Distribution Characteristics of Soil Organic Carbon and Its Influencing Factors in Xilingol Grassland (Postprint)

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Abstract

Soil organic carbon is one of the important indicators for soil nutrient evaluation and quality analysis. Studying the spatial distribution patterns of soil organic carbon across different grassland types is beneficial for grassland ecological restoration and rational land use. Taking the Xilingol Grassland as the study area, kriging interpolation, correlation analysis, simple linear regression, and principal component analysis were employed to explore the spatial differentiation patterns of soil organic carbon, in order to reveal the degree of influence of different factors on grassland soil organic carbon. The results showed that: (1) In meadow steppe, soil organic carbon contents in the 0–10 cm, 20–30 cm, and 40–50 cm soil layers were 23.28 $g \cdot kg^{-1}$, 12.71 $g \cdot kg^{-1}$, and 9.28 $g \cdot kg^{-1}$, respectively; in typical steppe, the values were 16.75 $g \cdot kg^{-1}$, 10.75 $g \cdot kg^{-1}$, and 7.20 $g \cdot kg^{-1}$, respectively; and in desert steppe, the values were 1.62 $g \cdot kg^{-1}$, 2.00 $g \cdot kg^{-1}$, and 1.73 $g \cdot kg^{-1}$, respectively. This indicates that soil organic carbon content in both meadow and typical steppes gradually decreases with increasing soil depth, whereas no significant differences were observed among different soil layers in desert steppe. (2) Different grassland types exert varying degrees of influence on soil organic carbon content; for the same soil depth, the general pattern was meadow steppe > typical steppe > desert steppe. Horizontally, organic carbon content was consistent with vegetation coverage distribution, showing a gradual decreasing trend from southeast to northwest. (3) In the analysis of influencing factors, soil organic carbon exhibited extremely significant negative correlations with altitude, temperature, and pH ($P < 0.01$), extremely significant positive correlations with precipitation, soil water content, available nitrogen, and available phosphorus ($P < 0.01$), and no significant correlations with slope, aspect, or available potassium ($P > 0.05$). (4) The primary factors influencing soil organic carbon were available nitrogen, precipitation, and temperature, while secondary factors included soil water content and available potassium; therefore, attention should be paid to nitrogen input and the control of hydrothermal conditions across different grasslands.

Full Text

Distribution Characteristics and Influencing Factors of Soil Organic Carbon in the Xilin Gol Steppe

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Abstract

Soil organic carbon (SOC) is a crucial indicator for evaluating soil nutrients and quality. Investigating the spatial distribution patterns of SOC across different steppe types facilitates ecological restoration and rational land use in grassland ecosystems. This study examined the Xilin Gol steppe using Kriging interpolation, correlation analysis, univariate linear regression, and principal component analysis to explore spatial differentiation patterns of SOC and reveal the influence of various factors. The results demonstrated that: (1) In meadow steppe, SOC content in the 0–10 cm, 20–30 cm, and 40–50 cm soil layers was 23.28 $g \cdot kg^{-1}$, 12.71 $g \cdot kg^{-1}$, and 9.28 $g \cdot kg^{-1}$, respectively; in typical steppe, values were 16.75 $g \cdot kg^{-1}$, 10.75 $g \cdot kg^{-1}$, and 7.20 $g \cdot kg^{-1}$; and in desert steppe, values were 1.62 $g \cdot kg^{-1}$, 2.00 $g \cdot kg^{-1}$, and 1.73 $g \cdot kg^{-1}$. SOC content in meadow and typical steppes decreased gradually with soil depth, whereas no significant differences existed among soil layers in desert steppe. (2) Different steppe types exerted varying influences on SOC content. For the same soil depth, SOC content generally followed the order: meadow steppe > typical steppe > desert steppe. Horizontally, SOC distribution aligned with vegetation coverage, gradually decreasing from southeast to northwest. (3) Correlation analysis revealed that SOC exhibited highly significant positive correlations ($P < 0.01$) with precipitation, soil water content, available nitrogen, and available phosphorus, and highly significant negative correlations ($P < 0.01$) with altitude, temperature, and pH. No significant correlations ($P > 0.05$) were found with slope, aspect, or available potassium. (4) Principal component analysis identified available nitrogen, precipitation, and temperature as the primary controlling factors of SOC, with soil water content and available potassium as secondary factors. Therefore, management should focus on regulating nitrogen input and hydrothermal conditions across different steppe types.

