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Changes in soil warming effects on microbial C, N and P cycling across seasons in a temperate calcareous mixed forest

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Global warming may accelerate soil carbon (C) and nutrient cycling as higher temperatures accelerate soil microbial and enzymatic activities. However, this enhanced soil C cycling can diminish with time due to the depletion of labile soil C or due to thermal acclimation of soil microbes, while the increased N cycling may be dampened over time in N-rich soils. Moreover, soil climate as well as the quality and quantity of plant inputs change between seasons, which could influence the C: nitrogen (N): phosphorus (P) stoichiometry of resources available for microbes and thereby alter the warming effect on microbial activities and nutrient cycling between seasons. Such seasonal changes caused inconsistent warming effects on extracellular enzyme activities and on soil respiration in some experiments, with warming effects turning from positive to negative between seasons, yet the underlying controls of these adverse effects are far from being well understood. In this study, we therefore aimed to investigate soil warming and seasonal effects on soil C, N, and P pools and processes in a temperate calcareous mixed forest. We collected soil samples in spring, summer and fall (May, August, and October 2019) from a long-term (>15 yrs) soil warming experiment in Achenkirch, Northern Limestone Alps, Austria (47°34′ 50″ N; 11°38′ 21″ E; 910 m a.s.l.). The samples were incubated at the corresponding in-situ temperatures in the laboratory. Microbial growth, respiration and C use efficiency were determined by following ^{18}O-H_2O incorporation in DNA and by gas analysis. ^{15}N pool dilution assays were applied to quantify gross rates of protein depolymerization, N mineralization, and nitrification, whilst gross rates of soil inorganic P mobilization were measured by a ^{33}P pool dilution assay. Moreover, we measured the potential soil enzyme activities of four hydrolases and two oxidases, and determined contents of labile (extractable) and microbial biomass C, N, and P. This study will thereby provide a comprehensive insight into how soil warming influences soil microbial C, N, and P cycling in a temperate calcareous mixed forest as well as into their energetic, stoichiometric and soil microclimatic constraints. The long-term nature of this soil warming experiment will therefore allow predictions of the future biogeochemical behavior of calcareous forest soils, and deduce potential feed-backs on forest productivity, atmospheric composition and climate change.