganic carbon content is 4.31 times that of organic carbon, and both soil organic and inorganic carbon contents exhibit high variability. (2) Among the soil physicochemical factors, all variables except available phosphorus and rapidly available potassium show significant or highly significant linear correlations with soil organic and inorganic carbon contents. (3) The random forest regression model explains 25% of the variation in soil organic carbon content and 70% of the variation in soil inorganic carbon content. Cation exchange capacity, ammonium nitrogen, silicon dioxide, silt content, iron oxides, and sand content are significant influencing factors for soil organic carbon content ($P < 0.05$), while silicon dioxide, sand content, iron oxides, and silt content are highly significant influencing factors for soil inorganic carbon content ($P < 0.01$). This study provides fundamental data support for research on carbon cycling processes and the assessment of carbon sequestration capacity in desert ecosystems.

Full Text

Soil Carbon Distribution Characteristics and Influencing Factors in Typical Desert Areas of Urad Rear Banner

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Abstract

To improve our understanding of soil carbon distribution characteristics in the desert regions of northwestern China, this study investigated the typical desert area in western Urad Rear Banner. Through a combination of profile investigation, sample collection, and laboratory analysis, the distribution characteristics and influencing factors of soil organic carbon and inorganic carbon content in the study area were explored. The results showed that: (1) The overall soil organic carbon content in the study area decreased with increasing soil depth, falling from 1.92 $g \cdot kg^{-1}$ in the $0-20$ cm layer to 0.57 $g \cdot kg^{-1}$ at depths below 1 m, whereas the overall soil inorganic carbon content increased with increasing soil depth, rising from 5.13 $g \cdot kg^{-1}$ in the $0-20$ cm layer to 8.71 $g \cdot kg^{-1}$ at depths below 1 m. The average inorganic carbon content across the $0-120$ cm depth was 4.31 times that of organic carbon, and both soil organic carbon and inorganic carbon exhibited high variability. (2) Among the soil physicochemical factors, all factors except available phosphorus and available potassium showed significant or highly significant linear correlations with soil organic carbon and inorganic carbon content. (3) Random forest regression models explained 25% of the variation in soil organic carbon content and 70% of the variation in inorganic carbon content. Cation exchange capacity, ammonium nitrogen, silica, silt content, iron oxides, and sand content were identified as significant influencing factors for organic carbon content ($P < 0.05$), while silica, sand content, iron oxides, and silt content were highly significant influencing factors for inorganic carbon content ($P < 0.01$). This study provides fundamental data support for research on carbon cycling processes and carbon sink capacity assessment in desert ecosystems.

Keywords: desert area; organic carbon; inorganic carbon; distribution characteristics; influencing factors

1 Introduction

To address the challenges posed by global climate change, China has proposed the “dual carbon”goals of “carbon peak”and “carbon neutrality,”aiming to achieve near-zero emissions by reducing carbon emissions and enhancing ecosystem carbon sink capacity. Desert ecosystems constitute an important component of the ecosystems in China’s northwestern arid and semi-arid regions, providing unique ecosystem services that play crucial roles in windbreak and sand fixation, water and soil conservation, and biodiversity maintenance. Moreover, desert ecosystems represent significant carbon pools in China’s terrestrial ecosystems and can function as carbon sinks. However, due to their vulnerability, they are highly susceptible to climate change and human activities, and the magnitude of their carbon sink and associated mechanisms remain uncertain. According to statistics, desert ecosystems in China cover a substantial portion of the national land area. With vegetation coverage and productivity far lower than other terrestrial ecosystems, carbon in desert ecosystems is primarily distributed in soils.

Soil carbon pools, as vital components of terrestrial ecosystem carbon reservoirs, comprise soil organic carbon (SOC) and soil inorganic carbon (SIC). The level of soil organic carbon content is jointly controlled by plant litter input and mineralization decomposition processes. Aboveground litter and underground dead roots represent the primary sources of soil organic carbon, while also being constrained by parent material and natural soil-forming factors. Compared with other ecosystems, desert ecosystems have lower organic carbon content per unit area, but their vast distribution area endows them with considerable organic carbon sequestration potential. Inorganic carbon constitutes the main component of soil carbon pools in desert ecosystems, typically existing as primary and secondary carbonates, with reserves often reaching several times that of organic carbon and accumulating at faster rates in soils. Soil moisture and parent material are important regulatory factors for its formation and transformation accumulation rates.

