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Supplement of

The role of geochemistry in organic carbon stabilization against microbial decomposition in tropical rainforest soils

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Supplemented information on valley positions

The following text represents the supplementary results and short discussion on geochemical soil parameters, SOC stocks and stabilization assessed at valley positions of contrasting parent material geochemistry investigated in tropical rain mountain forest in the border region of the Congo and Nile basement. We show that, in valley positions, significant variation in the size of SOC stocks are related to changes in hydrological conditions and alluvial processes compared to non-valley positions. Geochemical differences in SOC stabilization mechanisms between regions remain in place, but are less prominent in valleys than at non-valley positions.

SI 1 Supplementary results on valley positions

1.1 Pedogenic oxides

For valley positions, pyrophosphate extractable oxide mass (0.02 to 0.66 mass%) and oxalate extractable oxide mass (0.03 to 4.29 mass%) were low compared to DCB extractable oxide mass (0.11 to 10.79 mass%) (Fig. S1). In general, valley positions showed a comparable picture compared to non-valley positions (Fig. 3, S1) with the exception that valley soils in the mixed sedimentary region had considerably lower amounts of pedogenic oxides at all soil depths (< 0.27 mass%) compared to valley soils in the mafic and felsic region.

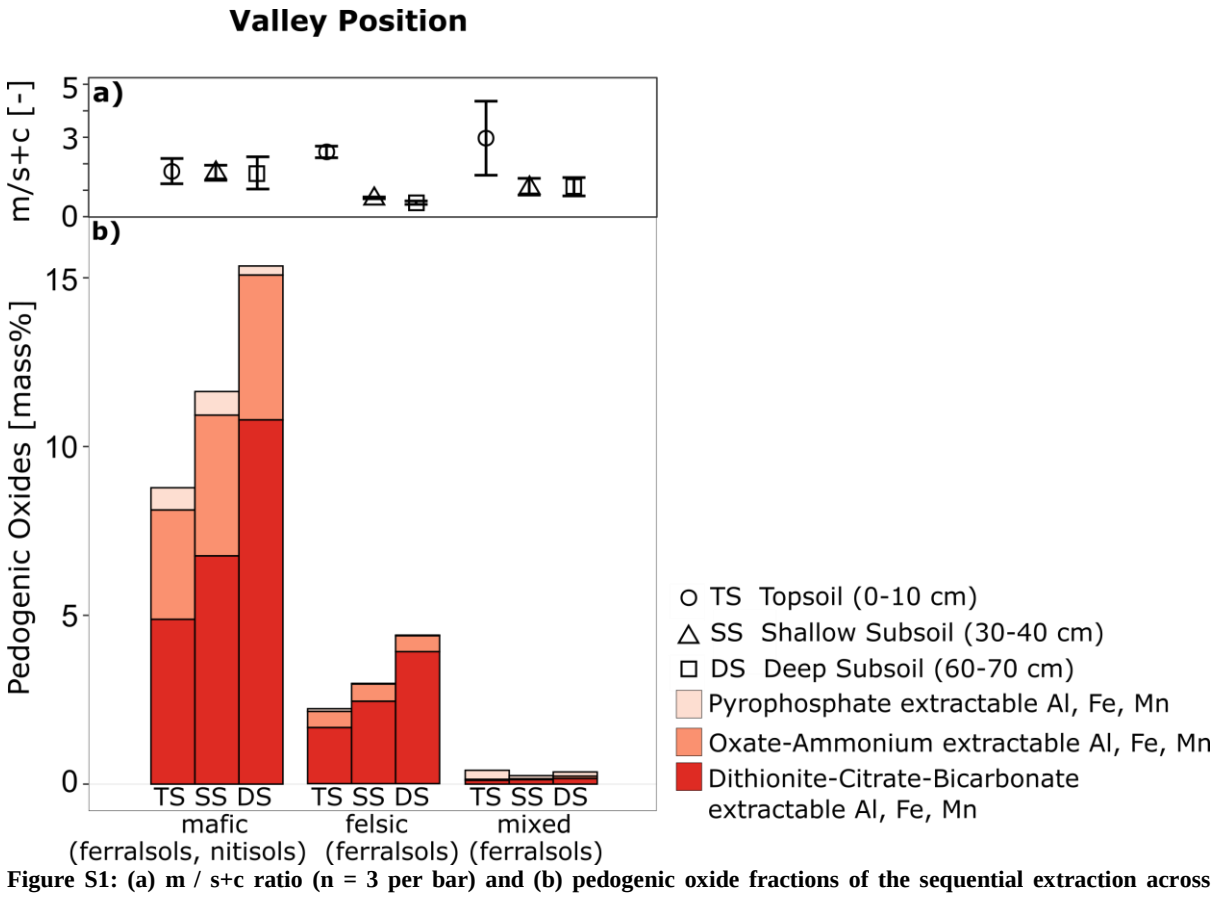

Figure S1: (a) m / s+c ratio (n = 3 per bar) and (b) pedogenic oxide fractions of the sequential extraction across geochemical regions in valley positions (n = 1 per bar). Error bars represent standard error.

