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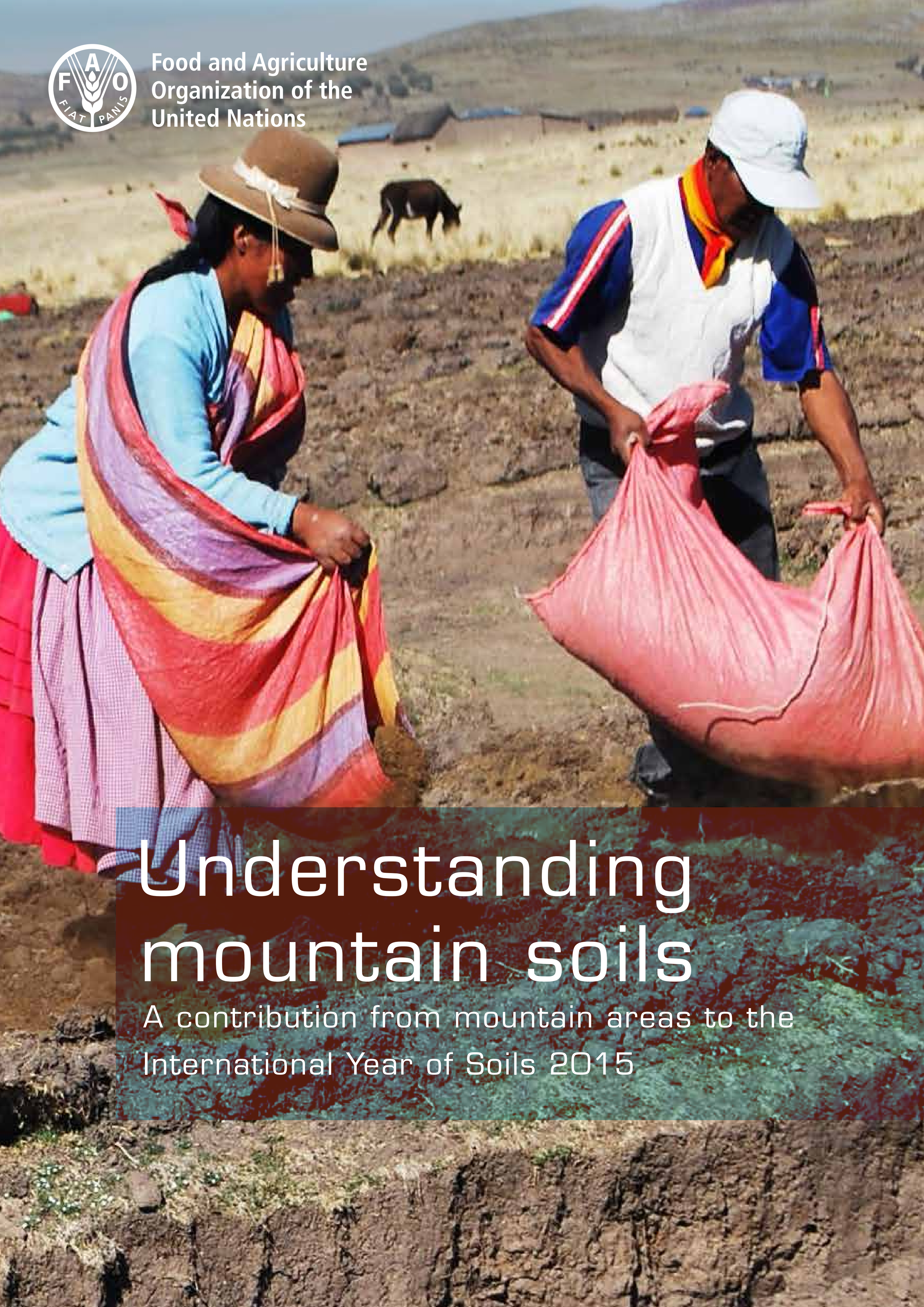

Understanding mountain soils

A contribution from mountain areas to the International Year of Soils 2015

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In collaboration with the Mountain Partnership Secretariat,
the Global Soil Partnership and
the University of Turin

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Cover photo: Community partners of Caritamaya, Pruno, Peru planting and composting potato in rehabilitated Sukaqollos (@FAO/Alipio Canahua)

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Foreword

Mountain soils have long performed a host of vital ecosystem services that help to ensure food security and nutrition to 900 million mountain people around the world and benefit billions more living downstream.

