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POLICY BRIEF

SUSTAINABLE SOIL MANAGEMENT IN MOUNTAIN REGIONS

Sustainable soil management in mountain regions

Contributors: Silvia Stanchi (University of Torino-DISAFA, NatRISK, Alpine Soil Partnership), Maksatbek Anarbaev (International University of Kyrgyzstan), Ian Hannam (Australian Centre for Agriculture and Law, School of Law, University of New England), Paul Illmer (University of Innsbruck), Nadine Praeg (University of Innsbruck), Julia Seeber (Eurac Research), Michael Steinwandter (Eurac Research), Bettina Weber (University of Graz), Michele Freppaz (University of Torino-DISAFA, NatRISK, Alpine Soil Partnership)
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Soil erosion in high alpine regions (here at 2600 m), aggravated by high stocks of grazing sheep and heavyweight cattle (Oberettes, Matsch/Mazia, South Tyrol)

MOUNTAIN SOILS: GENESIS, SPECIFICITIES AND ECOSYSTEM SERVICES

Mountain soils represent a finite, virtually **non-renewable resource** that provides essential **ecosystem services** for life on Earth, not only in the mountains but also downstream (FAO and ITPS, 2015). Although the average **soil formation rate** is not easy to assess, due to the **variability of the soil forming factors** (Jenny, 1941; Weil & Brady, 2017), FAO estimated that the formation of **2–3 cm of fertile soil can require up to 1000 years**. Such rates, which refer to soils in general, suggest that unsuitable soil management practices lead to soil degradation and loss that cannot be remediated in the average human lifespan.

In many mountain regions of the world, the landscape was strongly shaped by glaciations (Martignier & Verrecchia, 2013). Mountain soils are often subject to regressive pedogenesis due to disturbances (e.g. profile truncation and soil redistribution due to soil erosion & snow avalanches), thus they may be particularly fragile and vulnerable to degradation (Egli, 2014). Egli (2014) reported that mountain soils on silicate parent material can form at variable speeds ranging from nearly 0 (for older soils) to 6–7 mm y^{-1} for very young, thin soils, showing a clear decreasing trend with time. The **soil forming factors** according to Jenny (1941), i.e. **climate, living organisms** (including humans), **relief, parent material, and time**, show complex, strong interactions in mountain regions. For example, when considering the climate effect, a large set of variables must be taken into account (Thornton et al., 2021). The occurrence of snowfall and the snow-cover distribution across the year strongly affect the upper soil layers, making soil and snow act as a continuum (Freppaz et al., 2018);

the **snow-soil interface** affects the activity of microorganisms, the rhizosphere, and fauna, and as such plant phenology. The temperature gradient along a mountain slope simulates the effect of latitude, determining the vegetation type. Therefore, soils show very **high spatial variability** and range from agricultural soil in the flat river plains to alpine tundra soil above the treeline. Topography, i.e. the landform, can affect soil development and properties, such as organic matter content, soil moisture, and soil temperature, even at a very small scale (e.g. D'Amico et al., 2015). The chemical and physical **weathering** of the soil parent material is strongly dependent on climate and geomorphology, and very often, the pedogenic substrate has been redistributed by glacial, fluvioglacial, or eolian transport.

An often neglected characteristic of mountain soils is that they are inhabited by a wide range of organisms and form **hotspots for biodiversity** (Guerra et al., 2022). Soils generally harbor an enormous diversity of organisms, from microbes to invertebrates and small vertebrates. It is estimated that a quarter of known species live in soils (Orgiazzi et al., 2016). Organisms inhabiting mountain soils have developed particular adaptations to survive in cold environments and shallow habitats. Little is yet known about their biodiversity and distribution, despite their central role in soil formation, nutrient cycling, and carbon storage. Many of the specificities of mountain

Field-trip of the IPROMO summer school (Gressoney-La-Trinité, Aosta Valley)

A topsoil removed and deposited in the run-out zone by a glide-snow avalanche in the Valle d'Aosta Region (NW-Italy)

soils of the world have been reviewed by FAO (2015), in a book issued for the International Year of Soils, which underlined the role of **mountain peoples** in developing solutions and techniques, indigenous practices, knowledge, and sustainable soil management approaches that can ensure better resilience. More recently, a chapter of the book 'Recarbonizing soils – A technical manual of recommended management practices' (FAO, 2021) focused on mountain soils as **hotspots of carbon sequestration**, reviewing the role of carbon sinks carried out by soils in mountain regions, under different covers and management types. Additionally, Geitner et al. (2019) defined the most relevant **soil ecosystem services** in the Alps and reviewed their connection with soil chemical and physical properties. Such information can be transferred and applied to most of the mountain regions.

