



Cold ecosystems in a warmer climate: carbon fluxes at the alpine treeline under experimental soil warming

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The impact of climatic warming on the C balance of terrestrial ecosystems is uncertain because rising temperature increases both C gains through net primary production, but also respiratory C losses. 'Cold' ecosystems such as treeline ecotones will respond particularly sensitive to climatic changes because many processes are limited by temperature and soils store particular large amounts of labile soil organic matter. In our study, we investigate ecosystem responses to 9 years of elevated atmospheric CO₂ and to 3 years of experimental soil warming by 4°C. The added CO₂ contains another $\delta^{13}\text{C}$ signature than normal air, which allows the tracing of new carbon through the plant and soil system. This provides new insight into carbon cycling at the treeline and it shows which C flux respond most sensitive to climatic changes.

Results showed that soil warming increased soil CO₂ effluxes instantaneously and persisted for at least three vegetation periods (+35-45%; +80 to 120 g C m y⁻¹). In contrast, DOC leaching showed a negligible response of less than 5% increase. Annual C uptake of new shoots was not significantly affected by elevated soil temperatures, with a 10 to 20% increase for larch, pine, and dwarf shrubs, respectively, resulting in an overall increase in net C uptake by plants of 20 to 40 g C m⁻²y⁻¹. The Q₁₀ of 3.0 measured for soil respiration did not change compared to a three-year period before the warming treatment started, suggesting little impact of warming-induced lower soil moisture (-15% relative decrease) or a depletion in labile soil C. The fraction of recent plant-derived C in soil respired CO₂ from warmed soils was smaller than that from control soils (25 vs. 40% of total C respired), which implies that the warming-induced increase in soil CO₂ efflux resulted mainly from mineralization of older SOM rather than from stimulated root respiration. In summary, the 4 °C soil warming led to C losses from the studied alpine treeline ecosystem by increasing SOM decomposition more than C gains through plant growth.