



Supplement of

Parent material geochemistry – and not plant biomass – as the key factor shaping soil organic carbon stocks in European alpine grasslands

Annina Maier et al.

Correspondence to: Annina Maier (annina.maier@usys.ethz.ch)

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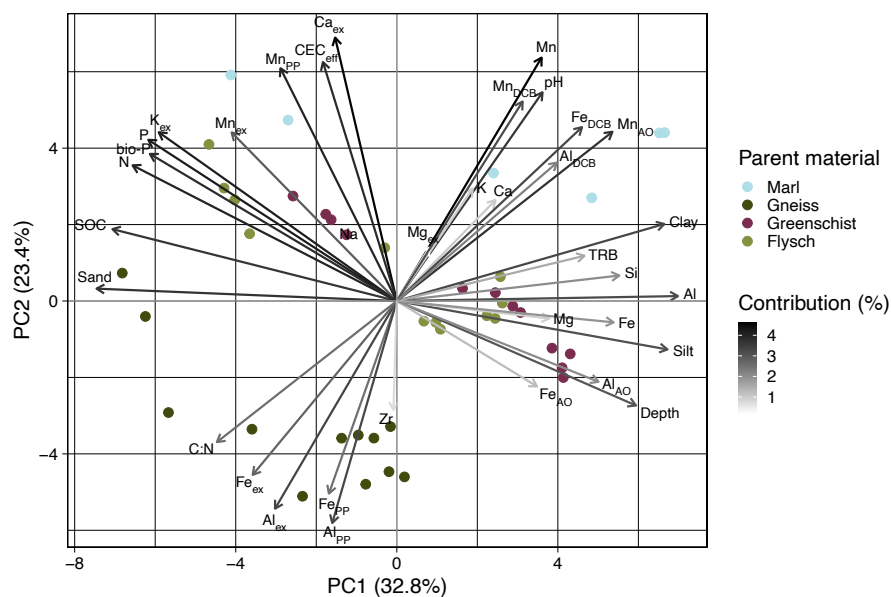


Figure S1. Principal component analysis biplot displaying the first two principal components (PC1 and PC2) for measured bulk soil variables, including depth, SOC, N, Zr, P, Na, K, Ca, TRB, Si, Mg, Fe, Fe_{DCB}, Fe_{ex}, Al, Al_{DCB}, Al_{ex}, Mn, Mn_{ex}, CEC_{eff}, sand, and silt. Observations are shown considering individual parent materials, corresponding to different respective colours. Scaled loadings of individual variables are shown as arrows. The colour of these arrows corresponds to their relative contribution (%) to the respective PCs. Dolomite observations are excluded as its observations were not considered in the SOC model predictions. Please note that the depicted variable contributions were computed to quantify the relative importance of each variable in defining the two first PCs. These contributions were calculated as the sum of squared loadings for each variable across PC1 and PC2.