SOIL DEGRADATION IN MOUNTAIN REGIONS: DRIVERS, CHALLENGES AND RESPONSES

According to FAO, degradation has several **drivers** such as:

- **population growth & urban expansion**
- **deforestation**
- **climate change**
- **pollution & waste disposal**
- **unsuitable management practices.**

Most of these drivers act, at variable extent, also in mountain areas (FAO, 2015; Schmeller et al., 2022). FAO and ITPS (2015) reported that mountain regions will be more vulnerable to soil-mediated natural hazards in the future, due to a combination of factors such as climate change, human population expansion, agricultural intensification, etc. However, the magnitude of the effects will vary greatly among geographical areas.

For example, mountain soils can be strongly affected by climate change, in particular by the changes in the snow/rainfall patterns, and the increased frequency of extreme meteorological events. For example, degrading permafrost can trigger rockfall, and increasing temperatures can contribute to glacier collapses such as the one which occurred on the Marmolada glacier in July 2022 (Dolomites, NE-Italy). Moreover, negative impacts of land-use changes such as abandonment of marginal agricultural areas or intensification of land use in more favorable sites affect both local and downstream populations. Finally, mountains still face considerable pressure due to infrastructure building, occurring also at very high elevations (e.g. in the Alps and in Central Asia).

The different **forms of soil degradation** according to FAO are: **biodiversity loss, salinization & sodification, nutrient imbalance, compaction, sealing, pollution, erosion, loss of organic carbon, and acidification**. At present, the relevance of these degradation forms in mountain areas is not always known, but it's widely recognized that climate change will exacerbate the soil degradation processes through increases in rainfall intensity, flooding, heat stress, dry spells, and permafrost thaw (IPCC, 2019). Soil processes are also affected by changing snow conditions with partitioning between evaporation and streamflow and between subsurface flow and surface run-off (Barnhart et al., 2016). The vulnerability of mountain areas has been underlined by FAO (2019), as mountain communities are particularly affected by food insecurity, due to the fragility of mountain ecosystems, often characterized by poor soil quality and a high incidence of disasters.

Sustainable soil management (SSM) can be a valuable tool to mitigate and prevent these effects, and general guidelines valid for all soil types were provided in the Voluntary Guidelines for Sustainable Soil Management by FAO (2017).

SSM is an integral part of sustainable land management and can contribute to Sustainable Development Goals promoting poverty eradication, food security, water regulation processes, responsible production, and others. Through guidelines specifically designed for mountain regions, soils could become a key to **building resilience** to threats and degradation in mountain areas. Among the main **barriers** to this process, there are the lack of knowledge and soil literacy among the general public, the scarce awareness of soils as a resource, their properties & variability. Additionally, in view of the uniqueness of soil and human resource management issues of mountain environments special attention must be given to preparation of the most appropriate legal and institutional systems to improve the sustainable management of the mountain soil environment.