Soils are the basis for healthy food production. They help people to mitigate and adapt to climate change by playing a key role in the carbon cycle and in water management, improving resilience to floods and droughts. Mountain soils, which vary greatly and are by their nature fragile, host 25 percent of terrestrial biodiversity including agro-biodiversity, crucial gene pools for locally adapted crops and livestock.

Soil is a fragile resource that needs time to regenerate. Every year, an estimated 12 million ha are lost through soil degradation. Mountain soils are particularly susceptible to climate change, deforestation, unsustainable farming practices and resource extraction methods that affect their fertility and trigger land degradation, desertification and disasters such as floods and landslides.

For mountain peoples this is a harsh reality that they face every day. Many mountain peoples – in ranges including the Himalayas and Andes as well as the Elburz Mountains and the Fouta Djallon Highlands – are family farmers who live by subsistence agriculture and often have poor access to basic infrastructure, health services, roads, transport and markets.

Local communities in mountain areas serve as the custodians of natural resources, including their soil. Over generations, living in their particular high-risk environments, they have developed solutions and techniques, indigenous practices, knowledge and sustainable soil management approaches that shape and protect ecosystems that ultimately provide water for at least half the world's population. Local and more recent knowledge can be successfully integrated, as is shown by terracing for rice production in Asia and agroforestry for cereal production in Latin America.

This publication intends to raise awareness of the global importance of mountain soils in providing critical ecosystem services and the need for their sustainable management. Building sustainable soil management capacity, promoting inclusive policies and governance, and investing in soil research and soil information systems are all necessary to ensure healthy soils for sustainable production systems that can improve the livelihoods of mountain peoples and, indirectly, everyone else as well.

To mark the International Year of Soils 2015, the Food and Agriculture Organization of the United Nations, the Mountain Partnership Secretariat, the Global Soil Partnership and the University of Turin have jointly issued this publication. *Understanding Mountain Soils* has been produced with in-kind contributions by Mountain Partnership members, non-governmental organizations, research institutes and universities in a concerted effort to bring key issues to the fore.

In 2015, the year in which the UN Sustainable Development Goals are being adopted, it is our aspiration to highlight how, through the provision of crucial ecosystem services, mountain soils can contribute to ensure overall sustainable development, reaching far beyond the peaks and deep into the surrounding lowlands.

The following chapters, with specific case studies, showcase the diversity of soil management approaches and the solutions that sustainable mountain management can provide.

José Graziano da Silva

José Graziano da Silva,
Director-General, Food and Agriculture Organization of the United Nations

Preface

The sixty-eighth United Nations General Assembly declared 2015 the International Year of Soils with the aim of increasing awareness and understanding of the importance of soils for food security and essential ecosystem functions.

Since 2002, the Mountain Partnership Secretariat has led global efforts to improve the lives of mountain peoples and protect mountain environments around the world.

The Mountain Partnership is a United Nations voluntary alliance of partners of governments, intergovernmental organizations and civil society, joining forces to implement initiatives at national, regional and global levels and helping mountain communities to overcome development challenges. Through its members, around 250, the Mountain Partnership works on the main pillars of advocacy, capacity development, joint projects on the ground, knowledge management and communications.

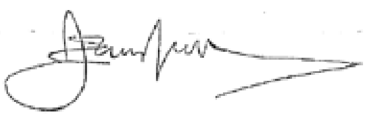
As the Mountain Partnership Secretariat is hosted at the Food and Agriculture Organization of the United Nations, it seemed only natural the Mountain Partnership to join forces to support the Food and Agriculture Organization of the United Nations and the Global Soil Partnership which have been mandated to facilitate the implementation of the International Year of Soils. This collaboration also includes the University of Turin, which has worked with the Mountain Partnership Secretariat for many years on the International Programme on Research and Training on Sustainable Management of Mountain Areas. The university – at the scientific forefront in studies of mountain soils, glaciers and erosion control – has brought its knowledge to this publication.

