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Soil organic matter formation: Convergence and divergence of three carbon pathways: Stabilization, recycling and losses

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Microbial transformation of organic substances is a key process of soil organic matter (SOM) formation. Carbon (C) entering the soil can be transformed in three main directions: i) stabilization over long period without relevant microbial utilization, ii) recycling by microorganisms for production of new and reparation of old cells, and iii) microbial utilization for energy production leading to C losses from soil as CO_2. So, individual compounds within huge diversity of the organic substances entering the soil will follow predominantly one of these directions, depending on the substance chemistry, soil properties, microbial activities and environmental conditions. Therefore, organic substances can have two general trends: i) they converge from any initially distinct compounds (e.g. in litter or rhizodeposition) to completely mixed, so that it is impossible to trace back their origin; or ii) divergence: the substances maintain their differences despite microbial transformations by SOM formation.

We proved two opposite hypotheses that convergence and divergence of the fate of organic substances depends on microbial utilization at two levels: 1) intermolecular: high recycling intensity leads to convergence, whereas stabilization leads to divergence of the C originated from various organic compounds, and 2) incorporation of C from various molecule positions into microbial metabolic cycles define the C fate at intramolecular level. We tested the first hypothesis based on own and literature data to the fate of polymeric substances: sugars, proteins, lipids and lignin. The second hypothesis was tested by the C atoms from various positions of pentoses and hexoses by position-specific ^{13}C and ^{14}C labeling.

The polymeric substances as well as monomers from the same chemical group clearly converge to three groups stabilization, recycling and losses. Carboxylic acids will be nearly completely mineralized and are lost from soil. The fate and functions organic compounds depend mainly on microbial recycling. Proteins, amino acids and sugars - key components of microbial biomass - are intensively recycled and e.g. proteins remain relatively long in soil.

For the intramolecular differences, we traced the fate of position-specific ^{13}C labeled glucose and ribose under field conditions for 800 days. Both sugars were simultaneously metabolized via glycolysis and pentose phosphate pathway. The similarity between position-specific ^{13}C recovery in microbial biomass and soil reflected high contribution of microbial necromass to SOM. The mean residence time of uniformly labeled ^{13}C ribose in the soil was 3 times longer than that of glucose. Consequently, ribose and glucose were incorporated into different cellular components, defining

their long-term fate in soil. The convergence of glucose C positions in soil and microbial biomass revealed that recycling dominated glucose transformation. In contrast, divergence of ribose C positions in soil revealed that intact ribose-derived cell components are reused or preserved in SOM.

Thus, convergence vs. divergence distinguished the two general trends explaining the long persistence of C at inter- and intra-molecular levels: microbial recycling leads to convergence, whereas slow decomposition and preservation define the divergence of C pathways in soil.