Keywords: soil organic carbon; distribution characteristics; influencing factors; Xilin Gol steppe

1 Introduction

Soil organic matter refers to all carbon-containing organic substances present in soil in various forms. As a fundamental component of soil fertility and quality, it represents a direct source of nutrients for plant growth. Most soil organic matter exists in the form of organic carbon, which participates in carbon cycling as either a carbon source or sink within terrestrial ecosystems. Under the influence of various factors, organic carbon exhibits distinct spatial distribution characteristics across different ecological environments. Consequently, studying the spatial distribution of SOC is essential for evaluating soil fertility and vegetation growth.

Research on SOC spatial distribution primarily focuses on horizontal and vertical dimensions. Regarding vertical distribution, scholars have investigated SOC characteristics in the Beijing plain area, Tibet' s Sygera Mountains, and Qinghai Lake wetlands, analyzing variation features across different soil depths. For horizontal distribution, studies have examined tea gardens in Wuyishan City, cultivated land around Kunming' s Dianchi Lake, and the Ebinur Lake wetland, revealing how different land use types influence SOC spatial distribution. Terrain factors significantly affect SOC content, as demonstrated in studies of Wuyishan tea gardens, Dianchi Lake farmland, and Aibi Lake wetlands. Vegetation type also plays a crucial role, with different plant communities producing varying SOC impacts.

Correlation analysis has identified significant relationships between SOC and environmental factors. In Inner Mongolia grasslands, SOC correlates significantly with soil water content and total nitrogen. Land use patterns emerge as important determinants of SOC content. Studies in Hainan' s secondary rainforests found highly significant positive correlations between SOC and total nitrogen, available nitrogen, and available phosphorus, highlighting the interplay between SOC and nutrient indicators.

The Xilin Gol steppe constitutes a vital component of Inner Mongolia' s grasslands, making SOC research in this region particularly important. Previous studies have yielded diverse results due to variations in research scale, scope, and regional characteristics. The geographical uniqueness of Inner Mongolia' s grasslands and their human-environment interactions have created uncertainty regarding spatial changes in SOC across different steppe types in both horizontal and vertical directions. Given that SOC responds to multiple interacting factors, this study investigates natural grasslands in the Xilin Gol region to analyze spatial distribution characteristics of SOC across meadow, typical, and desert steppes. The research examines influences of meteorological factors, terrain factors, soil water content, and soil physicochemical properties to identify primary controlling factors among numerous influences, providing fundamental references and theoretical support for grassland ecosystem stability and healthy soil quality development.

1.2 Data Collection and Sources

To investigate the influence of different steppe types on SOC, we established 30 sampling sites across the study area from east to west, considering terrain and vegetation types. The sampling transect passed through six counties: Sonid Right Banner, Erenhot City, Sonid Left Banner, Abag Banner, Xilinhot City, and East Ujimqin Banner. The sampling design included 10 sites in meadow steppe, 10 in typical steppe, and 10 in desert steppe. At each site, soil profiles were excavated to collect samples at depths of 0-10 cm, 20-30 cm, and 40-50 cm. Profile sampling prevented cross-contamination between layers and reduced error. Given that grassland vegetation typically has shallow root systems concentrated in surface layers, and that calcium accumulation layers generally appear below 30 cm, we employed stratified sampling to ensure representative characterization of SOC differences across steppe types.

A total of 270 soil samples (30 sites × 3 depths × 3 replicates) were collected using triangular sampling patterns at each site. Samples were placed in kraft paper bags, air-dried naturally in the laboratory, and passed through a 2 mm nylon sieve after removing large gravel and roots.

Meteorological data (annual average temperature and precipitation from 2000-2018) and other factors were obtained from the Resource and Environmental Science and Data Center. Terrain factors (altitude, slope, aspect) were extracted from ASTER GDEM data (30 m spatial resolution) sourced from the Geospatial Data Cloud. Land use type, soil type, and soil texture data were also incorporated into the analysis.

