Soil Organic Carbon Sequestration Dynamics Under Chronic Nitrogen Deposition in Temperate Deciduous Forest Ecosystems: An Empirical Analysis of Edaphic Microbiome Shifts and Litter Decomposition Rates Along a Deposition Gradient in Central Europe

Ashley Young
Professor
Technische Universität Dresden
Helmholtzstraße 10, 01069 Dresden, Saxony, Germany

Taylor Mitchell
D.Sc
Czech University of Life Sciences Prague
Kamýcká 129, 165 00 Praha-Suchdol, Prague, Czech Republic

Jamie Harris
Associate Professor
Wageningen University & Research
Droevendaalsesteeg 4, 6708 PB Wageningen, Gelderland, Netherlands

Drew Nelson
PhD
Adam Mickiewicz University in Poznań
ul. Wieniawskiego 1, 61-712 Poznań, Greater Poland Voivodeship, Poland

Abstract. Chronic atmospheric nitrogen (N) deposition constitutes a persistent driver of biogeochemical alteration in temperate deciduous forest soils, yet its cascading effects on edaphic microbial community composition and organic carbon (OC) stabilization pathways remain incompletely resolved. This study quantifies soil organic carbon (SOC) stocks, fungal-to-bacterial biomass ratios, and litter decomposition constants (k) across a replicated N-deposition gradient (5–42 kg N ha^{-1} yr^{-1}) spanning twelve forest stands in the Rhine–Ruhr and Bohemian Basin regions. Employing phospholipid fatty acid (PLFA) profiling, litterbag incubation assays, and density fractionation of mineral-associated organic matter (MAOM), we demonstrate that elevated N inputs suppress saprotrophic fungal activity by 34–51%, accelerate light-fraction OC mineralization, and ultimately reduce SOC sequestration efficiency by 18–27% relative to low-deposition reference sites. These findings underscore the urgency of integrating reactive N governance into regional carbon accounting frameworks.

Keywords: soil organic carbon sequestration, nitrogen deposition gradient, edaphic microbial community, litter decomposition kinetics, mineral-associated organic matter, phospholipid fatty

acid profiling, saprotrophic fungal suppression, temperate deciduous forest biogeochemistry, reactive nitrogen governance

Introduction

Terrestrial forest ecosystems store approximately 45% of the global soil organic carbon (SOC) pool, rendering them indispensable regulators of atmospheric CO_2 concentrations and, by extension, of contemporary climate trajectories. Within the temperate deciduous biome of Central Europe, this carbon sink function is increasingly imperiled by decades of chronic atmospheric nitrogen (N) deposition—a legacy of industrial combustion, intensive livestock husbandry, and synthetic fertilizer volatilization. Although reactive nitrogen fluxes to European forest canopies have declined marginally since peak deposition in the late twentieth century, current deposition loads in heavily industrialized corridors continue to surpass critical thresholds established by the UNECE Convention on Long-Range Transboundary Air Pollution, sustaining persistent stoichiometric imbalances in soil nutrient regimes. The mechanistic nexus between elevated N deposition and SOC dynamics is multifaceted and frequently contradictory in the literature. On one hand, nitrogenous subsidies may stimulate net primary productivity, augmenting aboveground litter inputs and theoretically enlarging the carbon flux entering the decomposer sub-system. On the other hand, a growing body of experimental evidence—anchored in enzymatic stoichiometry theory and the microbial carbon-use efficiency (CUE) framework—suggests that N enrichment fundamentally reconfigures the decomposer community toward bacterial-dominated assemblages with lower CUE, simultaneously down-regulating the ligninolytic extracellular enzyme activity of saprotrophic Basidiomycota. This enzymatic suppression impedes the depolymerization of recalcitrant aromatic compounds in fresh litter and, paradoxically, accelerates the mineralization of labile, mineral-associated organic matter fractions, yielding a net negative effect on long-term SOC stabilization. Despite compelling laboratory and mesocosm evidence, large-scale empirical verification along replicated, natural N-deposition gradients in situ remains scarce, particularly in the context of co-varying edaphic parameters such as soil pH, cation exchange capacity (CEC), and clay mineralogy. The present study addresses this knowledge gap by characterizing SOC pool partitioning, phospholipid fatty acid (PLFA)-inferred microbial community structure, and litter mass-loss kinetics simultaneously across twelve forest stands distributed along a well-characterized N-deposition gradient in the Rhine–Ruhr agglomeration and the Bohemian Basin. By integrating density fractionation of mineral-associated organic matter (MAOM) with particulate organic matter (POM) quantification and multi-year litterbag incubation data, this investigation aims to disentangle the direct stoichiometric effects of N deposition on decomposer physiology from indirect effects mediated through altered litter chemistry and soil acidity. The paper is structured as follows: Section 2 details site selection criteria, physicochemical characterization protocols, PLFA extraction and analysis procedures, and the litterbag experimental design. Section 3 presents quantitative results for SOC fractions, microbial biomass ratios, and decomposition rate constants (k) across the deposition

gradient. Section 4 interprets these findings within the theoretical framework of the microbial efficiency–matrix stabilization (MEMS) hypothesis and discusses policy implications for reactive nitrogen regulation and national carbon budget reporting. Section 5 synthesizes principal conclusions and identifies priority research vectors for subsequent investigation.

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