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Predicting 20-year soil organic carbon loss using Rock-Eval 6 thermal analysis

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Changes in global soil carbon stocks have considerable potential to influence the course of future climate change. To implement sequestration strategies and evaluate their efficiency it is essential to estimate the soil organic carbon (SOC) that is mineralized over a relatively short period of time (e.g., 20 years). Nonetheless, models of SOC dynamics often yield unrealistic values of the size of SOC pools. Thermal analysis methods provide cost-effective information on SOC thermal stability that has been shown to be qualitatively related to SOC biogeochemical stability. The objective of this work was to build the first quantitative thermal analysis-based model of the size of the SOC pool that is mineralized over a 20-year time period.

We used a unique set of 38 archived soil samples from four long-term bare fallow experiments in Northwestern Europe (Grignon, France; Rothamsted, Great Britain; Ultuna, Sweden; Versailles, France). At each site, we estimated the average SOC loss expressed as a concentration over several 20-year periods (4–7 per site). We divided site-specific concentrations of 20-year SOC loss by the SOC concentration at the beginning of these different 20-year periods for all soil samples to estimate their proportion of 20-year SOC loss. The 20-year SOC loss (CL20y) concentrations ranged between 0.6 and 14.1 g C$\cdot$kg^{-1} soil, while CL20y proportion ranged from 6 to 51% of total initial SOC.

Because climatic conditions and specifically temperature influence decomposition, we applied a thermal correction to CL20y by using thermal years instead of calendar years to account for differences in mean annual temperature (MAT) among the four bare-fallow sites. At all sites, thermal time (Gregorich et al., 2017) was calculated using the accumulated degree-days (base temperature = 0 °C) from the start of the bare-fallow. Then, using the average cumulated degree-days per calendar year recorded at the coldest site (Ultuna, SW), we calculated thermal years (1 thermal year = 2630 degree-days) and computed the SOC loss over 20 thermal years for all sites.

Samples were subjected to thermal analysis by Rock-Eval 6 (RE6) that generated a series of 30 thermal indicators reflecting their SOC thermal stability and bulk chemistry. Correlation analysis helped us select the most relevant RE6 parameters to predict CL20y concentration and proportion with a simple linear regression model. The hydrogen index (amount of hydrogen-rich effluents formed during the pyrolysis phase; mg HC$\cdot$g^{-1} SOC) was the best predictor of both CL20y concentration (R2 = 0.75, residual standard error = 1.65 g C$\cdot$kg^{-1} soil) and proportion (R2 = 0.71, RSE = 0.06%).

With thermal time, the range of CL20y concentration and proportion were smaller and models using the hydrogen index to predict CL20y concentration and proportion were also slightly more performant (R2 = 0.80, RSE = 0.29 g C$\cdot$kg^{-1} soil and 0.05%).

The RE6 thermal analysis method can thus predict in-situ SOC biogeochemical stability and with the use of the climatic correction (thermal time), this model predicting the 20-year SOC loss could be applied to more contrasted climates.

Reference: Gregorich et al., 2017. GCB, 23, 1725–1734.