Soil Carbon Sequestration Dynamics Under Differential Mycorrhizal Inoculation Regimes in Fragmented Temperate Deciduous Woodlands: A Microcosm-to-Landscape Scaling Analysis

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Abstract. Mycorrhizal fungal networks play a pivotal yet poorly quantified role in mediating soil organic carbon (SOC) stabilization within fragmented temperate deciduous woodlands. This study examined arbuscular and ectomycorrhizal inoculation gradients across experimentally isolated woodland patches in central Germany, combining phospholipid fatty acid (PLFA) profiling, stable isotope ($\delta^{13}C$) tracing, and landscape-scale LiDAR-derived canopy fragmentation indices. Results from 48 monitored microcosm plots, upscaled using spatially explicit carbon flux modelling, demonstrated that ectomycorrhizal dominance significantly enhanced recalcitrant SOC fractions (particulate organic matter; POM) by 23.4% relative to arbuscular-dominated plots. Edge-effect amplification under high landscape fragmentation reduced mycorrhizal hyphal network continuity by up to 38%, substantially diminishing SOC stabilization efficiency. These findings highlight the critical interdependence between woodland patch geometry, mycorrhizal community structure, and long-term carbon sink functionality.

Keywords: soil organic carbon stabilization, ectomycorrhizal networks, temperate woodland fragmentation, phospholipid fatty acid profiling, stable carbon isotope tracing, particulate organic matter, edge effects, carbon flux modelling, landscape ecology

Introduction

Terrestrial ecosystems sequester approximately 2.6 Pg of carbon annually, with temperate deciduous woodlands constituting one of the most critical, yet increasingly imperilled, carbon sink reservoirs in the Northern Hemisphere (Pan et al., 2011; Erb et al., 2018). As global mean temperatures continue to rise at an unprecedented rate—projected at 1.5–2.0°C above pre-industrial baselines by the late 2020s according to IPCC AR6 synthesis reports—

the functional integrity of soil carbon sequestration mechanisms has become a focal concern for both climate mitigation science and biodiversity conservation policy. Among the biotic drivers governing soil organic carbon (SOC) dynamics, mycorrhizal fungal networks have emerged as disproportionately influential mediators of carbon partitioning, mineral-organic association formation, and aggregate stability within the rhizosphere and detritusphere. Fragmentation of temperate woodland habitats, driven by agricultural expansion, infrastructure development, and altered disturbance regimes, imposes profound structural discontinuities on both above- and below-ground ecological networks. Patch isolation constrains the dispersal and colonization capacity of obligate symbiotic fungi, particularly ectomycorrhizal (ECM) taxa, whose hyphal foraging radii and interplant carbon transfer efficiencies are inherently scale-dependent (Simard et al., 2012; Clemmensen et al., 2015). Critically, the differential contributions of arbuscular mycorrhizal (AM) versus ECM communities to SOC stabilization pathways—specifically through the relative production of glomalin-related soil proteins (GRSP), necromass-derived particulate organic matter (POM), and mineral-associated organic matter (MAOM)—remain insufficiently characterized across fragmentation gradients at the landscape scale. Previous empirical studies have largely operated within spatially homogeneous forest stands or controlled mesocosms, neglecting the ecotone dynamics and edge-to-interior ratio amplification that characterize real-world fragmented woodland mosaics (Fahrig, 2003; Laurance et al., 2017). This methodological gap creates substantial uncertainty when extrapolating plot-level mycorrhizal carbon flux measurements to regional SOC budget assessments, limiting the accuracy of land surface models embedded within Earth System Models (ESMs). Furthermore, recent meta-analyses have underscored that mycorrhizal functional type—rather than plant species richness per se—is a primary determinant of SOC persistence across multiple temperate biomes (Soudzilovskaia et al., 2019; Steidinger et al., 2019). The present study addresses these deficiencies through an integrated microcosm-to-landscape analytical framework applied to fragmented deciduous woodlands across a documented fragmentation gradient in Thuringia, central Germany. Specifically, this paper: (i) quantifies mycorrhizal community compositional shifts along woodland patch-size and edge-effect gradients using PLFA biomarker analysis; (ii) traces carbon allocation pathways into distinct SOC fractions via stable ^{13}C isotope pulse-chase labelling; (iii) upscales plot-level measurements to landscape carbon flux estimates using high-resolution LiDAR canopy data and spatially explicit modelling; and (iv) evaluates the implications of observed mycorrhizal–fragmentation interactions for regional carbon accounting and woodland conservation prioritization frameworks.

References

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