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Soil dynamics at its extremes: insights from cosmogenic and fallout radioactive nuclides

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Soil production and denudation are important and opposing processes that ultimately determine soil formation trajectories and, thus, the landscape. High mountainous areas are geomorphologically active environments and are strongly shaped by the redistribution of sediments and soils. With global warming and the subsequent retreat of glaciers, these processes become increasingly important. New areas having fresh and mostly unweathered glacial till is exposed and soils start to form. The dynamics of soil production and denudation in these high-mountainous landscapes are, however, not yet fully understood. We therefore aimed at exploring the relationship between soil production and denudation at different stages of soil development. This was done by comparing a calcareous and a siliceous soil chronosequence in the central Swiss Alps over the last about 14 kyr. We calculated element mass balances to determine weathering rates and measured short- and long-term erosion rates based on meteoric $^{239+240}$Puand ^{10}Be. In both chronosequences, the erosion rates were highest in the young soils (on average 5−10 t ha^{-1} a^{-1} soil loss). Erosion rates decreased markedly after 3−5 ka of soil development (on average 1−2.5 t ha^{-1}a^{-1} soil loss) to reach a more or less stable situation after 10−14 ka (on average 0.3–2 t ha^{-1}a^{-1}). Chemical weathering and soil production rates also decreased over time, particularly on the calcareous soil sequence.

Depending on the relief and vegetational development, it takes up to 10 ka to reach soil and slope stability. Despite the very high erosion rates, particularly at the start of soil formation, mineral dissolution and transformation reactions are detected and a high rate of organic matter accumulation is measured. Soil production rates reach under such conditions extreme values. In the early stages of soil development, the parent material mainly drives soil formation while at later stages the vegetation becomes more dominant as it promotes surface stability, complex hydrological pathways and chemical weathering that determine water drainage and retention dynamics.