1.2 Variation in SOC properties in valley positions with geochemistry

SOC_{bulk}

SOC_{bulk} in topsoil was not significantly different between valley and non-valley positions. However, valley positions tended to be generally higher in SOC_{bulk} than their non-valley counterparts. In shallow subsoil, SOC_{bulk} was significantly higher in valley positions of the mafic site (SOC_{bulk}: 41.2 ± 4.6 t C ha^{-1}) compared to non-valley positions (SOC_{bulk}: 25.0 ± 0.2 to 30.0 ± 3.2 t C ha^{-1}), but no difference was found for subsoils of the felsic and mixed sedimentary region (Figs.4, S2).

Abundance of C fractions

In the felsic magmatic region, the abundance of microaggregate associated C and the ratio of m / s+c was more than twice as high in valley topsoils (m / s+c: 2.5 ± 0.4) compared to non-valley topsoils (m / s+c: 1.2 ± 0.5 to 1.4 ± 0.5) (Figs. 3a, S1a). Additionally, $SOC_{>250\ \mu m}$ in topsoil of valley positions of the mixed sedimentary region was about threefold higher in valleys (22.2 ± 12.3 %) compared to the corresponding non-valley positions (6.5 ± 7.1 to 6.7 ± 4.0 %) (Figs. 4b, S2b), and the ratio of m / s+c exhibited a much higher variance in topsoils (Figs. 3a, S1ab).

