

Research Progress on the Spatiotemporal Dynamics of Soil Organic Carbon in Arable Land based on Space-Ground Integration

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Abstract

This study explores the spatiotemporal dynamics of soil organic carbon in arable land and its management strategies, emphasizing the importance of organic carbon in arable ecosystem health. By integrating space and ground technologies, the study employs a combination of remote sensing and in-situ observations to analyze the impact of different tillage practices, climate change, and soil types on the dynamics of organic carbon. The results indicate that fertilization management, crop rotation and intercropping, and vegetation cover all have significant effects on enhancing soil organic carbon. The study provides a scientific basis for the effective management of soil organic carbon and points out the directions and challenges for future research, promoting the in-depth development of soil ecological studies.

Keywords

Space-Ground Integration; Organic Carbon; Dynamics.

1. Introduction

Soil, as an essential component of the Earth's surface system, is not only the foundation of agricultural production but also plays a crucial role in the global carbon cycle and climate change. Cultivated soil, being one of the soil types most heavily influenced by human activities, sees changes in its organic carbon content that directly affect soil fertility, food security, and ecosystem service functions [1-2]. Therefore, in-depth research on the spatiotemporal dynamics of soil organic carbon in cultivated land is of great significance for ensuring soil health, enhancing agricultural productivity, and addressing climate change [3-4]. In recent years, with the rapid development of remote sensing technology, Geographic Information Systems (GIS), and the Internet of Things, integrated air-ground technology has been increasingly applied in soil research. By combining multi-source data from ground monitoring, unmanned aerial vehicle low-altitude remote sensing, and satellite remote sensing, integrated air-ground technology can achieve precise monitoring and simulation of the spatiotemporal changes in soil organic carbon, providing a scientific basis for soil resource management and sustainable agricultural development, which is of great significance for ensuring soil health, enhancing agricultural productivity, and addressing climate change [5-6].

2. Spatiotemporal Dynamics Characteristics of Soil Organ Carbon in Cultivated Land

2.1. The Impact of Different Tillage Practices on Soil Organic Carbon Dynamics

Different tillage practices have a significant impact on the accumulation, distribution, and dynamic changes of soil organic carbon. Traditional tillage methods are relatively simple, mainly relying on plowing and planting single crops such as rice and wheat, which often lead to the loss of soil organic carbon [7]. In contrast, modern diversified tillage practices, such as direct seeding, mulching, and summer cropping, have a positive effect on the accumulation of soil organic carbon [8]. Direct seeding reduces soil erosion and water evaporation caused by tillage, which helps in the accumulation of organic carbon in the soil, but it requires good tillage skills and is not suitable for all types of farmland. Mulching tillage is beneficial for the accumulation of organic matter in the soil because organic materials can reduce soil temperature fluctuations, promote the growth and reproduction of microorganisms, and thus favor the accumulation of organic carbon in the soil. Summer cropping can effectively increase the organic matter content in the soil, improve soil structure, and enhance soil productivity.

In summary, the choice of appropriate tillage practices is crucial for the accumulation and protection of soil organic carbon. Farmers should adopt suitable tillage practices based on local topography, climate, soil resources, and other conditions to promote the sustainable development of agricultural production and the maintenance of soil health.

2.2. The Impact of Climate Change on Soil Organic Carbon in Cultivated Land

Global climate change has profound effects on the soil carbon cycle, thereby influencing the spatiotemporal distribution of soil organic carbon in cultivated land. Climate change primarily affects soil organic carbon by impacting plant growth and the decomposition rate of soil organic carbon. Changes in climate affect plant growth, which in turn alters the amount of plant residues returned to the soil annually, contributing to the accumulation of soil organic carbon [9]. Climate change also affects the decomposition rate of soil organic carbon; global warming can accelerate soil respiration, leading to increased release of CO₂ into the atmosphere and a reduction in soil organic carbon content [10]. Moreover, climate change can impact soil moisture and temperature conditions, which in turn affect the activity of soil microbes and the rate of organic carbon decomposition. Particularly in agricultural ecosystems such as paddy fields, temperature changes can affect the emission of CH₄, further impacting global climate change.