RECOMMENDATIONS

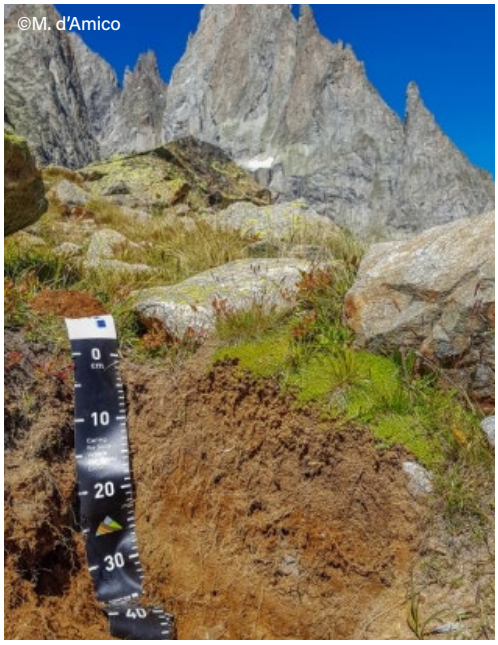
- improve soil literacy in mountain areas
- promote the knowledge of mountain soils at the local and regional level
- rank the main soil degradation drivers & types for mountain soils (with a regional approach, based on the specificity of mountain soils)
- develop SSM voluntary guidelines tailored on mountain areas
- prepare appropriate legal and institutional systems to improve the sustainable management of the mountain soil environment
- involve relevant stakeholders in SSM in mountain areas
- promote mountain soils issues & challenges in regional soil partnerships (e.g. Alpine Soil Partnership)

THE ALPINE SOIL PARTNERSHIP

In the framework of the EU-Interreg Alpine Space project Links4Soils, the Alpine Soil Partnership (AlpSP) was launched in May 2017, during the project kick-off meeting in Ljubljana, Slovenia. The meeting allowed the first review of needs and ideas about the sustainable management of alpine soils from Alpine Region stakeholders, taking into account the sub-regional-level priorities and natural and cultural conditions of the Alpine Region. The AlpSP is aiming towards federating various stakeholders and institutions in the Alpine Region. As a bottom-up network, people and organizations working for sustainable soil management are invited to join the Alpine Soil Partnership by signing a Memorandum of Understanding. Close cooperation with existing network structures such as the CIPRA, the EUSALP AG6, the Alpine Convention – Soil Working Group, the European Soil Partnership (ESP), and the Global Soil Partnership (GSP) started. From 2020 until 2022 the Alpine Soil Partnership Chair was held by the University of Torino, with the support of the Federal Ministry Republic of Austria – Climate Action, Environment, Energy, Mobility, Innovation and Technology (AT), Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (DE), and the Swiss Confederation (CH).

THE INTERNATIONAL PROGRAMME ON RESEARCH AND TRAINING ON SUSTAINABLE MANAGEMENT OF MOUNTAIN AREAS (IPROMO)

The International Programme IPROMO offers annual 2-week courses on the sustainable management of mountain areas and is organized by the Mountain Partnership Secretariat of the Food and Agriculture Organization of the United Nations (FAO) with the University of Torino and the University of Tuscia. The training program was established in 2006 at the request of several Mountain Partnership members, who had identified the lack of mountain-related capacity development programs as a concrete obstacle to the sustainable development of mountains around the world. IPROMO takes place in two charming Italian alpine venues – Ormea and Pieve Tesino – and is financially supported by the Mountain Partnership Secretariat hosted by the Food and Agriculture Organization of the United Nations (FAO), the University of Torino and the University of Tuscia, the town of Ormea and a number of local authorities and private sector partners. Every year, a full day was dedicated to the mountain soils, such as in 2018 (Alpine soils, ecosystems services, and bioeconomy), 2020 (Climate change and mountain soils), and 2022 (Mountain soils: key for building resilience).



