Modelling the role of mycorrhizal associations in soil carbon cycling: insights from global analyses of mycorrhizal vegetation

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Summary

Mycorrhiza, a symbiotic association between plant roots and fungi, profoundly influences global carbon cycling by mediating nutrient uptake, especially in terrestrial ecosystems. This intricate relationship enhances the ability of plants to access essential nutrients, particularly phosphorus and nitrogen, while the fungi receive carbohydrates from the plant. The result is a mutually beneficial partnership that not only contributes to the health and growth of plants but also plays a crucial role in soil carbon dynamics. Hence, the distribution of mycorrhizal vegetation worldwide, ranging from tundra to lush forests, constitutes a key driver in shaping carbon dynamics within ecosystems.

The ubiquity of mycorrhizal associations spans the globe, encompassing a diverse array of ecosystems. From the arctic tundra to tropical rainforests, mycorrhizal fungi form symbiotic relationships with a multitude of plant species. This widespread distribution is a testament to the adaptability and importance of mycorrhizal associations in various environmental conditions.

The type of mycorrhizal association, be it arbuscular mycorrhizae (AM) or ectomycorrhizae (EM), is intricately linked to the types of plants that dominate a particular biome. In boreal and temperate forests, where coniferous trees like pines and firs reign, ectomycorrhizal associations are prevalent. These fungi envelop the roots of their host plants with a dense network of hyphae, enhancing nutrient absorption and forming characteristic fruiting bodies like mushrooms. In contrast, arbuscular mycorrhizal associations are partly formed inside plant roots and are commonly found in a broad spectrum of ecosystems, ranging from grasslands to tropical rainforests. The tropical biome, with its vast biodiversity, exhibits a rich tapestry of mycorrhizal associations, contributing to the adaptability and resilience of the vegetation.

The influence of mycorrhizal vegetation on global carbon circulation is profound and multifaceted. Mycorrhizal associations contribute to the storage and release of carbon in the soil through their role in plant litter decomposition, nutrient cycling, and the formation of organic compounds. Understanding this impact is crucial for accurate assessments of soil carbon dynamics and predictions of how ecosystems respond to environmental changes, including climate change and land-use alterations. In this thesis, I delve into the fundamental aspects of mycorrhizal associations and their implications for the soil carbon cycle.

Chapter 2 tackles a critical question: How do ectomycorrhizal and arbuscular mycorrhizal fungi differ in the decomposability of their mycelia? Ecto- and arbuscular mycorrhizal fungi, ubiquitous in terrestrial ecosystems, constitute a significant portion of soil microbial biomass. By employing in-vitro cultivation techniques, I successfully analyzed the chemical traits underpinning the decomposability of their fungal material. The sixteen species of mycorrhizal fungi examined provide valuable insights into the chemical composition of these symbiotic organisms. The outcomes do not only contribute to mycorrhizal litter decomposition models but also emphasize the need to explicitly consider differences in litter quality among dominant mycorrhizal types in soil carbon cycle assessments.

Ecosystems dominated by AM or EM exhibit distinct soil carbon dynamics. However, existing models lack explicit conceptualizations of mycorrhizal impacts. Chapter 3 introduces a mechanistic model named Yasso-Myco, that separates mycorrhizal impacts from climatic factors, addressing the challenge posed by the tight correlation between global climate patterns and mycorrhizal vegetation distribution. By separating mycorrhizal impacts from climatic factors, the model significantly improves long-term predictions of decomposition dynamics, providing a comprehensive representation of mycorrhizal influences on litter decomposition.

Despite evidence pointing to varied soil carbon dynamics in ecosystems with different mycorrhizal types, little is known about their global impact. Focussing on the global scale, Chapter 4 examines the least understood pathway of mycorrhizal impact: mycorrhizal mediation of plant litter decomposition. Utilizing the Yasso-Myco model developed in Chapter 3, I estimate global long-term plant litter decomposition rates based on different types of mycorrhizal vegetation. The findings highlight that the mycorrhizal type of dominant vegetation controls the variability in decomposition rates, emphasizing mycorrhizal type-specific decomposition environments. Additionally, the chapter explores how the magnitude of mycorrhizal impacts differs across various biomes, advancing our understanding of the effects of plant-microbial interactions on the global dynamics of labile and recalcitrant soil carbon compounds.

Mycorrhizal fungi exhibit high sensitivity to environmental changes, including those induced by climate change. In a world undergoing environmental transformations, Chapter 5 further explores the sensitivity of mycorrhizal fungi to climate change and its implications for future ecosystem functioning. By projecting changes in mycorrhizal vegetation globally under different environmental scenarios, the study quantifies the impact of these changes on leaf litter decomposition. The findings have significant implications for global carbon cycling, providing insights into the complex interplay between climate change and ecosystem features. Understanding the future evolution of mycorrhizal vegetation distribution is crucial for predicting the response of terrestrial ecosystems to global environmental change and developing effective management strategies to mitigate climate change.

In conclusion, this thesis provides a comprehensive exploration of mycorrhizal associations and their impact on the global carbon cycle. The detailed exploration of mycorrhizal chemistry, integration into soil carbon models, global estimation of their impact, and consideration of future environmental changes collectively advance our understanding of the intricate relationship between mycorrhizal vegetation and soil carbon dynamics. The results underscore the critical role of mycorrhizal associations in shaping the global carbon cycle, emphasizing their influence on decomposition processes and soil carbon dynamics. As we confront the challenges of a changing climate and evolving land-use patterns, understanding the contributions of mycorrhizal associations to carbon cycling becomes imperative for effective ecosystem management and climate change mitigation. These insights are essential for developing effective strategies to mitigate the impacts of global land-use and climate change on ecosystem functioning.