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Priming in permafrost soils: High vulnerability of arctic soil organic carbon to increased input of plant-derived compounds

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Arctic ecosystems are warming rapidly, resulting in a stimulation of both plant primary production and soil organic matter (SOM) decomposition. In addition to this direct stimulation, SOM decomposition might also be indirectly affected by rising temperatures mediated by the increase in plant productivity. Higher root litter production for instance might decrease SOM decomposition by providing soil microorganisms with alternative C and N sources ("negative priming"), or might increase SOM decomposition by facilitating microbial growth and enzyme production ("positive priming"). With about 1,700 Pg of organic C stored in arctic soils, and 88% of that in horizons deeper than 30 cm, it is crucial to understand the controls on SOM decomposition in different horizons of arctic permafrost soils, and thus the vulnerability of SOM to changes in C and N availability in a future climate.

We here report on the vulnerability of SOM in arctic permafrost soils to an increased input of plant-derived organic compounds, and on its variability across soil horizons and sites. We simulated an increased input of plant-derived compounds by amending soil samples with 13C-labelled cellulose or protein, and compared the mineralization of native, unlabelled soil organic C (SOC) to unamended control samples. Our experiment included 119 individual samples of arctic permafrost soils, covering four sites across the Siberian Arctic, and five soil horizons, i.e. organic topsoil, mineral topsoil, mineral subsoil and cryoturbated material (topsoil material buried in the subsoil by freeze-thaw processes) from the active layer, as well as thawed material from the upper permafrost.

Our findings suggest that changes in C and N availability in Arctic soils, such as mediated by plants, have a high potential to alter the decomposition of SOM, but also point at fundamental differences between soil horizons. In the organic topsoil, SOC mineralization increased by 51% after addition of protein, but was not affected by cellulose, suggesting predominant N limitation of the microbial decomposer community, and a high vulnerability of SOM to increases in N availability. In contrast, in mineral subsoil and thawed permafrost, SOC mineralization was stimulated by both cellulose and protein (between 23 and 120%), cellulose- and protein-derived C was efficiently incorporated into the microbial biomass, and effects of both cellulose and protein were significantly correlated. These findings suggest predominant C limitation of the microbial decomposer community in deeper, mineral horizons of arctic permafrost soils, and point at a high vulnerability of SOM to increased C availability, e.g., due to higher root litter production. We estimate that on a circum-arctic scale, increases in C and N availability have the potential to stimulate SOC mineralization in the order of several Tg C per day. Together with the direct stimulation of SOC mineralization by rising temperatures, this indirect stimulation can counteract the increased CO_2 fixation by plants, and thus reduce the C sink strength of arctic ecosystems or even provoke net ecosystem C losses that might induce a positive feedback to global warming.