Mountain soils in the Alps show high pedodiversity Ph. Links4Soils

References

1. Barnhart, T.B. et al. (2016) 'Snowmelt rate dictates streamflow', Geophysical Research Letters, 43(15), pp. 8006–8016. Available at: https://doi.org/10.1002/2016GL069690.
2. D'Amico, M., Gorra, R. and Freppaz, M. (2015) 'Small-scale variability of soil properties and soil-vegetation relationships in patterned ground on different lithologies (NW Italian Alps)', Catena, 135, pp. 47–58. Available at: https://doi.org/10.1016/j.catena.2015.07.005.
3. Egli, M., Dahms, D. and Norton, K. (2014) 'Soil formation rates on silicate parent material in alpine environments: Different approaches-different results?', Geoderma, 213, pp. 320–333. Available at: https://doi.org/10.1016/j.geoderma.2013.08.016.
4. FAO. 2015. Understanding Mountain Soils: A contribution from mountain areas to the International Year of Soils 2015, by Romeo, R., Vita, A., Manuelli, S., Zanini, E., Freppaz, M. & Stanchi, S. Rome, Italy.
5. FAO and ITPS. 2015. Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.
6. FAO 2017. Voluntary Guidelines for Sustainable Soil Management Food and Agriculture Organization of the United Nations Rome, Italy.
7. FAO and UNCCD. 2019. Vulnerability to food insecurity in mountain regions: land degradation and other stressors. Bonn, Germany.
8. FAO and ITPS. 2021. Recarbonizing global soils: A technical manual of recommended management practices. Volume 2: Hot spots and bright spots of soil organic carbon. Rome, FAO.
9. Freppaz, M. and Williams, M.W. (2015) Soil genesis in recently deglaciated areas, Understanding Mountain Soils: A contribution from mountain areas to the the International Year of Soils 2015. Freppaz, M. et al. (2018) 'Topsoil and snow: a continuum system', Applied Soil Ecology, 123(June 2017), pp. 435–440. Available at: https://doi.org/10.1016/j.apsoil.2017.06.029.
10. Geitner C., Freppaz M., Lesjak J., Schaber E., STANCHI S., D'Amico M., Vrscaj B. (2019). Soil Ecosystem Services in the Alps - An introduction for decision-makers. Agricultural Institute of Slovenia, 78 pp., ISBN: 978-961-6998-35-2.
11. Guerra, C.A. et al. (2022) 'Global hotspots for soil nature conservation', Nature, 610(7933), pp. 693–698. Available at: https://doi.org/10.1038/s41586-022-05292-x.
12. Jenny, H. (1941) The factors of soil formation. Dover Publications, New York.
13. IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].
14. Martignier, L. and Verrecchia, E.P. (2013) 'Weathering processes in superficial deposits (regolith) and their influence on pedogenesis: A case study in the Swiss Jura Mountains', Geomorphology, 189, pp. 26–40. Available at: https://doi.org/10.1016/j.geomorph.2012.12.038.
15. Orgiazzi, A. et al. (2016) 'A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity', Science of the Total Environment,

545–546, pp. 11–20. Available at: https://doi.org/10.1016/j.scitotenv.2015.12.092.

16. Schmeller, D.S. et al. (2022) 'Scientists' warning of threats to mountains', Science of the Total Environment, 853(September). Available at: https://doi.org/10.1016/j.scitotenv.2022.158611.Thornton, J.M. et al. (2021) 'Toward a definition of Essential Mountain Climate Variables', One Earth, 4(6), pp. 805–827. Available at: https://doi.org/10.1016/j.oneear.2021.05.005.
17. Weil, R.R.,& Brady, N.C. 2017. The Nature and Properties of Soils. 15th Edition, Pearson.
18. Further resources
19. FAO "Understanding Mountain Soils" https://www.fao.org/3/i4373e/i4373e.pdf
20. FAO "Status of the World's Soil Resources" https://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/
21. FAO "Recarbonizong Global Soils – A technical manual of recommended management practices. Volume 2 - Hot spots and bright spots of soil organic carbon" https://www.fao.org/documents/card/en/c/cb6378en
22. FAO "Vulnerability to food insecurity in mountain regions: land degradation and other stressors" https://www.fao.org/3/ca6015en/CA6015EN.pdf
23. FAO "Voluntary Guidelines for Sustainable Soil Management" https://www.fao.org/3/bl813e/bl813e.pdf
24. Alpine Soil Partnership webpage https://alpinesoils.eu/soil-partnership/alpine-soil-partnership/
25. GMBA https://www.google.com/url?q=https://www.gmba.unibe.ch/research/working_groups/mountain_soil_biodiversity&sa=D&source=docs&ust=1675089560246184&usg=AOvVaw-3mU9ID_rlMiuduciD8v5ZI

Please send enquiries to:

eurac research

Institute for Alpine Environment

Email: julia.seeber@eurac.edu

Università di Torino

Email: silvia.stanchi@unito.it

Mountain Partnership Secretariat

Email: info@mountainpartnership.org