Current research on soil carbon distribution and influencing factors remains a critical field in global change studies. Scholars both domestically and internationally have conducted extensive research on carbon distribution and influencing factors in forest, grassland, and farmland ecosystems, demonstrating that vegetation type, land use patterns, and soil physicochemical factors all affect soil carbon distribution. However, previous studies on soil carbon in desert ecosystems have primarily focused on organic carbon, potentially leading to serious underestimation of their carbon sequestration capacity and limiting the ability to protect and enhance soil carbon sinks in arid regions under climate change scenarios. In arid regions, soil inorganic carbon accumulates more readily under conditions of low soil moisture and weak microbial activity, and is therefore receiving increasing attention. Conducting research on the distribution and influencing factors of soil carbon in desert ecosystems can improve understanding of regional biogeochemical cycles and is significant for ecological restoration, carbon sink capacity assessment, and terrestrial carbon cycle process research in northwestern China’ s desert regions.

2 Materials and Methods

2.1 Study Area Overview

The study area is located in the high plain region of western Urad Rear Banner, Bayannur City, Inner Mongolia, bordering Alxa Left Banner to the west, Hangjin Rear Banner and Dengkou County to the south, and South Gobi Province of Mongolia to the north. It represents a typical arid desert region in western Inner Mongolia. The soil types are primarily gray-brown desert soil and aeolian sandy soil, with desert landscapes mainly consisting of deserts and gobi. The climate is classified as a mid-temperate continental plateau climate, characterized by dry conditions and scarce precipitation. The average annual temperature is 6.5°C, with the lowest temperatures occurring in January. Annual precipitation is less than 100 mm, while annual evaporation can reach up to 2500 mm, far exceeding precipitation. The frost-free period is 160 days, and the freezing period extends from November to March of the following year. The average wind speed is 2.2 $m \cdot s^{-1}$. Vegetation is sparse with coverage mostly below 15%, dominated by xerophytic and super-xerophytic shrubs, semi-shrubs, and small semi-shrubs. The plant communities are primarily composed of *Salsola passerina*, *Kalidium foliatum*, *Reaumuria soongarica*, *Haloxylon ammodendron*, *Nitraria tangutorum*, *Artemisia ordosica*, *Caragana microphylla*, and *Achnatherum splendens* as dominant species.

2.2 Sample Collection

Soil represents the primary carbon sink in desert ecosystems. Taking the typical desert area in western Urad Rear Banner as the research object, soil samples were collected to determine total carbon, organic carbon, total phosphorus, cation exchange capacity, and oxide contents, analyzing the distribution characteristics of soil organic carbon and inorganic carbon in remote desert ecosystems and exploring the influence of physicochemical factors on carbon distribution to provide data support for strengthening research on carbon cycling processes and accurately assessing carbon sink capacity in arid desert ecosystems.

In July 2022, three profile survey routes were established around the Bayan Wendur Desert in western Urad Rear Banner. Profile sampling points were set along each route based on vegetation distribution and lithological characteristics (Table 1). Due to harsh environmental conditions and the uninhabited nature of most of the study area, profile point placement followed principles of road accessibility and relative uniform distribution. A total of 23 soil profile points were established across the three routes, with distances between adjacent profile points exceeding 500 m. Due to the complexity of regional soil formation processes, some locations had thin soil layers with high gravel content in lower horizons, so only surface layer samples were collected. For well-developed soil profiles, samples were collected according to the 0—20 cm, 20—40 cm, 40—60 cm, 60 − 80 cm, 80 − 100 cm, and 100 − 120 cm layer divisions, yielding a total of 103 stratified soil samples from the profiles. Meanwhile, undisturbed soil was collected using cutting rings according to the above layers for soil water content determination.

Before sample collection, information including elevation, latitude and longitude, landform, and dominant vegetation was recorded for each profile point. Stratified soil samples were collected from the profiles, thoroughly mixed within the

Note: Figure translations are in progress. See original paper for figures.