In every mountain region, soils constitute the foundation for agricultural development, supporting essential ecosystem functions and food security, and hence are crucial to sustaining life. Mountain peoples' relationship with their soil is deeply rooted in their heritage and, over the centuries, they have developed solutions and techniques that have proved to be a key to resilience.

The aim of this publication is to describe the main features of mountain soil systems, their environmental, economic and social values, the threats they are facing and their cultural heritage. Case studies provided by Mountain Partnership members and partners around the world showcase challenges and opportunities as well as lessons learned in soil management.

The International Year of Soils 2015 presents a fitting opportunity to raise awareness and promote the sustainable management of mountain soils on behalf of mountain peoples – peoples who are often marginalized, not included in decision–making processes and development programmes, and increasingly affected by soil–related disasters.

We hope this publication will help to trigger change, by increasing understanding of mountain soils' significance and the roles they play in society at large.



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Acronyms and abbreviations

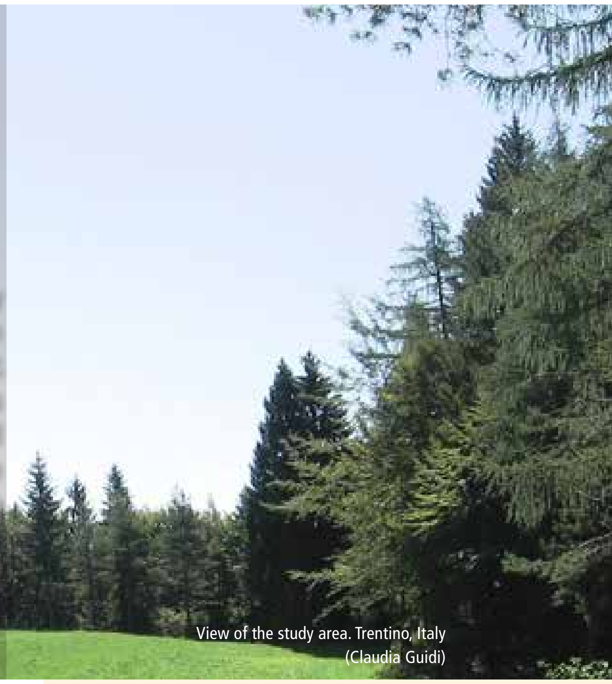
AKF	Aga Khan Foundation
Al	Aluminium
BMP	Beneficial management practice
BSP	Beles SUNRise Project
C	Carbon
Ca	Calcium
$CaCl_2$	Calcium chloride
Cd	Cadmium
CDE	Centre for Development and Environment
CHIESA	Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa
CHT	Chittagong Hill Tracts
CIAT	International Center for Tropical Agriculture
CIDE, CSIC-UV-GV	Centro de Investigaciones sobre Desertificación
CO_2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSSI	Compound specific stable isotope
DEM	Digital elevation model
DESIRE	European Desertification mitigation and remediation of land
EC	European Commission
EEA	European Association of Archaeologists
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
FRN	Fallout radionuclides
FYM	Farmyard manure
GCI	Geospatial Cyber-Infrastructure
GEF	Global Environment Facility
GIAHS	Globally Important Agricultural Heritage Systems
GSP	Global Soil Partnership
GWP	Global warming potential
H	Hydrogen
IAEA	International Atomic Energy Agency
ICARDA	International Center for Agricultural Research for the Dry Areas
ICIPE	International Centre of Insect Physiology and Ecology
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
IPROMO	International Programme on Research and Training on Sustainable Management of Mountain Areas
IRD	Institute de Recherche pour le Développement
IUCN	International Union for the Conservation of Nature
IYS	International Year of Soils
JRC	Joint Research Centre
K	Potassium
LER	Local elevation range
LHWP	Lesotho Highlands Water Project
LIA	Little Ice Age
LTER	Long-term ecological research
MAE	Ministry of Environment (Ecuador)

