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Feedbacks between water erosion and soil thinning

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Soil erosion rates frequently exceed the pace at which new soil is formed. This imbalance can lead to soil thinning (i.e., truncation) whereby subsoil horizons, and the underlying parent material, emerge progressively closer to the land surface. These subsurface horizons may have contrasting physical, chemical, and biological properties from those of the original topsoil. Hence, soil thinning can induce changes in topsoil erodibility – a fact that has been largely overlooked in erosion modelling research and could affect long-term projections of soil erosion rates. Here we present a model-based exploration of the potential feedbacks between water erosion and soil thinning, using measured data from 265 agricultural soil profiles in the United Kingdom. We simulated annual erosion rates on these soil profiles with the Modified Morgan-Morgan-Finey model, assuming time-constant land cover, topographic, and rainfall parameters. As the original topsoil was successively removed, our model gradually mixed the subsurface horizons into a 20 cm ploughing layer. We applied this modelling framework on a yearly time-step over a 500-year period, or until the ploughing layer reached the bottom of the lowermost soil horizon. Soil texture, stone cover, and soil organic carbon content for the ploughing layer were recalculated for each time-step through a mass-balance model. Soil bulk density and soil moisture content at field capacity were estimated for each time-step by pedo-transfer functions developed from our own dataset. In addition, we employed a Monte Carlo simulation with 100 iterations per year to provide a forward error assessment of the modelled soil losses. We found that simulated erosion rates on 42 % of the soil profiles were sensitive to truncation-induced changes in soil properties during the analysed period. Among the profiles sensitive to soil thinning, 68 % displayed a negative trend in modelled erosion rates. This was largely explained by decreasing silt contents on the surface soil due to selective removal of this more erodible particle size fraction and the presence of clayey or sandy substrata. Moreover, an increased residual stone cover shielded the surface soils from detachment by raindrop impact and surface runoff. The soil profiles with a positive trend in erosion rates were characterised by the presence of siltier subsoil horizons, which increased topsoil erodibility as they were mixed into the ploughing layer. Overall, our results demonstrated how modelled erosion rates could be sensitive to truncation-induced changes in soil properties, which in turn may accelerate or slow down soil thinning. These feedbacks are likely to affect how we calculate soil lifespans and make long-term projections of land degradation.