1.3 Methods

1.3.1 Laboratory Analysis Methods Soil organic carbon was determined using the potassium dichromate volumetric external heating method. Soil pH was measured potentiometrically, available potassium by NH_4OAC extraction-flame photometry, available phosphorus by molybdenum-antimony colorimetry, and available nitrogen by alkali diffusion method. Soil water content was measured gravimetrically: fresh soil samples were weighed in aluminum boxes (M_1), oven-dried at 105°C to constant weight (M_2), and calculated as: Soil water content (%) = $(M_1 - M_2) / M_2 \times 100\%$.

1.3.2 Coefficient of Variation The coefficient of variation (CV) measures data dispersion, calculated as $CV = (SD / AV) \times 100\%$, where SD is standard deviation and AV is mean value. Higher CV indicates greater variability. The classification standard: $CV > 100\%$ indicates strong variability, 10-100% moderate variability, and <10% weak variability.

1.4 Data Processing

Descriptive statistics, correlation analysis, and regression analysis were performed using SPSS 22.0. ArcGIS 10.6 was used for Kriging interpolation to generate horizontal distribution maps. Origin 8.5 and Canoco 5.0 were employed for chart production and principal component analysis, respectively.

2 Results and Analysis

2.1 Characteristics of Soil Organic Carbon Content in Different Steppe Types

Descriptive statistics for SOC across three steppe types and soil layers are presented in Table 1. For the same soil depth, meadow steppe consistently showed the highest SOC content, while variation coefficients generally followed the pattern: desert steppe > typical steppe > meadow steppe. In meadow steppe, maximum, minimum, and mean SOC values all decreased with depth, with significant differences between surface (0–10 cm) and deeper layers ($P < 0.05$). Variation coefficients showed the opposite trend: 40–50 cm > 20–30 cm > 0–10 cm, all indicating moderate variability. This pattern reflects the high surface biomass in meadow steppe, where SOC is primarily influenced by surface vegetation and root systems, causing spatial variability to increase from surface to deeper layers.

Typical steppe exhibited similar depth trends, with significant differences between surface and deeper layers ($P < 0.05$) but no significant difference between middle and deep layers. Variation coefficients showed a unique pattern: 20–30 cm > 0–10 cm > 40–50 cm, likely due to calcium accumulation layers appearing below 30 cm, which differentiated SOC characteristics in the 20–30 cm layer.

Desert steppe displayed no consistent depth pattern, with maximum, minimum, and mean values all highest in the 20–30 cm layer (1.62, 2.00, and 1.73 $g \cdot kg^{-1}$ for 0–10 cm, 20–30 cm, and 40–50 cm, respectively). No significant vertical differences were observed, reflecting sparse vegetation, extensive surface exposure, and dominance of aeolian sandy soils. Long-term accumulation has impoverished surface soil fertility, resulting in slightly lower surface SOC compared to the 20–30 cm layer, though not significantly. Below 30 cm, calcium accumulation layers reduce SOC content relative to the 20–30 cm layer, making the 20–30 cm layer most enriched in organic carbon.

Comparing steppe types at the same depth revealed significant differences in surface layer (0–10 cm) SOC content ($P < 0.05$), with meadow steppe > typical steppe > desert steppe. In the middle layer (20–30 cm), meadow and typical steppes showed minor differences but both differed significantly from desert steppe ($P < 0.05$). In the deep layer (40–50 cm), SOC declined markedly, mostly below 10 $g \cdot kg^{-1}$, with only a few eastern areas exceeding this threshold. Across the entire study area, SOC distribution aligned with steppe types, decreasing from meadow to typical to desert steppe, primarily due to differences in vegetation coverage and moisture.

