Subsoil organic carbon response to land use in mountain soils

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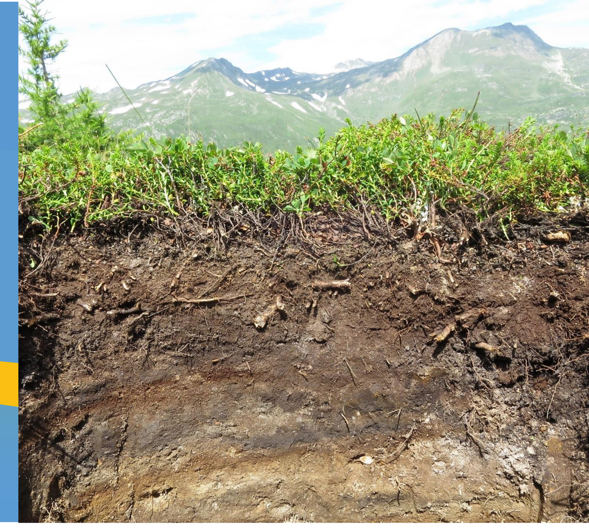


MOUNTAIN SOILS IN A CONTEXT OF GLOBAL CHANGE

Soils of mountain regions (Fig. 1) are estimated to contain large amounts of organic matter, equivalent to stocks found in high-latitude boreal and tundra soils. Land cover and land use are also expected to change rapidly in mountain regions due to socio-economic transitions and climate change, which is occurring at a faster rate than in lowland areas. These anthropogenic impacts have the potential to strongly affect soil organic matter storage. Most studies of land-use change have however focused on topsoils; whether similar trends will hold true for subsoils remains unknown.

We first investigated the potential decoupling between topsoil and subsoil organic matter dynamics by sampling 46 profiles of the central Swiss Alps representing a wide range of parent material and soil forming conditions. Secondly, the effects of environmental perturbations on subsoil organic matter were specifically investigated in podzolic profiles composing a disturbance chronosequence on the West Coast of British Columbia, Canada.

Figure 1: A high-altitude podzolic profile in the Western Swiss Alps (Greppon Blanc, 2300 m).

SUBSOIL ORGANIC MATTER DYNAMICS

Using Rock-Eval pyrolysis as a proxy for organic matter dynamics, we investigated potential differences between the three main parts of the solum: the litter layer (OL horizon), the topsoil (A horizons) and the subsoil (B horizons). Rock-Eval pyrolysis measures the degree of thermal stability of the organic matter. The R-index, which represents the relative resistance of organic matter to pyrolysis, was chosen as an integrative indicator of organic matter maturation and stabilization processes (Sebag *et al.* 2016).

In the litter layer, the R-index was related to the organic matter stoichiometry (C:N ratio, hydrogen index) and to the nature of vegetative inputs (plant communities). In the topsoil, the only important explanatory factor was the organic C concentration. Finally, in the subsoil, soil texture and the geochemical environment rose to prominence. This suggests a shift in determinants of organic matter dynamics from biological and biochemical controls in the litter layer, to physical control in the topsoil (degree of organic in-mixing), to textural, mineralogical and geochemical controls in the subsoil (Fig. 2).