In summary, climate change significantly affects the spatiotemporal distribution of soil organic carbon in cultivated land. Effective measures are needed to address the challenges that climate change poses to the soil carbon cycle, such as reducing the loss of soil organic carbon and enhancing soil carbon sequestration capacity through reasonable agricultural management practices.

2.3. The Impact of Soil Type and Topography on Organic Carbon Dynamics

Soil type and topography are significant factors affecting the dynamics of soil organic carbon, influencing the input, output, and distribution patterns of soil organic carbon, thereby impacting its dynamic changes [11]. Different types of soils have varying physical, chemical, and biological properties, which in turn affect the accumulation and decomposition rates of soil organic carbon. For instance, soils such as chernozem and alpine meadow soil typically have higher organic carbon densities, while soils like aeolian sandy soil have relatively lower organic carbon densities. This is primarily because different soil types vary in terms of organic matter input, water and nutrient retention capacity, and microbial activity. The impact of topography on soil organic carbon dynamics is mainly reflected in aspects such as elevation, slope, and

aspect [12]. Elevation affects the content of soil organic carbon by influencing climatic conditions like temperature and precipitation. Slope and aspect affect the input and output of soil organic carbon by impacting factors such as soil erosion, water and soil loss, and the spatial distribution of light and moisture.

In summary, soil type and topography are important factors affecting the dynamics of soil organic carbon. It is necessary to adopt appropriate management measures for different soil types and topographical conditions to optimize the accumulation and distribution of soil organic carbon, thereby enhancing soil fertility and agricultural production capacity.

3. Application of Integrated Air-Ground Technology in Soil Organic Carbon Research

3.1. Application of Spatial Remote Sensing Technology in Soil Organic Carbon Monitoring

Spatial remote sensing technology plays an essential role in the monitoring of soil organic carbon (SOC). Remote sensing technology uses sensors mounted on platforms such as satellites and unmanned aerial vehicles to collect information about the electromagnetic waves reflected or emitted from the Earth's surface, achieving non-contact measurement of soil characteristics. In terms of soil organic carbon monitoring, remote sensing technology is mainly applied in large-scale monitoring, multi-temporal monitoring, quantitative estimation, and environmental factor correlation analysis [13].

3.2. Integration of Ground Observations and Aerial Remote Sensing Data

The combination of ground observations and aerial remote sensing data is the core of integrated air-ground technology. Accurate soil organic carbon content data is obtained through ground observations, serving as the basis for the interpretation of remote sensing images and model validation; at the same time, the large-scale, multi-temporal monitoring capabilities provided by remote sensing technology are utilized to conduct continuous observations of the spatiotemporal dynamics of soil organic carbon. Specific methods of integration include data calibration and validation, model fusion, and spatiotemporal complementarity [14].

3.3. Advantages and Limitations of Integrated Air-Ground Methods

Integrated air-ground technology offers multiple advantages in the study of the spatiotemporal dynamics of soil organic carbon. Remote sensing technology provides the capability for large-scale, rapid monitoring of soil organic carbon, which is conducive to assessing changes in soil carbon pools at regional and even global scales [15]. By analyzing time series of remote sensing images, it is possible to track the dynamic changes in soil organic carbon and reveal its spatiotemporal distribution patterns. Combining ground observation data with remote sensing image information enables the complementarity of data in space and time and improves the precision, enhancing the comprehensiveness and accuracy of soil organic carbon monitoring [16]. However, there are certain limitations. The accuracy of remote sensing technology is influenced by various factors (such as sensor performance, atmospheric conditions, surface coverage, etc.), and it may not reach the precision level of ground-measured data. The acquisition, processing, and analysis of remote sensing data are relatively complex and require professional technical and equipment support. At the same time, obtaining ground-measured data also requires a significant investment of human, material, and time resources. Soil organic carbon estimation models are influenced by a variety of factors (such as soil type, climatic conditions, vegetation coverage, etc.), and the uncertainty of the models may be relatively large. Therefore, when applying integrated air-ground methods for soil organic carbon monitoring, it

is necessary to fully consider the impact of these factors and take corresponding measures to reduce uncertainty [17].