2.2 Horizontal Distribution Characteristics of Soil Organic Carbon

Horizontal SOC distribution was analyzed using Kriging interpolation based on sampling site coordinates. As shown in Table 2 and Figure 2, mean SOC decreased with depth: 14.17 ± 10.33 g · kg^{-1} (0-10 cm), 8.71 ± 5.94 g · kg^{-1} (20-30 cm), and 6.18 ± 4.24 g · kg^{-1} (40-50 cm). Variation coefficients followed the pattern 0-10 cm > 40-50 cm > 20-30 cm, all indicating moderate variability. The surface layer (0-10 cm) showed the greatest instability due to surface biomass abundance.

SOC content exhibited a banded distribution from east to west, consistent with the three steppe types. In the 0-10 cm layer, SOC showed patchy distribution, with 15-20 g · kg^{-1} occurring as "islands." With increasing depth, vegetation influence weakened while altitude became a controlling factor—higher altitudes corresponded to lower SOC content. The study area' s altitude ranged from 769-1936 m, generally lower in the east and higher in the west. Surface SOC distribution was less affected by altitude than by surface litter accumulation.

2.3 Analysis of Influencing Factors on Layered Soil Organic Carbon

To clarify factors influencing SOC variation, we examined terrain factors (altitude, slope, aspect), meteorological factors (mean annual temperature, precipitation), soil water content, and soil chemical properties (pH, available nitrogen, available phosphorus, available potassium). Correlation analysis assessed the degree of influence each factor exerted on SOC across different soil layers.

2.3.1 Correlation with Terrain Factors Correlation analysis between three terrain factors and SOC across soil layers (Table 3) revealed negative relationships between altitude and SOC, with significant negative correlations in 0-10 cm and 20-30 cm layers ($P < 0.01$). This indicates altitude significantly influences surface SOC in Xilin Gol grasslands—higher altitudes correspond to lower SOC content. Slope and aspect showed no significant correlations with SOC across layers ($P > 0.05$). Slope primarily affects soil nutrient characteristics through surface leaching and water redistribution, but the study area' s gentle terrain (mostly 0°-2° slopes) prevented clear correlations. Aspect influences vegetation distribution through effects on precipitation, temperature, and solar radiation allocation, but in this region' s flat topography, aspect' s unstable nature and lack of long-term effects resulted in weak, non-significant impacts on SOC, consistent with findings from agricultural soils in southeastern Chongqing.

2.3.2 Correlation with Meteorological Factors Meteorological factors are essential natural influences on SOC. We analyzed 2000-2018 mean annual temperature and precipitation data. Climate conditions are primary determinants of steppe type distribution and vegetation net primary productivity, significantly influencing soil nutrient content. Results showed highly significant negative correlations between SOC and temperature across all depths ($P < 0.01$), with R^2

values of 0.532, 0.427, and 0.313 for 0-10 cm, 20-30 cm, and 40-50 cm layers, respectively. Temperature' s constraining effect weakened with depth. Higher temperatures reduce SOC by accelerating soil water evaporation, mineral dissolution and precipitation, and organic matter decomposition and humus formation, thereby promoting element migration and transformation while reducing organic carbon accumulation.

Precipitation showed highly significant positive correlations with SOC across layers ($P < 0.01$), with R^2 values of 0.612, 0.537, and 0.403, respectively. Precipitation' s influence weakened with depth compared to surface layers. In arid and semi-arid regions, limited precipitation is largely absorbed by plants for transpiration, reducing its impact on deeper soils. Precipitation affects particle decomposition and mineralization, playing a crucial role in the atmosphere-vegetation-soil ecological cycle.

2.3.3 Correlation with Soil Water Content Soil water content influences SOC primarily by affecting microbial activity, inhibiting carbon decomposition, and constraining carbon accumulation. Higher soil moisture reduces soil respiration, impedes aeration, and lowers organic matter mineralization, resulting in carbon input exceeding output and facilitating SOC storage. Linear regression between SOC and soil water content in corresponding layers showed significant positive correlations ($P < 0.05$), with correlation strength decreasing with depth: $R^2 = 0.512$, 0.437, and 0.356 for 0-10 cm, 20-30 cm, and 40-50 cm layers, respectively. This confirms soil water content as a significant SOC factor—greater water content reduces soil permeability, decreases carbon release, and increases accumulation, consistent with precipitation effects. Water influences carbon cycling through surface and subsurface leaching, and as a critical factor for vegetation growth, it promotes deeper root systems, enhanced microbial activity, and accelerated litter decomposition, all affecting SOC content.