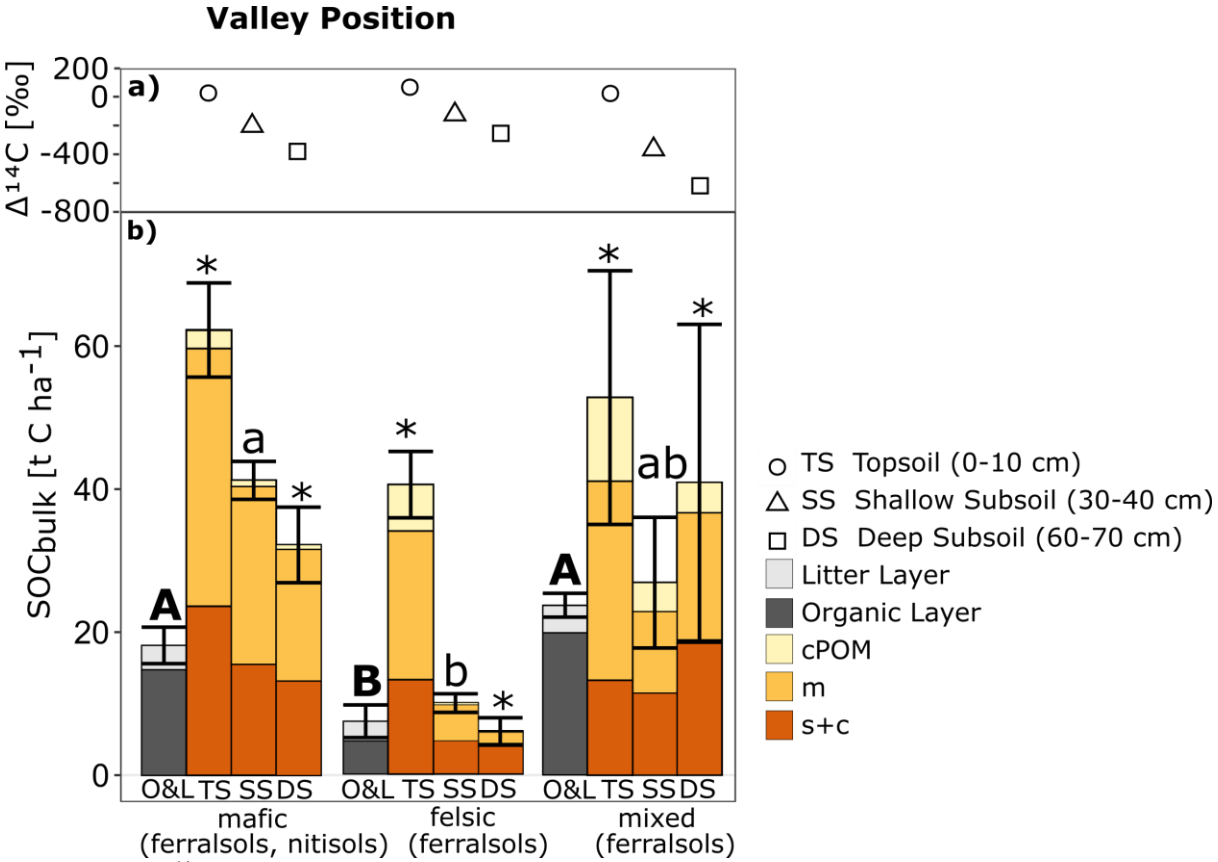

Figure S2: (a) $\Delta^{14}C$ across geochemical regions in valley positions (n = 1 per bar). (b) SOC_{bulk} and fractions across geochemical regions in valley positions (n = 3 per bar). Where letters share the same font type, means were compared to each other with letters indicating significant differences between geochemical regions per soil layer. Asterisks indicate no significant differences in means (p > 0.05). cPOM – coarse particulate organic matter, m – waterstable microaggregates, s+c – free silt and clay fraction.

Changes in ^{14}C signature

Soils from all geochemical regions at valley positions were more depleted in $\Delta^{14}C$ with increasing soil depth (Fig. S1a). The $\Delta^{14}C$ ranged from 65.1 ± N/A ‰ (felsic) to 20.4 ± N/A ‰ (mixed sedimentary) in the topsoil, and -256.5 ± N/A ‰ (felsic) to -617.4 ± N/A ‰ (mixed sedimentary). The contribution of FOC to soil C in the mixed sedimentary region increased with soil depth for valley positions, ranging from 1.8 ± N/A % FOC in topsoils to 43.5 ± N/A % in subsoils (Table S1).

Table S1: Proportion of biogenic vs. fossil derived organic carbon (OC) in soils developed from mixed sedimentary rocks in valley positions (n=1). Standard deviation was not applicable (N/A). FOC values in felsic and mafic soils = 0 % (data not shown).

depth increment	amount of biogenic OC (%)	amount of fossil OC (%)
0 - 10 cm	98.2 ± N/A	1.8 ± N/A
30 - 40 cm	72.1 ± N/A	27.9 ± N/A
60 - 70 cm	56.5 ± N/A	43.5 ± N/A

1.3 Rotated principal component explained variance and loadings

For valley soils, five rPCs were determined (rPC_v) explaining 92.7 % of the variance in the valley position subset (Table A4, Fig. S3). $rPC1_v$ (Eigenvalue 10.7, explaining 38.2 % of the variance) represents solid phase mineralogy, in which total metal oxide concentration, total P and oxalate extractable oxides concentration had strong positive loadings (≥ 0.98), while total Si, pH / clay ratio and sand content had strong negative loadings (≤ -0.69). $rPC2_v$, (Eigenvalue 9.65, explaining 34.5 % of the variance) represents the chemistry of the soil solution and silt content where CEC base saturation, pH and CEC base saturation / clay ratio showed strong positive loadings (≥ 0.92) while CIA, $SOC_{organic}$ and exchangeable acidity showed negative loadings (≤ -0.78). $rPC3_v$ (Eigenvalue 2.5, explaining 9 % of the variance) represents bioavailable P and Al weathering. Bioavailable P showed positive loadings (0.69), while Al_{dcb} / Al_t ratio showed negative loadings (-0.91). $rPC4_v$ (Eigenvalue 1.65, explaining 6 % of the variance) represents root input and exchangeable acidity, both having strong positive loadings (≥ 0.55). $rPC5_v$ (Eigenvalue 1.46, explaining 5 % of the variance) represents Fe weathering and litter C stock in which both the Fe_{dcb} / Fe_t ratio and Litter C stock (SOC_{litter}) had strong positive loadings (≥ 0.66).