MAGAP	Ministry of Agriculture, Livestock and Fisheries (Ecuador)
masl	Metres above sea level
Mg	Magnesium
Mn	Manganese
MP	Mountain Partnership
MPS	Mountain Partnership Secretariat
N	Nitrogen
NatRisk	Research Centre on Natural Risks in Mountain and Hilly Environments
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental organization
NPP	Net primary production
NVME	Non-Volcanic Mountain Ecosystems
O	Oxygen
OECD	Organisation for Economic Cooperation and Development
OM	Organic matter
ORASECOM	Orange-Senqu River Commission
P	Phosphorus
POM	Particulate organic matter
QSMAS	Quesungual Slash and Mulch Agroforestry System
REE	Rare earth elements
ROS	Rain-on-snow
RUSLE	Revised universal soil loss equation
SB	Slash-and-burn
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
SECO	Swiss State Secretariat for Economic Affairs
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales
SENESCYT	Secretaría de Educación Superior Ciencia, Tecnología e Innovación
SGP	Small Grants Programme (GEF-UNDP)
SKCRF	Senaapathy Kangayam Cattle Research Foundation
SLM	Sustainable land management
SOC	Soil organic carbon
TANUVAS	Tamil Nadu Veterinary and Animal Sciences University
UBC	University of British Columbia
UMSNH	Universidad Michoacana de San Nicolás de Hidalgo
UN	United Nations
UNAM	Universidad Nacional Autónoma de México
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Pogramme
UNEP	United Nations Environment Programme
UNIFG-SAFE	University of Foggia, Department of the Sciences of Agriculture, Food and Environment
UNIPG	Università degli Studi di Perugia
UNITO	Università di Torino
UNIVPM	Università Politecnica Delle Marche
UPM	Universidad Politécnica de Madrid
WCMC	World Conservation Monitoring Centre
WHC	Water holding capacity
WOCAT	World Overview of Conservation Approaches and Technologies
WRB	World Reference Base for Soil Resources

Forest expansion on grassland affects soil carbon protection

Claudia Guidi, Lars Vesterdal, Damiano Gianelle, Jakob Magid and Mirco Rodeghiero

Abandonment of mountain grasslands followed by progressive forest expansion is a widespread phenomenon in mountain areas of Europe. Grassland abandonment can affect the accumulation of carbon in the soil and its susceptibility to external disturbances. The quantity and degree of protection of the carbon in soil decreased due to forest expansion on grassland in a study area in the Southern Alps (Trentino, Italy). The forest expansion caused a higher vulnerability of soil carbon to decomposition and climate change-induced perturbations.



View of the study area. Trentino, Italy (Claudia Guidi)

Grassland abandonment is the dominant land-use change in many European mountain areas. In the European Alps, 41 percent of farms and 20 percent of the usable agricultural land were abandoned from 1980 to 2000, which in most cases led to natural forest colonization. This land-use change can have a significant impact on the amount of carbon stored in soil, ultimately affecting the atmospheric carbon dioxide (CO_2) levels. Moreover, forest expansion on abandoned grasslands can affect the protection of soil organic carbon (SOC) from environmental modifications or disturbances (Box 1).

Box 1

The protection of soil organic carbon (SOC) against decomposition (*i.e.* stability) results from the synergy of various mechanisms, such as molecular characteristics of SOC; spatial inaccessibility against decomposers by occlusion; and organo-mineral associations. Spatial inaccessibility and organo-mineral interactions are recognized as the main drivers of SOC stability..

Contrasting trends in SOC have been reported for mountain regions following forest expansion on grasslands, therefore its effects on SOC content and protection are largely unknown. This study aims to to fill this knowledge gap, considering that it is likely that large areas of agricultural lands in mountain regions will be abandoned over the next decades and that forest will take over the abandoned areas.

It was investigated how forest expansion on abandoned grasslands affected the content (stocks) and the protection of SOC. The project was carried out from 2011 to 2015, examining a study area in Trentino province (Italy), where the forest area increased by 5 percent from 1973 to 1999. The study area has an elevation of 1 150 masl, with mean annual air temperature of 7.2 °C and mean annual precipitation of 1 278 mm (1992–2011). The soil in the area is a Cambisol, with a clay texture and calcareous parent material.