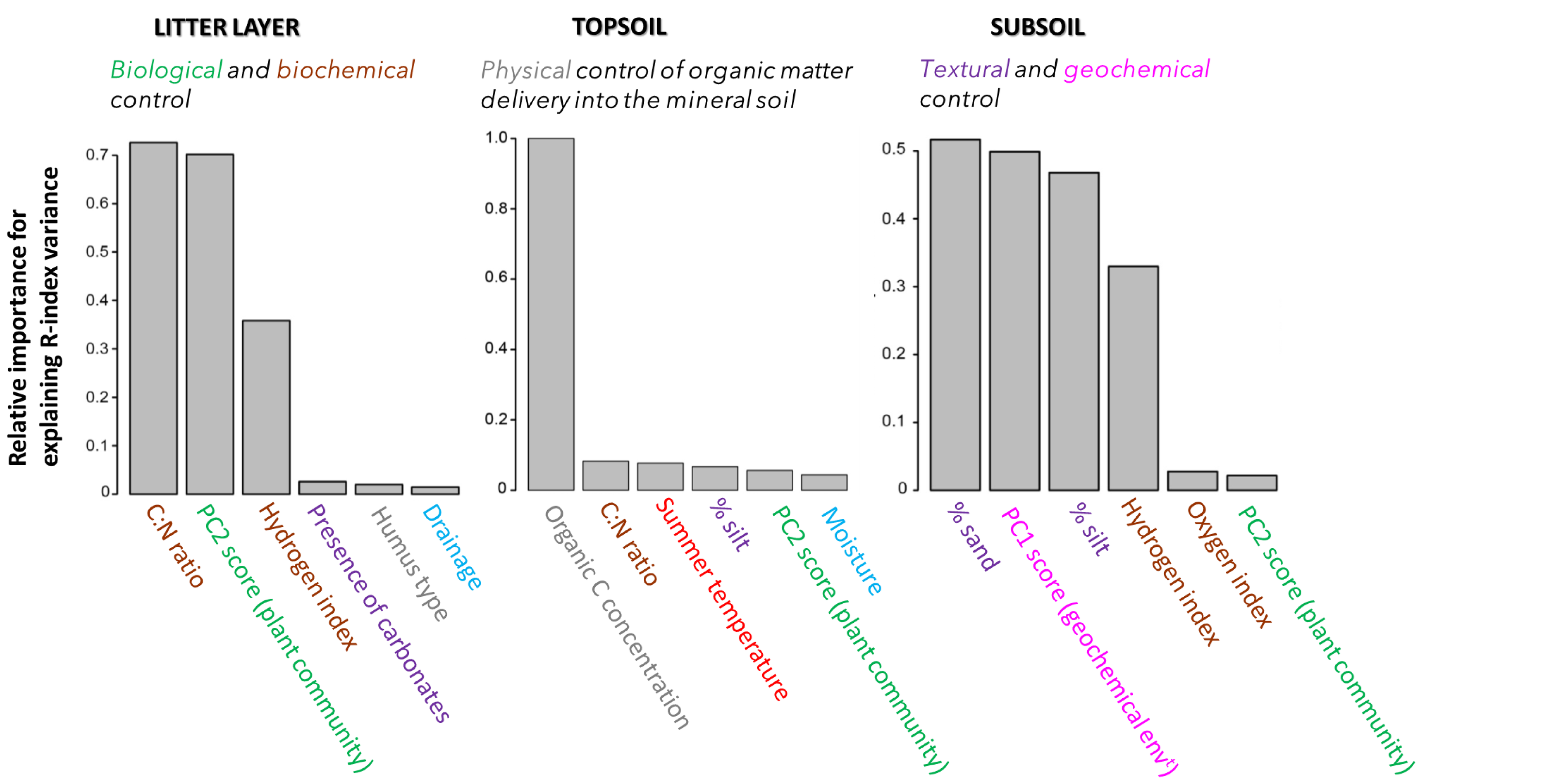
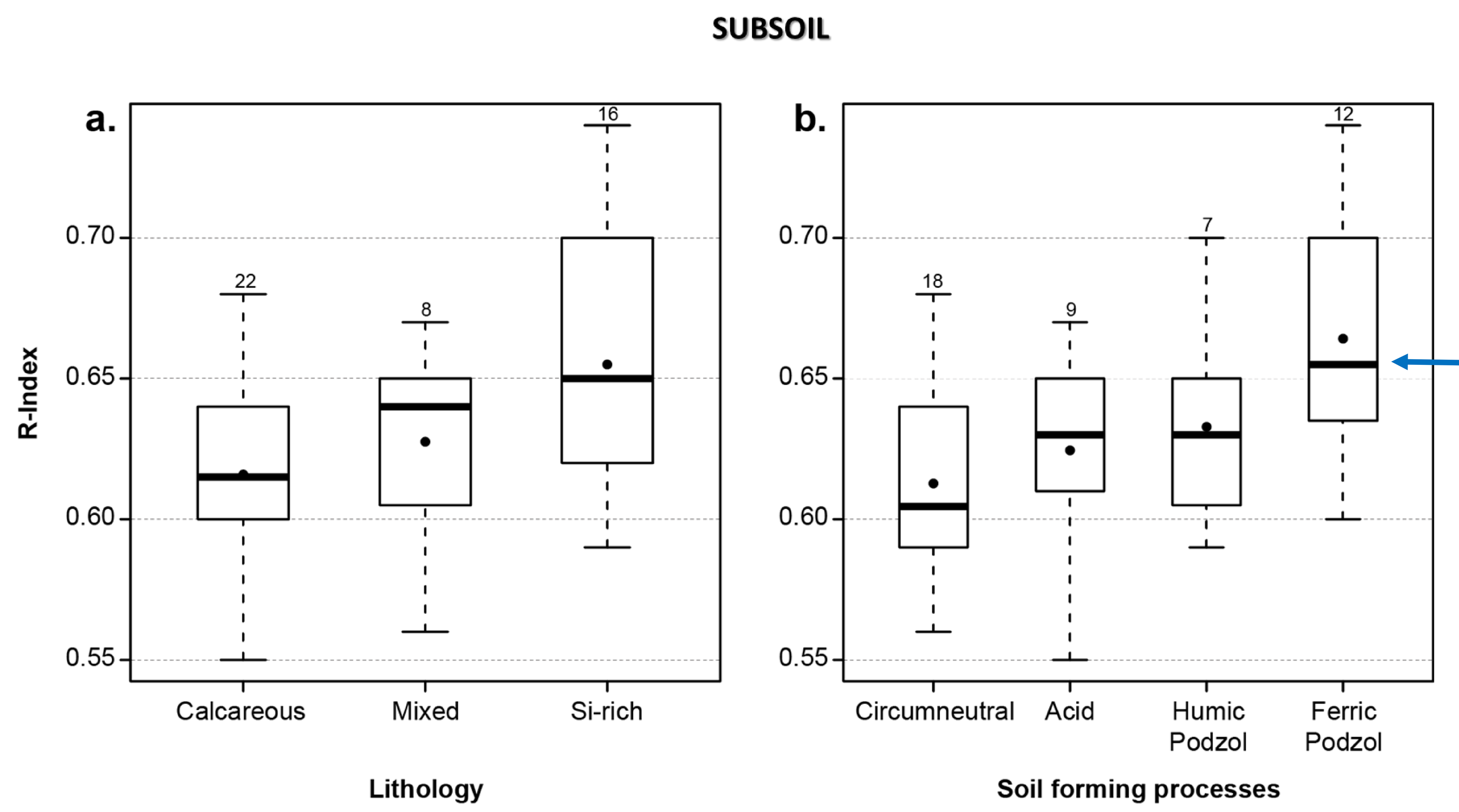