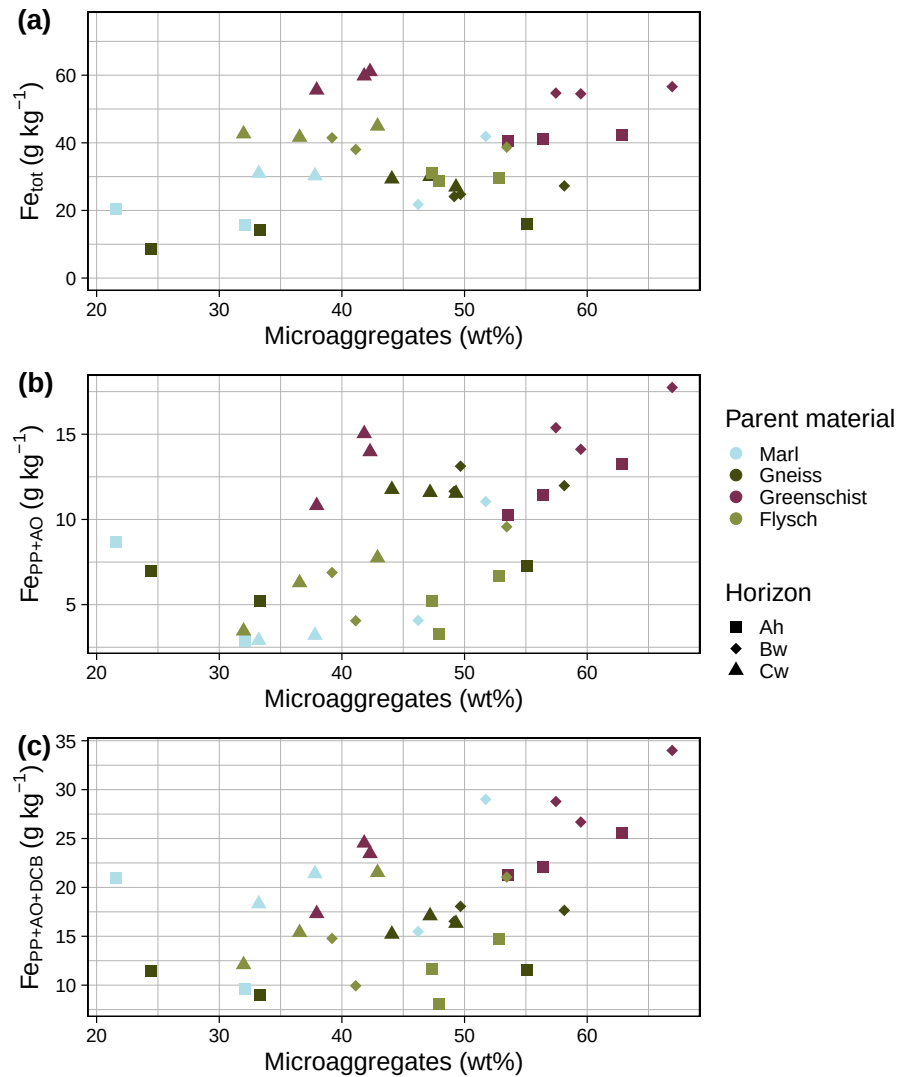


Figure S2. (a) Total Fe concentrations (g kg^{-1}) vs. MA (wt%), (b) sum of Fe concentrations from both Fe_{pp} and Fe_{ao} vs. MA (wt%), (c) sum of Fe concentrations Fe_{pp}, Fe_{ao}, and Fe_{dcb} vs. MA (wt%) . Observations from the Dolomite site were excluded from this figure as its Oh horizon is organic and showed signs of POM contamination in the MA fraction. Note that the individual panels show different y-axis ranges but share the same x-axis range.

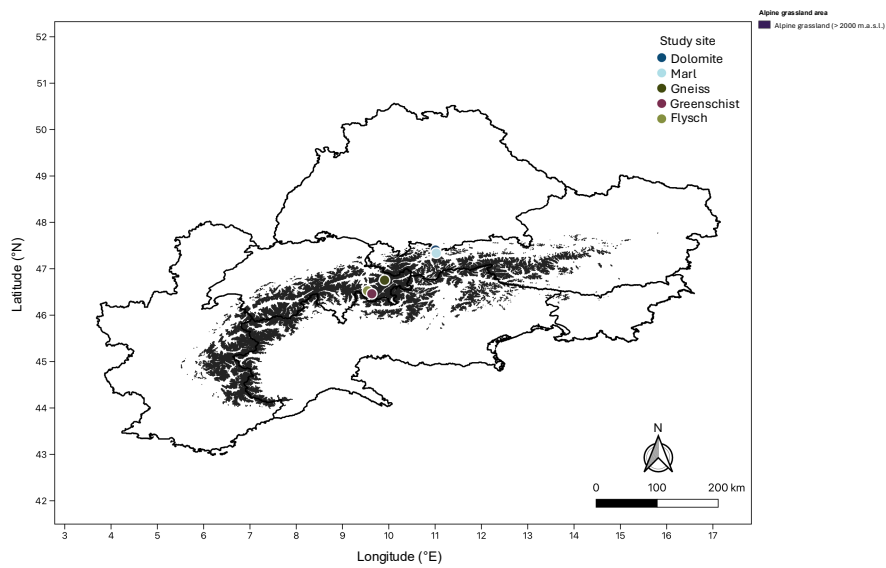


Figure S3. Areas within the extent of the European Alps, as defined by the area included in the European Strategy for the Alpine Region, that are covered by alpine grassland (> 2000 m.a.s.l.) This data was extracted from Marsoner et al. (2023).