2.3.4 Correlation with Soil Chemical Characteristics SOC is a key factor influencing soil fertility. Its interactions with available nitrogen, phosphorus, and potassium were examined. SOC showed highly significant negative correlations with pH across all layers ($P < 0.01$), with correlation strength weakening with depth. This indicates pH is an important SOC constraint. In strongly acidic or alkaline soils, microbial activity is restricted, weakening organic matter decomposition and transformation, thereby reducing SOC content.

SOC exhibited highly significant positive correlations with available nitrogen in all layers ($P < 0.01$), stronger than correlations with available phosphorus or potassium, demonstrating a strong positive relationship. Available nitrogen represents an external expression of soil nitrogen, which exists primarily as organic and inorganic forms. As a fundamental component of amino acids in organisms, nitrogen is essential for root growth and development, promoting absorption and utilization of other nutrients. Better root growth enhances microbial activity and carbon-nitrogen cycling, facilitating SOC accumulation.

SOC showed highly significant positive correlations with available phosphorus ($P < 0.01$), weakening with depth. Available potassium showed highly significant positive correlation only in the surface layer (0-10 cm, $P < 0.01$), with no significant relationships in deeper layers, similar to findings from cultivated land in Zhejiang Province.

2.3.5 Principal Controlling Factors of Soil Organic Carbon Principal component analysis (PCA) was conducted on factors influencing SOC, including meteorological, terrain, soil water content, pH, and available nutrients. Results (Figure 6) revealed distinct differences in factor effects. Among available nutrients, available nitrogen exerted the greatest influence, followed by available phosphorus, with available potassium having the weakest effect. Precipitation showed stronger influence than soil water content. Among promoting factors, slope had relatively weak effects. Among inhibiting factors, temperature was primary, with pH, altitude, and aspect having similar influence magnitudes.

Thus, SOC is closely related to nitrogen accumulation and has important geographical significance. The analysis confirms that in Xilin Gol grasslands, SOC is controlled by multiple interacting factors including climate, terrain, soil physicochemical properties, biomass, and human activities.

3 Discussion

3.1 Influence of Different Steppe Type Characteristics on Soil Organic Carbon

This study analyzed SOC interactions with meteorological, terrain, soil chemical, and water content factors, but did not examine soil texture, type, or land use patterns in detail. To address this, we classified soil texture by steppe type to explore physical characteristics' influence on SOC.

Across all three steppe types, soil texture was dominated by sand particles, with desert steppe showing the highest sand content (36.09% of total sand). Larger particle sizes in desert steppe result in poor water retention, loose structure, rapid organic matter decomposition, and weak organic matter storage capacity, leading to low nutrient content. Clay content was highest in meadow steppe (36.29% of total clay) and lowest in desert steppe. Higher clay content enriches surface organic matter, promotes better plant growth, reduces particle size, enhances water retention, improves microbial activity, and facilitates water conservation and carbon cycling, thereby increasing SOC content. Thus, soil texture is an important SOC factor, directly affecting soil bulk density and porosity.

Soil type distribution showed that calcium soils (chernozem, chestnut soil, brown calcic soil) dominated the Xilin Gol grassland. From east to west, surface humus content gradually decreased. Under grassland use, herbaceous root systems are shallow, limiting their influence on deep soils. Calcium accumulation became apparent below 30 cm, creating conditions unfavorable for organic matter accumulation and transformation, resulting in high surface SOC that decreased sharply with depth.

Arid soils, characterized by low humus content, sparse vegetation, and water deficiency, showed obvious calcium accumulation processes and extremely weak humus formation, affecting SOC content characteristics. In the southern agro-pastoral ecotone, some immature soils (primarily aeolian sandy soils) appeared due to improper land use causing soil degradation. These soils, located in the Hunshandake Sandy Land, consist mainly of meadow, steppe, and desert aeolian soils. Therefore, soil type plays a fundamental role in influencing SOC content variation.