In the study area, a land-use gradient was examined comprising four successional stages: (i) managed grassland, mown twice a year and manured once a year for at least the past 100 years; (ii) grassland abandoned approximately ten years ago; (iii) early-stage forest, where Norway spruce colonized a grassland abandoned around 1970; and (iv) old forest, dominated by European beech and Norway spruce, and already present in the historical land register of 1861. The researchers collected the organic layers and mineral soil samples up to 30 cm depth within three plots for each successional stage.

A decrease of mineral soil carbon stock going from the managed grassland to the old forest was observed. The SOC accumulation within the forest organic layers could not fully compensate the mineral SOC stock difference between the forest and the grassland. This resulted in an overall decrease in the total SOC stock following forest establishment and an increase in organic layer contribution to total SOC stocks (Figure 1). Moreover, the decrease in SOC stocks within the mineral soil mainly took place in protected fractions of SOC, *i.e.* the stable aggregates, while the SOC in unprotected fractions, *i.e.* the particulate organic matter (POM), increased following forest expansion on grasslands (Figure 2).

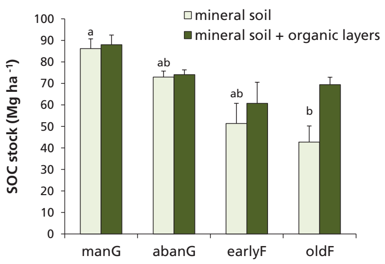


Figure 1: SOC stocks at the four successional stages (manG: managed grassland; abanG: abandoned grassland; earlyF: early-stage forest; oldF: old forest) in mineral soil (0–30 cm) and organic layers. Error bars represent the standard error of the mean (n = 3). Different letters indicate significant differences within soil layers based on multiple comparisons after Kruskal-Wallis, with P < 0.05

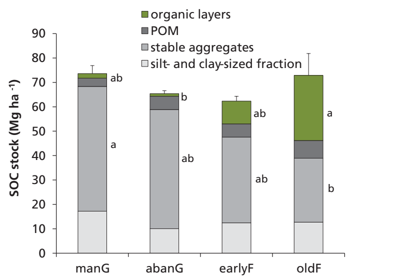


Figure 2: SOC stocks at the four successional stages (manG: managed grassland; abanG: abandoned grassland; earlyF: early-stage forest; oldF: old forest) in fractions within the mineral soil (0–20 cm) and in organic layers. Error bars represent the standard error of the mean of total SOC stocks (n = 3). Different letters indicate significant differences within fractions based on multiple comparisons after Kruskal-Wallis, with P < 0.05. If no letters are present, no significant differences were observed among successional stages

Box 2

It was used a physical method for soil fractionation that separated:

- POM not occluded within stable aggregates (size > 50 μm; density < 1.6 g cm^{-3});
- stable aggregates (size > 50 μm; density > 1.6 g cm^{-3});
- silt- and clay-sized fraction (size <50 μm).

The increased contribution of organic layers and POM to total SOC suggests that the physical protection of SOC decreased due to forest expansion on grassland. The SOC stored in the superficial organic layers is usually more affected by environmental and management-induced modifications than SOC in the mineral soil. Moreover, when ecosystems are disturbed, the SOC stored in POM fractions within the mineral soil often undergoes rapid losses (Box 1). According to our findings, forest SOC stocks would be more susceptible than grassland SOC stocks against management modifications or climatic changes, although the tree canopy can naturally shelter soils against water erosion and temperature extremes.

Forest expansion on mountain grasslands caused a decrease in soil carbon stock within the mineral soil and within the physically protected fractions. The findings have both ecological and management implications for the sequestration of carbon in soil and climate change mitigation.

Lessons learned

- Forest successional stages did not accumulate as much carbon in soil as the managed grassland in a mountain area.
- Managed grasslands are precious resources for mountain areas and can store soil carbon that is better protected against disturbances than the carbon stored in forest soils.
- Soil carbon became more vulnerable to decomposition, *e.g.* under climate change or management induced-perturbations.