Figure 2: The six main explanatory variables influencing the thermal stability of organic matter in different soil layers. Influential variables were selected using an information theoretic framework based on the Aikaike's information criterion (IT-AIC), in which a range of models including the R-index as the dependent variable and maximum three simultaneous predictor variables were compared. See Matteodo et al. (2018) for details.

More specifically, in the subsoil, organic matter properties varied as a function of soil mineralogy and of the pedogenetic trajectory, which was chiefly influenced by texture and geochemistry (Fig. 3). Ferric podzols developed on acid and coarse-textured parent materials contained organic matter with the highest thermal stability.



The organic matter in the subsoil layers of ferric podzols have a high thermal stability. Is this indicative of a high degree of stabilization and resistance to environmental perturbations?

Figure 3: The R-index of organic matter in subsoil horizons varies (a) with the mineralogical composition of soil parent material and (b) the type and advance of pedogenic processes. The "Circumneutral" category refers to weakly differentiated solums (Cambisols, Leptosols, Regosols, Gleysols, Stagnosols) with a subsoil of pH > 6, while the "Acid" category refers to weakly differentiated solums with a subsoil at pH < 5.6.

EFFECTS OF LAND DISTURBANCE

The effects of environmental perturbation on podzolic subsoil organic matter were evaluated by assessing the effects of clear-cut logging on a forested slope of Western British Columbia. Following forest harvest, soil organic matter content showed a temporary increase before returning to control values in regenerating plots (Fig. 4).

