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Editorial

Forest Soil Carbon Cycle in Response to Global Change

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Forests constitute a critical component of terrestrial carbon reservoirs, with a substantial amount of carbon stored in soil as organic carbon, holding significant potential for climate change mitigation [1–3]. As global changes and human disturbances intensify, the fate of forest soil carbon reservoirs has drawn increasing attention in recent years. Within these reservoirs, stable and unstable carbon fractions sourced from plants and microbes often exhibit distinct sensitivities to environmental changes and human disturbances [2,4]. Even minor changes in soil carbon dynamics could exert substantial influence over global carbon cycling, affecting the pattern of terrestrial carbon sources and sinks [1]. These changes may further feed back into global change processes, including climate warming, extreme drought events, and rising atmospheric nitrogen deposition [3,5]. The current urgency of global change highlights the importance of continued research into both short-term and long-term dynamics of forest soil carbon and the key driving mechanisms through rigorous experimental and empirical approaches.

Despite the extensive research conducted concerning global change impacts over the years, the significance of several key research challenges remains unresolved. For instance, (1) the differential impacts of specific climate factors on forest soil carbon dynamics, (2) the mechanisms underlying how microbial community composition and activity drive soil organic matter turnover under global change scenarios, and (3) the role of vegetation features and their controlling mechanisms on forest soil carbon dynamics. More specifically, litter decomposition, soil respiration, nutrient cycling, and plant vs. microbial communities are all intertwined processes influenced by changing climatic conditions, environmental factors, and biological interactions. To underscore the multifaceted nature of forest soil carbon in relation to global change factors, in this Special Issue, we synthesized 10 articles, particularly addressing the intricate responses of soil carbon and nitrogen dynamics to changes in precipitation, nitrogen and phosphorus deposition, acid rain, and seasonal variations. Additionally, the diversity of forest types, spanning from Mediterranean and subtropical natural forests to plantations, contributes to the complexity of these responses and research novelty.

The response of forest soil carbon and related functions to global change is a multifaceted process that is influenced by a range of climatic and biological factors [6–9]. Consistent with this, Santonja et al. emphasize the sensitivity of litter decomposition to changes in macro-climatic conditions, revealing that litter mass losses in Mediterranean forests are significantly lower under drier circumstances [8]. However, when addressing climate impacts on soil carbon, subtle changes in the local environment should be noted. Importantly, Li et al. demonstrated differential responses of soil respiration components and total belowground carbon allocation to nitrogen and phosphorus depositions in Moso bamboo (*Phyllostachys heterocycle* (Carr.) Mitford *cv. Pubescens*) forests [6]. While soil respiration and autotrophic respiration also exhibited strong seasonal variability, phosphorus deposition stimulated heterotrophic respiration, suggesting soil carbon loss [6]. Notably,

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nitrogen and phosphorus deposition did not affect total soil respiration or belowground carbon allocation in the same way, underlining the importance of considering the intricate relationships between different nutrient inputs (e.g., nitrogen–phosphorus imbalance) when assessing belowground carbon dynamics. Wang et al. explored the effects of different types of acid rain on soil respiration in plantations, underscoring the complexity of soil carbon responses to acid rain lies in the specific composition of acid rain [7]. Additionally, Xiong et al. conducted an elevational gradient study to mimic climate warming in subtropical forests, showing that seasonal variations in nitrogen availability play a crucial role in shaping soil microbial communities with consequences for soil carbon dynamics [10]. This highlights the importance of considering the seasonal dynamics of soil carbon responses to global change as well as the crucial role of microbial communities and nuanced context-dependent variations (e.g., tree species, community composition, and functional traits) in mediating the effects of global change factors on soil carbon processes.

Microbial processes play a pivotal role in shaping soil carbon dynamics across diverse ecosystems [8–12]. In Mediterranean forests of southern France, soil organic carbon and nitrogen stocks showed limited responses to precipitation reduction but litter decomposition slowed down [8], indicating that litter and soil may harbor distinct microbial communities with different resistance to drought. Drought-induced changes in fine root and arbuscular mycorrhizal fungi growth in a Chinese fir plantation further underscored the significance of these symbiotic relationships in enhancing tree nutrient uptake and resistance to drought [11]. Similarly, no major changes in microbial communities under long-term nitrogen deposition were observed in a subtropical natural forest [9], which is possibly due to microbial resistance or functional redundancy, although some sensitive microbial groups can still regulate the balance between soil carbon and nutrient availability [9]. Given the seasonal nature of microbial communities corresponding to environmental heterogeneity [10], the nuanced impact of acid rain composition on microbial thermal adaption (i.e., Q_{10}, temperature sensitivity of soil respiration) in *Cunninghamia lanceolata* and *Michelia macclurei* plantations [7] and contrasting microbial responses to nitrogen and phosphorus deposition in Moso bamboo forests [6] indicate the context-dependent nature of forest soil carbon dynamics under global change. In this context, in typical forests undergoing multispecies restoration in subtropical China [12], soil fungal communities and functional guilds transitioned depending on tree species composition, underlining the need to further disentangle the role of vegetation features in plant–microbial interactions.

In the context of how vegetation features influence soil carbon dynamics, several key insights emerge from the synthesized papers [8,12–14]. Firstly, the dominant tree species in Mediterranean forests, such as *Quercus ilex*, *Quercus pubescens*, and *Pinus halepensis*, exhibit differential effects on litter decomposition rates, which could be attributed to variations in litter traits (e.g., elemental stoichiometry) that control the decomposition process. These differences in vegetation features may also interact with soil shallowness and stoniness, contributing to variations in carbon and nitrogen stocks along the litter–soil continuum [8]. Similarly, research conducted in a protected forest in Kulon Progo Community Forestry demonstrates that distinct tree species and their characteristics, including canopy cover and canopy height, are associated with variations in soil organic carbon content and the rate of soil organic matter decomposition [13]. Furthermore, shifts in soil fungal communities were observed in response to the multispecies restoration of a *Pinus massoniana* plantation in subtropical China, where *Ascomycota* and, thus, saprotrophs dominated in monoculture *P. massoniana* plantations, whereas *Basidiomycota* and symbiotroph dominated in secondary mixed forests. These changes were strongly correlated with species-specific litter quality and edaphic biogeochemistry [12]. Even for urban forests facing more frequent human disturbances, the relationship between the floristic composition and key soil variables (carbon–nitrogen ratios; carbon–nitrogen stocks) still holds [14]. Together, these findings collectively emphasize the intricate interactions between vegetation characteristics, microbial functions, and soil carbon dynamics, shedding light on the complexity of terrestrial carbon reservoirs under global change.

Overall, these studies collectively underline the complexity and context-dependent nature of forest soil carbon dynamics under global change, emphasizing the need for integrated, multifaceted approaches that consider specific environmental gradients, deposition experiments, microbial community dynamics, and the types of global change factors when assessing and predicting these critical processes [6–15]. Given the challenges in the face of a changing climate, knowledge synthesized in this Special Issue will be instrumental in optimizing forest management practices and enhancing our ability to mitigate climate change through the preservation and enhancement of soil carbon reservoirs. Further research taking advantage of the novel knowledge gained, methods utilized, and uncertainties discovered in this Special Issue, with an in-depth exploration of microbial communities, plant–microbial interactions, microbial thermal adaption, and their role in carbon use efficiency [4,16], promises to provide a more holistic understanding of "Forest Soil Carbon Cycle in Response to Global Change".

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