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Long-term effects of short-term perturbations of microbial conditions in soil

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The way living systems react to destabilizing perturbations determines their biological integrity. Hence, a system's resilience depends on its ability to recover to its initial state. Soil systems are regularly subjected to fluctuations in their chemical and physical environment. For instance, plant root exudation of labile compounds and freeze-thaw cycles are known to influence microbial activity and soil nutrient transformations. Here, we investigated soil resilience to a one-time glucose addition, and a single freeze-thawing event. We hypothesized that such brief disturbance events affect the system's structure for a short time only, before returning to its initial state.

Beech forest soil was subjected to two treatments: (a) addition of ^{13}C-glucose (5 mg g^{-1} soil), and (b) a one-time freeze-thawing event (-20 °C overnight). Soils were subsequently stored in the dark under constant conditions at 20 °C for the following 6 months. To follow changes in microbial community composition and microbial storage compounds over time, we analyzed the fatty acids of phospho- and neutral lipids (PLFAs, NLFAs). Moreover, we measured C and N in microbial biomass and dissolved organic matter to elucidate temporal dynamics of C and N availability and stoichiometry. Measurements were done in the short (4h, 1d, 4d, 6d) and long term (84d, 160d) after the treatments.

Both treatments had substantial and long-term effects on microbial community composition and C/N stoichiometry of microbial biomass and dissolved organic matter. Even though added glucose was metabolized within 4 days, it led to a long-standing increase in bacterial and fungal PLFA biomarkers, which persisted for at least 84 days, and levelled off only after 160 days. Fungal-specific NLFAs stayed enhanced even after 160 days, indicating increased long-term C storage in fungal biomass. Only a negligible proportion of the C additionally stored in fungal-specific NLFAs, however, stemmed from the originally added ^{13}C. Microbial community composition in glucose-treated soils diverged with time from their counterparts in the control soils, being distinctly different in the long term. Freeze-thawing significantly decreased fungal and bacterial NLFAs, and tended to decrease fungal and bacterial PLFAs. Moreover, it led to a rapid shift in the microbial community that persisted for the duration of the experiment. Interestingly, both treatments led to a decrease in microbial biomass N in the short-term, but significantly increased N in the microbial biomass (relative to the control) in the long-term. While glucose addition and freeze-thawing showed contrasting effects on dissolved N in the short term, both treatments significantly reduced dissolved N in the long term.

Contrary to our expectations, our results demonstrate that short-term manipulations of microbial conditions in soil can lead to significant and long-standing shifts of both, microbial community composition and C and N pools. This is surprising as microbial communities and the pools they influence are generally assumed resilient against small perturbations. Given the ubiquity of root exudation and freeze-thaw cycles in natural soil systems, our results have implications for our current understanding of the dynamics in the soil system.