4. Future Research Directions

Future research needs to focus on improving the structure of soil organic carbon models, enhancing the resolution of driving data, and quantifying uncertainty assessments. In addition, progress has been made in the simulation studies of spatiotemporal variability of soil organic carbon, which will help to gain a deeper understanding of the response of soil organic carbon to climate change and its mechanisms.

In summary, integrated air-ground management strategies for cultivated soil organic carbon need to consider factors such as tillage practices, fertilization management, crop rotation, and intercropping, and to effectively monitor and assess through integrated air-ground technologies. The implementation of these strategies will provide a scientific basis for the effective management of soil organic carbon, point out the direction and challenges of future research, and promote the in-depth development of soil ecological research.

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References

- [1] Liu, C. The sources and influencing mechanisms of eroded soil organic carbon in the hilly region of the Loess Plateau [J]. Hunan University, 2019.
- [2] Zhang, Z. The characteristics of soil organic carbon storage in the alpine region of Sanjiangyuan and its connection with climate and vegetation changes [D]. Nanjing Agricultural University, 2015.
- [3] Zhao, G. Research on the spatiotemporal differentiation and driving forces of cropland productivity in Northeast China [D]. Shanxi Normal University, 2023.
- [4] Si, S. C., Wu, Y. C., Li, Y., et al. Progress and prospects in the study of soil health for arable land and grassland [J]. *Acta Pedologica Sinica*, 2022.
- [5] Li, F. X. Application and discussion of unmanned aerial vehicle technology in grassland ecological remote sensing monitoring [J]. *Bulletin of Surveying and Mapping*, 2017(7):5.
- [6] Shi, Z., Liang, Z. Z., Yang, Y. Y., et al. Current status and prospects of agricultural remote sensing research [J]. *Transactions of the Chinese Society of Agricultural Machinery*, 2015, 46(2):247-260.
- [7] Wang, J., Xue, Y., Pan, J. J., et al. The impact of tillage and straw return on soil aggregate organic carbon and crop yield [J]. *Journal of Soil and Water Conservation*, 2018, 32(5):7.
- [8] Zheng, H. B. The impact of tillage methods on soil environment and the growth and development of maize [D]. Shenyang Agricultural University, 2018.
- [9] Li, B. Z., Zhou, P., Li, Y. H., et al. Research progress on the continuous carbon sequestration mechanism of paddy soil in subtropical regions [J]. *Journal of Huazhong Agricultural University*, 2022, 41(6):8.
- [10] Fang, R., Yu, Z. H., Li, Y. S., et al. The impact of elevated atmospheric CO₂ concentration and temperature on farmland soil carbon pool and microbial community structure [J]. *Chinese Journal of Agricultural Science*, 2021, 54(17):14.
- [11] Sun, W. Y., Guo, S. L., Song, X. Y. The impact of topography and land use on the spatial distribution of soil organic carbon in the surface layer of the hilly and gully region of the Loess Plateau [J]. *Journal of Natural Resources*, 2010(3):11.

- [12] Nan, Y. F., Guo, S. L., Zhang, Y. J., et al. The impact of slope aspect and position on the changes of soil organic carbon and nitrogen in small watershed terraced fields [J]. *Journal of Plant Nutrition and Fertilizer*, 2012.
- [13] Yu, D. Y., Pan, Y. Z., Long, Z. H., et al. Measurement of the soil and water conservation value of ecosystem in Yunnan Province based on remote sensing technology [J]. *Journal of Soil and Water Conservation*, 2006, 20(2):174-178.
- [14] You, H. C. Remote sensing inversion and spatial differentiation of forest soil organic carbon [J]. *Fujian Agriculture and Forestry University*, 2012.
- [15] Zou, R. Y. Study on the spatial variation characteristics of soil organic carbon in farmland of the Poyang Lake basin and their influencing factors [D]. *Jiangxi University of Finance and Economics*, 2019.
- [16] Huang, C. B., Dian, Y. Y., Zhou, Z. X., et al. Forest change monitoring based on time series statistical characteristics [J]. *Journal of Remote Sensing*, 2015, 19(4):12. DOI:10.11834/jrs.20154104.
- [17] Li, N., Wang, G. X., Gao, Y. C., et al. Research progress on soil organic carbon in the ecosystem of the Qinghai-Tibet Plateau [J]. *Soil*, 2009.