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Carbon flows by soil organic matter formation: A review based on 13C natural abundance

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Aggregation of mineral and organic particles is a key process of soil development, which promotes carbon (C) stabilization by hindering decomposition of plant and microbial residues. All microbial utilization and C stabilization processes lead to ^{13}C fractionation and consequently to various $\delta^{13}C$ values of organic matter in aggregate size classes, sand, silt, and clay-sized particles, as well as density fractions. Differences in $\delta^{13}C$ within the aggregates and density fractions may have two reasons: 1) preferential stabilization of organic compounds with light or heavy $\delta^{13}C$ and/or 2) stabilization of organic materials after passing one or more microbial utilization cycles, leading to respiring of ^{13}C depleted CO_2 and heavier $\delta^{13}C$ in remaining C. Assuming these two reasons, the new approach based on the natural differences in stable C isotopic composition between SOM fractions was proposed and tested on soils developed solely under C3 vegetation (arable, coniferous and deciduous forests) in boreal climate (Gunina and Kuzyakov, 2014). This approach assumes that: 1) ^{13}C enrichment between the SOM fractions corresponds to successive steps of SOM formation; 2) ^{13}C fractionation (but not the $\delta^{13}C$ signature) depends mainly on the transformation steps and not on the C precursors. Consequently, ^{13}C enrichment of SOM fractions allows reconstructing the SOM formation pathways. To prove these initial results we reviewed $\delta^{13}C$ values of soils globally and focused on the i) estimation of the validity of this approach for soils developed under various climatic conditions and parent materials, and depending on fertilization, and ii) C flows not only between aggregate size classes and density fractions but also between various particle size classes of the soils (i.e. sand, silt, and clay) and iii) on revealing the intensities of natural ^{13}C fractionation during the stabilization of litter C in aggregates, particle size classes, and density fractions. Results showed that density fractions were ^{13}C enriched in the order: free particulate organic matter (POM) < light occluded POM < heavy occluded POM < mineral fraction, with the strongest increase between the light occluded and heavy occluded POM. The maximum ^{13}C fractionation during stabilization of litter C in density fractions and aggregate size classes was < 2‰. $\Delta^{13}C$ enrichment of the SOM fractions showed that the main direction of C flows within the aggregates and SOM fractions was from the macroaggregate-free POM to the mineral microaggregate fraction. Thus, despite some limitations, $\delta^{13}C$ natural abundance approach based on ^{13}C fractionation within individual steps of SOM formation is very useful and probably the sole approach to estimate C flows under steady-state without labeling.