Land use patterns alter soil structure and cycling mechanisms, affecting nutrient content. The study area was dominated by grassland in the north, cultivated land in the south, with scattered forest and unused land. Grassland soils primarily consisted of calcium soils with dark, fertile surface layers formed through interactions between herbaceous root systems and humus cycling. Unlike forest vegetation, grassland humus accumulation depends mainly on underground roots and surface plant residue decomposition, influencing carbon cycling and SOC content. Different land use types show varying sensitivity to SOC content across soil layers.

3.2 Influence of Climate, Topography, and Soil Physicochemical Properties on Soil Organic Carbon

Climate variation significantly affects SOC input and output processes. Different climate conditions influence vegetation types and biomass, indirectly determining SOC input changes. SOC decomposition and transformation are also affected by hydrothermal relationships, with temperature and precipitation influencing microbial activity and abundance. Microorganisms are the primary drivers of organic matter decomposition and transformation at different soil depths. Water and heat variations affect both plant photosynthesis rates and vegetation water requirements, influencing plant productivity, and may also alter microbial activity and decomposition rates, impacting SOC accumulation.

In the Xilin Gol grassland, SOC showed significant positive correlation with precipitation and negative correlation with temperature, consistent with research on the Northeast China Transect. Hydrothermal factors significantly affect SOC content variation.

Terrain influences SOC by redistributing temperature, water, and resources. Different altitudes create varying soil moisture and heat conditions, producing different SOC effects. In addition to altitude, slope and aspect also affect SOC. Different aspects influence plant photosynthesis rates and temperature-driven soil water evaporation. Slope magnitude affects soil physical properties —steeper slopes accelerate surface water loss and alter soil mechanical composition, subsequently affecting plant growth and microbial activity. Research in the middle Qilian Mountains showed that surface SOC increased with altitude, while subsurface SOC first increased then decreased with altitude. Our study found significant negative correlation between SOC and altitude across 0-50 cm, differing from previous results. This discrepancy may arise from our uniform analysis of surface, middle, and deep SOC across the large east-west grassland transect, where decreasing plant diversity from east to west and multiple factor interactions produced different outcomes. In grassland regions, vegetation quantity appears more influential than altitude.

Soil pH is a basic property affecting the existence, availability, and transformation of chemical elements. Strongly acidic or alkaline environments constrain microbial activity, weakening organic matter decomposition and reducing SOC. Our finding of significant negative correlation between pH and SOC aligns with research in the Heihe River basin.

In summary, SOC in the Xilin Gol steppe is jointly influenced by climate, terrain, soil physicochemical properties, biomass, and human activities. Natural and soil factors interact complexly, exerting compound effects on SOC. Human impacts manifest primarily through grazing and land use changes. In natural grasslands, grazing intensity affects vegetation primary productivity, reduces vegetation coverage, accelerates soil weathering, decreases nutrient content, and reduces biomass input to SOC. Livestock also enhance soil respiration, promoting carbon transformation and decomposition. To deeply understand grassland SOC dynamics, detailed analysis of factor mechanisms is needed to clarify SOC storage and its relationships with influencing factors for accurate assessment.

4 Conclusion

1. SOC content varied substantially across different steppe types in the Xilin Gol grassland. For the same soil depth, content generally followed: meadow steppe > typical steppe > desert steppe. Horizontally, SOC distribution aligned with vegetation patterns, decreasing from southeast to northwest. Vertically, SOC content followed 0-10 cm > 20-30 cm > 40-50 cm, with substantial reduction rates. All layers showed moderate spatial variability: 0-10 cm > 40-50 cm > 20-30 cm.

2. SOC content correlated significantly with meteorological, terrain, soil water content, and soil chemical factors. Specifically, SOC showed highly significant negative correlations ($P < 0.01$) with temperature, altitude, and pH, and highly significant positive correlations ($P < 0.01$) with precipitation, soil water content, available nitrogen, and available phosphorus. Correlations with slope, aspect, and available potassium were not significant ($P > 0.05$).

3. Principal component analysis identified available nitrogen, precipitation, and temperature as primary controlling factors of SOC content, with available phosphorus and soil water content as secondary factors.

