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What do carbon fractions and C:N ratios tell us about the origin of carbon in German agricultural soils?

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Agricultural soils in Germany store about 2.5 Pg (1 Pg = 10^{15} g) of organic carbon in 0-100 cm depth. If this carbon was all powdered charcoal, it would fill a train with 61 million carriages, extending 2.5 times the distance to the moon. This study aimed at better understanding the origin of the organic carbon contained in mineral soils under agricultural use. For this, total organic carbon (TOC), C:N ratios and particulate organic carbon (POC) of 2,939 crop- and grassland sites scattered in a 8x8 km grid across Germany were evaluated. RandomForest algorithms were trained to predict TOC, C:N, POC and their respective depth gradients down to 100 cm based on pedology, geology, climate, land-use and management data. The data originated from the first German Agricultural Soil Inventory, which was completed in 2018, comprising 14,420 mineral soil samples and 36,163 years of reported management.

In 0-10 cm, land-use and/or texture were the major drivers for TOC, C:N and POC. At larger depths, the effect of current land-use vanished while soil texture remained important. Additionally, with increasing depth, soil parent materials and/or pedogenic processes gained in importance for explaining TOC, C:N and POC. Colluvial material, buried topsoil, fluvio-marine deposits and loess showed significantly higher TOC and POC contents and a higher C:N ratios than soil that developed from other parent material. Also, Podzols and Chernozems showed significantly higher TOC and POC contents and a higher C:N ratio in the subsoil than other soil types at similar depths because of illuvial organic matter deposits and bioturbation, respectively. In 30-70 cm depth, many sandy sites in north-western Germany showed TOC, POC and C:N values above average, which was a legacy of historic peat- and heathland cover. The depth gradients of TOC, POC and C:N showed only little dependence on soil texture suggesting that they were robust towards differences in carbon stabilization due to organo-mineral associations. Instead, these depth gradients were largely driven by land-use (redistribution of carbon in cropland by ploughing) and variables describing historic carbon inputs (e.g. information on topsoil burial). Hardpans with packing densities > 1.75 g cm^{-3} intensified the depth gradients of TOC, POC and C:N significantly, suggesting that such densely packed layers restricted the elongation of deep roots and therefore reduced organic carbon inputs into the subsoil.

Today’s soil organic carbon stocks reflect past organic carbon inputs. Considering that in 0-10 cm, current land-use superseded the effect of past land-cover on TOC while land-use showed no effect on POC and C:N, we conclude that topsoil carbon stocks derived from relatively recent carbon inputs (< 100 years) with high turnover. In the subsoil, however, most carbon originated from the soil parent material or was translocated from the topsoil during soil formation. High C:N ratios and POC content of buried topsoils confirm low turnover rates of subsoil carbon. The contribution of recent, root-derived carbon inputs to subsoils was small but significant. Loosening of wide-spread hardpans could facilitate deeper rooting and increase carbon stocks along with crop yield.