(a) Illuvial horizons (Bs-BC)		Soil organic C (%)	Total N (%)
Control	(mature forest)	1.7 ± 0.1 a	0.08 ± 0.01
Logged plots	(1 - 5 years)	2.3 ± 0.2 b	0.10 ± 0.01
Regenerating plots	(8 - 15 years)	1.6 ± 0.2 a	0.07 ± 0.01

(b)

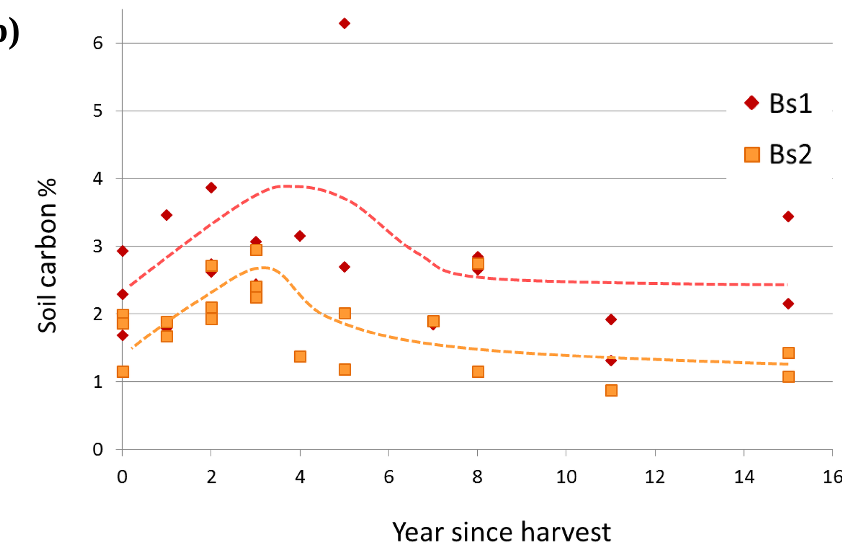


Figure 4: Variations of organic matter content in a disturbance chronosequence comprising plots having undergone clear-cut harvest 1 to 15 years prior to sampling. (a) Mean ± standard error of the mean for control, logged and regenerating plots. Statistically significant differences at α = 0.05 are indicated by different letters. (b) Graphical representation of unprocessed data. Dashed trendlines are illustrative only. Details in Grand & Lavkulich (2012).

Similarly, the amount of poorly crystalline Al and Fe phases showed a peak in logged plots before decreasing below control values in regenerating plots (Fig. 5).

(a) Illuvial horizons (Bs-BC)	Imogolite (g/kg)	Ferrihydrite (g/kg)
Control (mature forest)	23.2 ab	3.6 ab
Logged plots (1 - 5 years)	29.1 a	4.8 a
Regenerating plots (8 - 15 years)	15.9 b	2.8 b

(b)