References

[1] Hao Liting, Wu Faqi. Characteristics and evolution of soil nutrients of dam land and terrace in a loess hilly area[J]. *Bulletin of Soil and Water Conservation*, 2019, 39(5): 16-22.

[2] Li Li, Zhu Wenbo, Liu Junjie, et al. Soil organic carbon heterogeneity and its influencing factors in Baotianman nature reserve[J]. *Resources and Environment in the Yangtze Basin*, 2020, 29(3): 687-695.

[3] Batjes N H. Soil carbon stocks and projected changes according to land use and management: A case study for Kenya[J]. *Soil Use and Management*, 2004, 20(3): 350-356.

[4] Bouma J, Doran J W. Methods for assessing soil quality[M]. SSSA Special Publication No.49, Soil Science Society of America, 1996.

[5] Li Ling, Zhang Yu, Lu Xiaoyan, et al. Spatial distribution of soil organic matter in tea gardens of Wuyishan City[J]. *Journal of Yangtze University: Natural Science Edition*, 2019, 16(11): 60-65, 67.

[6] Tan Haiyan, Tong Jiangyun, Bao Tao, et al. Analysis on temporal and spatial variation of soil nutrient content in Dianchi district of Kunming City[J]. *Southwest China Journal of Agricultural Sciences*, 2019, 32(7): 1614-1620.

[7] Wang Yonghui, Jiao Li. The characteristics and storage of soil organic carbon in the Ebinur Lake wetland[J]. *Acta Ecologica Sinica*, 2016, 36(18): 5893-5901.

[8] Hu Yingjie, Kong Xiangbin, Yao Jingtao. Vertical distribution of soil organic carbon in plains areas of Beijing[J]. *Acta Ecologica Sinica*, 2019, 39(2): 561-570.

[9] Ma Heping, Dong Zhu. Vertical distribution characteristics of surface soil organic carbon on the north slope of Sygera Mountains, Tibet[J]. *Journal of Plateau Agriculture*, 2020, 4(2): 115-122.

[10] Cao Shengkui, Cao Guangchao, Chen Kelong, et al. Characteristics of alpine wetland soil organic carbon variations around Qinghai Lake[J]. *Soils*, 2013, 45(3): 392-398.

[11] Liu M Y, Chang Q R, Qi Y B, et al. Aggregation and soil organic carbon fractions under different land uses on the tableland of the Loess Plateau of China[J]. *Catena*, 2014, 115(11): 19-28.

[12] Zhu Meng, Feng Qi, Zhang Mengxu, et al. Patterns and influencing factors of soil organic carbon in grasslands of the middle Qilian Mountains[J]. *Acta Agrestia Sinica*, 2018, 26(6): 1322-1329.

[13] Zhang Zhibo, Liu Tao, Wu Qingshan, et al. Distribution characteristics and influencing factors of organic carbon content in soil of Dongping Lake wetland[J]. *Yellow River*, 2019, 41(7): 92-96, 147.

[14] Li Lanhua, Yang Yong, Sarengerile. Soil organic contents in relation to

soil physicochemical properties in typical steppe of Inner Mongolia[J]. *Anhui Agricultural Science Bulletin*, 2015, 21(19): 68-70.

[15] Huang Xianfei, Zhou Yunchao, Zhang Zhenming, et al. Characteristics and affecting factors of soil organic carbon under land uses: A case study in Houzhai River basin[J]. *Journal of Natural Resources*, 2018, 33(6): 1056-1067.

[16] Li Long, Zhou Fei, Tian Jie, et al. Effects of topographic factors on soil organic carbon content in semi-arid regions[J]. *Northern Horticulture*, 2019, 43(16): 104-109.

[17] Feng Sijie, Zhao Yanyun, Li Yuanheng, et al. The differences and influencing factors of topsoil organic carbon storage in typical steppe of Inner Mongolia[J]. *Chinese Journal of Grassland*, 2019, 41(2): 116-120.

[18] Motavalli P P, Palm C A, Parton W J, et al. Soil pH and organic C dynamics in tropical forest soils: Evidence from laboratory and simulation studies[J]. *Soil Biology and Biochemistry*, 1995, 27(12): 1589-1599.