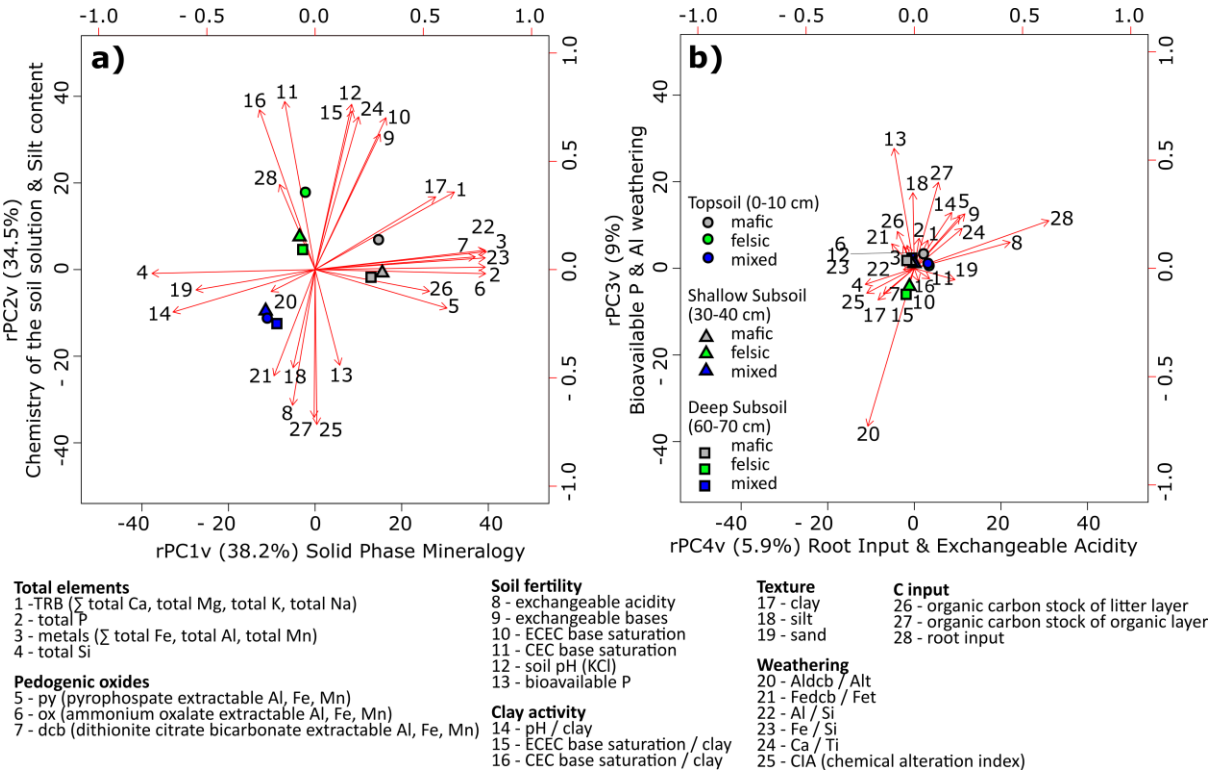

Figure S3: Biplots of the varimax rotated principal component analysis. (a) $rPC1_v$ and $rPC2_v$ and (b) $rPC3_v$ and $rPC4_v$ of non-valley positions (N = 9). Observations cluster together based on similarities within geochemical regions and their distinction to other geochemical regions. Vector length indicates how strongly variables influence a specific rPC. The angles between vectors display the degree of auto-correlation between variables. Small angles represent positive correlations and high degree of autocorrelation, diverging angles represent negative correlations and high degree of autocorrelation, high angles indicate no correlations between variables and/or rPCs.

SI 2 Supplementary short discussion on valley positions

2 Soil C stabilization driven by soil chemistry and parent material rather than topography

In contrast to our initial hypothesis that topography affects C stabilization in tropical forest soils through lateral material movements, we found no indication of this in our analysis (Table A1). This is supported by Drake et al. (2019) who showed that C fluxes from pristine forest catchments within the same study area are characterized by young C from organic layers, with no indication of erosion of older, mineral stabilized C. Similarly, Wilken et al. (2021), using plutonium tracers to analyze soil redistribution along forest hillslopes did not detect any signs of decadal erosional processes of soils for the same sites as used in this study. Even though material fluxes due to lateral water fluxes along slopes cannot be excluded over longer time scales (e.g. 100 to 1,000 years), our results pointed to no recent natural or anthropogenic induced erosional processes in the investigated sites. However, there was a detectable effect on SOC_{bulk} between positions that are affected by riverine and alluvial dynamics with regularly high water saturation (valleys) vs. well-drained positions (non-valleys), with valleys generally having higher SOC_{bulk} than their non-valley counterparts. Valley bottoms might be affected not only by sediments derived from associated hillslopes but also from material redistribution throughout the entire catchment during flood events (Douglas and Guyot, 2005). In addition, soil moisture conditions at the valley bottoms might be affected not only from interflow from the hillslopes but also from temporarily high ground water levels (Bonell, 2005). These fluvial and hydraulic conditions can then lead to higher SOC stocks in valleys than at the non-valley positions by reducing the decomposition rates due to soil water logging and inhibit microbial C decomposition

(Wiaux et al., 2014). Despite having the lowest content of pedogenic oxides, which are important stabilization partners at the non-valley positions, we observe similar SOC stocks in the valley positions as for non-valley positions in the mixed sedimentary region. Valley positions in the mafic region show even higher SOC stocks although having less pedognic oxides compared to non-valley positions. Gleyic properties and fluvial sedimentation processes recorded in valley soils during profile description (Doetterl and Fiener, 2021) supported this interpretation. Overall, we found that in valley positions differences in SOC variables are rather related to changes in hydrological conditions and alluvial processes than by chemical soil properties.

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