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Inacessible Andean sites reveal land-use induced stabilisation of soil organic carbon

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Human activity affects properties and development of ecosystems across the globe to such a degree that it is challenging to get baseline values for undisturbed ecosystems. This is especially true for soils, which are affected by land-use history and hold a legacy of past human interventions. Therefore, it is still largely unknown how soil would have developed "naturally" and if processes of organic matter stabilisation would be different in comparison to managed soils. Here, we show undisturbed soil development, i.e. the processes of weathering and accumulation of soil organic carbon (SOC), by comparing pristine with grazed sites in the high Andes (4500 m) of southern Peru. We located study plots on a large ledge (0.2 km^2) that is only accessible with mountaineering equipment. Plots with pristine vegetation were compared to rangeland plots that were constantly under grazing management for at least four millennia. All "state factors"; climate, potential biota, topography, parent material and time; besides "land-use" were, therefore, identical.

Vegetation change, induced by grazing management, led to lower vegetation cover of the soil, thereby increasing soil surface temperatures and soil acidification. Both factors increased weathering in rangeland soils, as indicated by the presence of pedogenic oxides, especially amorphous Al-(oxy)hydroxides (oxalate-extractable Al). Higher losses of base cations (K, Na, Ca) and lower pH-values were related to a low base saturation of exchange sites in rangelands. Therefore, rangeland soils were classified as Umbrisol, whereas soils under pristine vegetation were classified as Phaeozeme. All profiles were rich in SOC (100 to 126 g kg-1) with no significant differences in concentrations or stocks. SOC of rangeland soils was, however, less available for microorganisms (proportion of microbial C on SOC: 1.8 vs. 0.6% in pristine and rangeland soils, respectively) and showed higher stability against thermal degradation. Reasons for these findings were a high proportion of complexed SOC in rangeland soils (25 to 36 vs. 59% of SOC were extractable with Na-pyrophosphate in pristine and rangeland soils, respectively). Moreover, less C was associated with the light fraction (< 1.6 g cm-3), but more with the silt fraction (< 1.6 g cm-3 and size between 63 and 2μm). Differences of the δ13C signatures of vegetation and soil ($\Delta\delta$13C plant-soil) were lower in all density-size fractions and even negative in the light fraction of rangeland soils, meaning that these were more depleted or less enriched with 13C relative to vegetation. This could indicate stabilisation of old C derived from former pristine vegetation (having a lower 13C signature), presence of pyrogenic carbon or specific stabilisation of depleted compounds.

Overall, our the approach of using large, inaccessible sites as reference for continuously used sites revealed that grazing management had tremendous effects on the partitioning of SOC among different fractions, but not on the total stocks. Since SOC in rangeland soils was more effectively stabilised, reactions to environmental changes should be slower and SOC in pristine soils is likely to react more sensitive.