[19] Shang Ze' an, Song Hanqing, Shu Qi, et al. Soil organic carbon distribution and the influencing factors in the tropical lowland secondary rainforest of Ganshiling, Hainan Island[J]. *Ecology and Environmental Sciences*, 2021, 30(2): 297-304.

[20] He Hongsheng, Tian Qing, Wang Lide, et al. Study on vegetation community characteristics and soil physical and chemical properties of abandoned land in Qingtu Lake[J]. *Arid Zone Research*, 2021, 38(1): 223-232.

[21] Cao Liguo, Liu Puxing, Zhang Kexin, et al. Analysis on response of grasslands to climate change and its spatial difference in Xilin Gol League[J]. *Arid Zone Research*, 2011, 28(5): 789-794.

[22] Bao Shidan. *Soil Agrochemical Analysis*[M]. 3rd ed. Beijing: China Agriculture Press, 2000: 22-114.

[23] Ma Zice, Yu Hongbo, Cao Congming, et al. Spatiotemporal characteristics of fractional vegetation coverage and its influencing factors in China[J]. *Resources and Environment in the Yangtze Basin*, 2020, 29(6): 1310-1321.

[24] Wang Shufang, Wang Xiaoke, Ouyang Zhiyun. Characteristics and influencing factors of soil organic carbon in upstream watershed of Miyun Reservoir in North China[J]. *Soils*, 2011, 43(4): 515-524.

[25] Wang Shuping, Zhou Guangsheng, Lyu Yucai, et al. Distribution of soil carbon, nitrogen and phosphorus along Northeast China Transect (NECT) and their relationships with climatic factors[J]. *Chinese Journal of Plant Ecology*, 2002, 48(5): 513-517.

[26] Wang Yuanbo, Zhao Ruifeng, Zhang Lihua, et al. Soil organic carbon and its influencing factors on the different plant communities in the middle reaches of the Heihe River wetland[J]. *Pratacultural Science*, 2020, 37(5): 833-844.

[27] Fu Hua, Chen Yaming, Wang Yanrong, et al. Organic carbon content in major grassland types in Alxa, Inner Mongolia[J]. *Acta Ecologica Sinica*, 2004, 24(3): 469-476.

[28] Shi Fei, Xu Meng, Zhang Xubo, et al. Vertical distribution of soil organic carbon and influential factors along vegetation transect on west slope of Mount Segrila, southeastern Tibet[J]. *Journal of Plant Nutrition and Fertilizers*, 2020, 26(5): 942-953.

[29] Jing Jiansheng, Liu Ziqi, Luo Ding, et al. Distribution characteristics and influencing factors of soil organic carbon in karst depression[J]. *Journal of Forest and Environment*, 2020, 40(2): 133-139.

[30] Zhang Lijun, Ma Wanzhu, Xiang Jiamin, et al. Soil available potassium status and its influencing factors in cultivated land of Zhejiang Province[J]. *Journal of Zhejiang Agricultural Sciences*, 2020, 61(4): 607-611.

[31] Hao Lu, Wu Xiangdong. Analysis on the spatiotemporal change of steppe productivity and its driving factors in Inner Mongolia[J]. *Arid Zone Research*, 2006, 23(4): 577-582.

[32] Cao Xianghui, Long Huaiyu, Zhou Jiaogen, et al. Analysis of spatial variability and influencing factors of topsoil organic carbon and total nitrogen in Hebei Province[J]. *Journal of Plant Nutrition and Fertilizer*, 2016, 22(4): 937-948.

[33] Jia Hao, Yan Ningzhen, Cheng Yongyi, et al. Spatial distribution characteristics and influence factors of soil organic carbon in farmland in southeast Chongqing[J]. *Journal of Nuclear Agricultural Sciences*, 2019, 33(6): 1256-1263.

[34] Wang Yanlong, Wang Xiaoli, Ma Yushou. Effect of slope aspect on vegetation growth and soil nutrient characteristics of alpine grassland in the source region of Yangtze River[J]. *Pratacultural Science*, 2018, 35(10): 2336-2346.

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