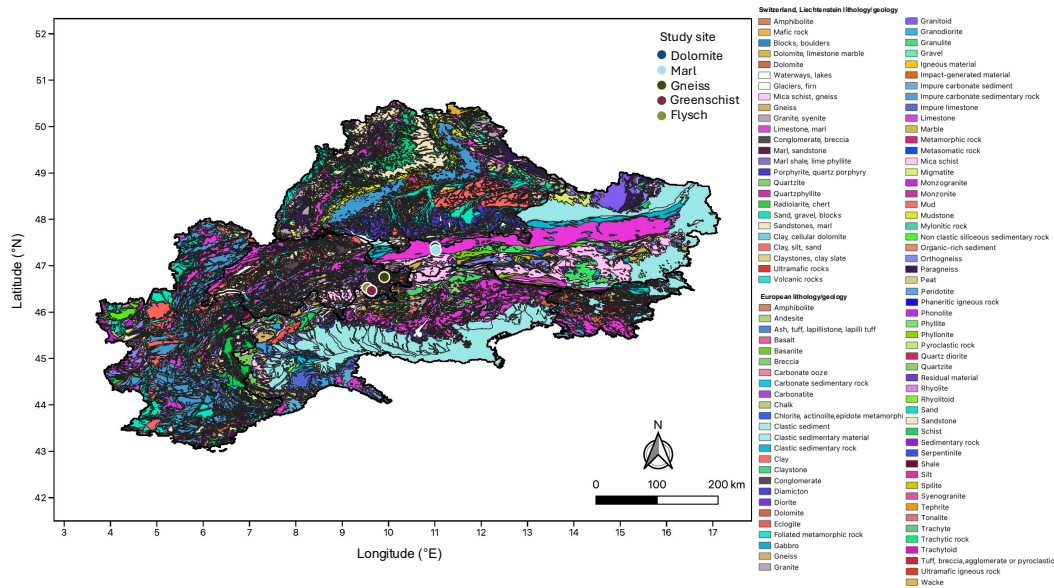


Figure S4. Lithologies/geologies within the extent of the European Alps, as defined by the area included in the European Strategy for the Alpine Region. Please note that the lithological/geological data from Switzerland has a resolution of 1:500'000 and was extracted from Federal Office of Topography swisstopo (2012). The lithological/geological data from the rest of Europe has a resolution of 1:1'000'000 and was extracted from European Geological Data Infrastructure (EDGI) (2018). Please note the two different legends for the Swiss and Liechtensteinese data compared to that of the rest of Europe.

Table S1: Absolute and relative alpine grassland area (ha) within the extent of the European Alps, as defined by the area included in the European Strategy for the Alpine Region, per European lithology/geology class (excluding Switzerland, Liechtenstein), at a resolution of 1:1'000'000 (European Geological Data Infrastructure (EDGI), 2018).