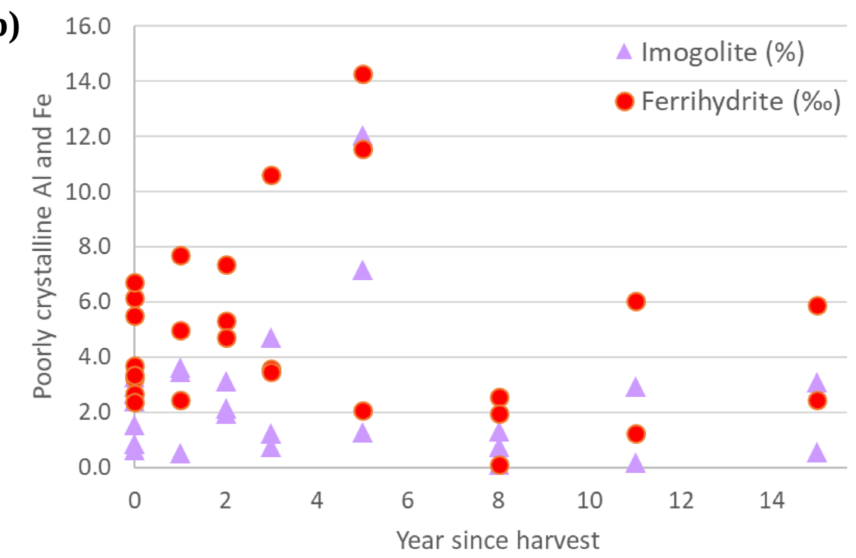


Figure 5: Variations of poorly crystalline aluminosilicates (imogolite-type material) and pedogenic oxides (ferrihydrite) in the same disturbance chronosequence. (a) Mean ± standard error of the mean for control, logged and regenerating plots. Statistically significant differences at α = 0.05 are indicated by different letters. (b) Graphical representation of unprocessed data.

Taken together, these data suggest a temporary increase in the strength of the podsolization process following forest harvest, likely due to the excess litter decomposition and illuviation of organic acids caused by massive inputs of logging slash (fine branches and needles) to the litter layer. This dynamic suggests that organic matter in podzolic subsoil is not inherently stable, but depends on the maintenance of reactive mineral species which can themselves be impacted by changes in the edaphic environment.

PERSPECTIVES

Overall, our data indicate that organo-mineral and organo-metal interactions are of prime importance to organic matter accumulation in the subsoil, and that understanding the response of deep soil C stocks to land use change will require consideration of the geochemical and mineralogical environment.

Our results further suggest that so-called reactive mineral phases may themselves be impacted by land use, in turn affecting deep soil C stabilization and destabilization processes. Little is actually known about naturally-occurring poorly crystalline phases (Fig. 6). Further research into the nature and reactivity of these phases seems highly warranted.

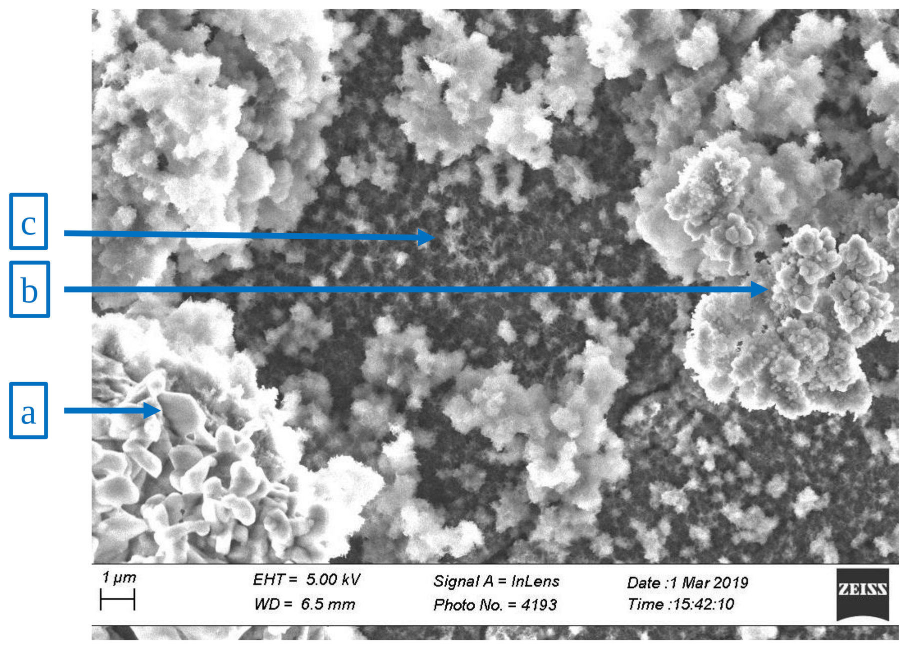


Figure 6: Scanning electron micrograph of the colloidal fraction of a podzolic subsoil horizon showing at least three different phases:
(a) Micrometric platelets, possibly of kaolinitic clays;
(b) Globular organo-metallic flocculates;
(c) Al-bearing needles and stars.

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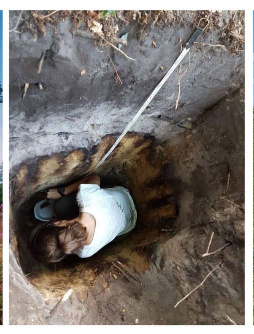



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