

森林土壤碳库空间变异研究进展³

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摘 要: 森林土壤碳库是全球碳循环系统的关键组成部分,其数量和稳定性深刻影响大气二氧化碳水平,对生态碳汇具有重要意义。明确变化环境下森林土壤碳库的时空异质性和复杂性是开展森林土壤碳库管理的前提,但目前对此仍缺乏深入了解。本文旨在通过回顾国内外相关研究文献,梳理森林土壤碳库形成机理,系统分析森林土壤碳库空间变异特征及其关键影响因素相关进展,探讨森林碳库空间异质性研究方法,明确今后森林土壤碳库空间变异研究的重点问题,为森林土壤碳库的维持与提升研究提供关键基础。总体而言,森林土壤碳库的空间变异研究仍然存在较大的不确定性。在不同气候区,森林土壤碳库的差异尤为明显:热带地区的土壤有机碳(SOC)输入和输出均较高,因而其土壤碳库相对丰富;而寒带地区由于低温,土壤碳库则表现出高度稳定性。与湿润地区相比,干旱地区因水土流失严重,森林土壤碳库的空间异质性则显著增强。此外,在不同海拔和地形条件下,高海拔地区的土壤碳库积累更为显著,更适合SOC的固存,而低海拔地区的土壤碳库周转速度较快。不同土层深度的环境下,SOC含量差异显著,深层土壤储存了大量的SOC,受全球气候变化影响,其释放大量CO₂的潜力不容忽视。不同国家和地区的森林经营管理和土地利用方式差异明显,发达地区的森林土壤碳储量普遍高于欠发达地区。此外,森林土壤碳库的空间变异受到气候、植被、地形、人类活动和火灾等多重因素的影响,这些因素之间的关系并非简单的线性,而是相互作用形成了森林土壤碳库的异质性特征。在研究方法上,传统调查方法适用于小范围的研究,而新型模型方法能够扩展研究区域并进行未来预测,尽管其精度略逊于传统方法。今后应扩大研究的区域尺度,进一步探索土地利用变化的平衡点,并加强在多种因素影响下的森林土壤碳库研究。此外,结合不同研究方法的优点,全面理解土壤碳库的动态特征,同时关注深层土层的土壤研究,以获取更全面的森林土壤碳储量数据。

关键词: 森林土壤; 土壤碳库; 土壤有机碳; 空间变异; 影响因素

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Research progress on spatial variation of forest soil carbon pool

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Abstract: Forest soil carbon pools are critical components of the global carbon cycle, with their quantity and

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stability profoundly influencing atmospheric carbon dioxide levels and playing a significant role as ecological carbon sinks. Understanding the spatiotemporal heterogeneity and complexity of forest soil carbon pools under changing environmental conditions is a prerequisite for effective management of these carbon stores. However, current knowledge in this area remains insufficiently developed. This paper aims to review relevant domestic and international literature, elucidate the mechanisms underlying the formation of forest soil carbon pools, systematically analyze the spatial variability characteristics of these pools and their key influencing factors, and explore methodologies for studying spatial heterogeneity. It also identifies critical issues for future research on spatial variation in forest soil carbon pools, thereby providing a foundational basis for efforts to maintain and enhance these carbon reservoirs. Overall, research on the spatial variability of forest soil carbon pools still encounters considerable uncertainty. The disparities in forest soil carbon pools across different climatic zones are particularly pronounced: tropical regions exhibit high inputs and outputs of soil organic carbon (SOC), leading to relatively rich soil carbon reservoirs, whereas boreal regions demonstrate significant stability in their soil carbon pools due to lower temperatures. In contrast to humid regions, arid areas experience intensified spatial heterogeneity of forest soil carbon pools due to severe soil and water loss. Moreover, under varying elevation and topographical conditions, high-altitude regions accumulate soil carbon more significantly, favoring SOC retention, whereas low-altitude areas exhibit faster turnover of soil carbon pools. The SOC content varies significantly across different soil depths, with substantial quantities of SOC stored in deeper soils, which, influenced by global climate change, hold considerable potential for releasing CO₂ into the atmosphere. Variations in forest management practices and land use across different countries and regions result in consistently higher soil carbon stocks in developed areas compared to less developed ones. Additionally, the spatial variability of forest soil carbon pools is influenced by multiple factors, including climate, vegetation, topography, human activities, and fire; the relationships among these factors are not merely linear but interactively contribute to the heterogeneous characteristics of forest soil carbon pools. In terms of research methodologies, traditional survey methods are suitable for small-scale studies, while novel modeling approaches can expand research areas and facilitate future predictions, albeit with slightly lower precision compared to conventional methods. Future research should aim to broaden the spatial scale of studies, further explore the balance points of land use changes, and strengthen investigations into forest soil carbon pools under the influence of various factors. Moreover, integrating the advantages of different research methodologies will enable a comprehensive understanding of the dynamic characteristics of soil carbon pools, while also focusing on deeper soil layers to obtain more comprehensive data on forest soil carbon reserves.

Key words: forest soil; organic carbon pool; soil organic carbon; spatial variation; influencing factor