Lithology/geology	Alpine grassland area (ha)	Relative grassland coverage (%)
Mica schist	83831	17.6
Limestone	57306	12.0
Schist	42975	9.0
Quartzite	38283	8.0
Gneiss	37662	7.9
Impure carbonate sedimentary rock	31541	6.6
Conglomerate	17658	3.7
Phyllite	17121	3.6
Dolomite	17034	3.6
Peridotite	16188	3.4
Marble	13130	2.8
Migmatite	13088	2.7
Monzogranite	10799	2.3
Orthogneiss	9986	2.1
Sandstone	9738	2.0
Granite	6894	1.4
Tonalite	6212	1.3
Amphibolite	5303	1.1
Eclogite	5052	1.1
Granulite	5003	1.1
Diamicton	4977	1.0
Metasomatic rock	4376	0.9
Phyllonite	3386	0.7
Andesite	3361	0.7
Paragneiss	2503	0.5
Rhyolite	2461	0.5
Serpentinite	2124	0.4
Sedimentary rock	1413	0.3
Metamorphic rock	1381	0.3

Lithology/geology	Alpine grassland area (ha)	Relative grassland coverage (%)
Clastic sediment	1207	0.3
Basalt	1203	0.3
Monzonite	931	0.2
Diorite	590	0.1
Impure carbonate sediment	573	0.1
Clastic sedimentary rock	252	0.1
Mudstone	244	0.1
Chlorite, actinolite, epidote, metamorphic rock	198	0.0
Clay	122	0.0
Rhyolitoid	99	0.0
Igneous material	11	0.0
Granitoid	2	0.0

Table S2: Absolute and relative alpine grassland area (ha) within the extent of the European Alps, as defined by the area included in the European Strategy for the Alpine Region, per Swiss lithology/geology class (for Switzerland and Liechtenstein), at a resolution of 1:500'000 (Federal Office of Topography swisstopo, 2012).

Lithology/geology	Alpine grassland area (ha)	Relative grassland coverage (%)
Mica schist, gneiss	63604	24.3
Marl shale, lime phyllite	40218	15.4
Limestones, some marl	36146	13.8
Granite, syenite	28882	11.0
Gneiss	27161	10.4
Clay, silt, sands	21452	8.2
Dolomite	12989	5.0
Alkaline rocks	8677	3.3
Conglomerates, breccia	5933	2.3
Amphibolites	4834	1.8
Blocks, boulders	4679	1.8
Quartzite	2696	1.0
Porphyrine, quartz porphyrite	1391	0.5
Glaciers, firn	1141	0.4
Sands, gravel, boulders	651	0.2

Lithology/geology	Alpine grassland area (ha)	Relative grassland coverage (%)
Clays, cellular dolomite	454	0.2
Dolomites, limestone marble	333	0.1
Volcanic rocks	165	0.1
Waterways, lakes	120	0.0
Radiolarites, chert	113	0.0
Marl, some sandstone	37	0.0
Ultramafic rocks	23	0.0
Quartz phyllite	14	0.0

Table S3. Relative coverage of European alpine grasslands (> 2000 m.a.s.l.), within the extent of the European Alps, as defined by the area included in the European Strategy for the Alpine Region, that falls within specific climatic boundary conditions, i.e. mean annual precipitation (MAP) of 1210 ± 100 mm and mean annual temperature (MAT) of 2 ± 1 °C.

Variable	Condition	Pixels, where condition = TRUE	Total grassland pixels	Relative coverage (%)
MAP	1210 ± 100 mm	3344	13738	24.3
MAT	2 ± 1 °C	1571	13782	11.4

References

- European Geological Data Infrastructure (EDGI): Pan-European (EDGI) Geology 1:1000000 [data set]., https://maps.europe-geology.eu/#baslay=baseMapGEUS&extent=156647.78120184876,1155970,8348332.218798151,5309410&layers=onegeoeuro_surface_lithology, 2018.
- 5 Federal Office of Topography swisstopo: Lithological Map of Switzerland 1:500 000 — Lithology Hauptgruppen [data set]., https://data.geo.admin.ch/browser/index.html#/collections/ch.swisstopo.geologie-geotechnik-gk500-lithologie_hauptgruppen?.language=en, 2012.
- Marsoner, T., Simion, H., Giombini, V., Egarter Vigl, L., and Candiago, S.: A detailed land use/land cover map for the European Alps macro region, *Scientific Data*, 10, 468, <https://doi.org/10.1038/s41597-023-02344-3>, publisher: Nature Publishing Group, 2023.