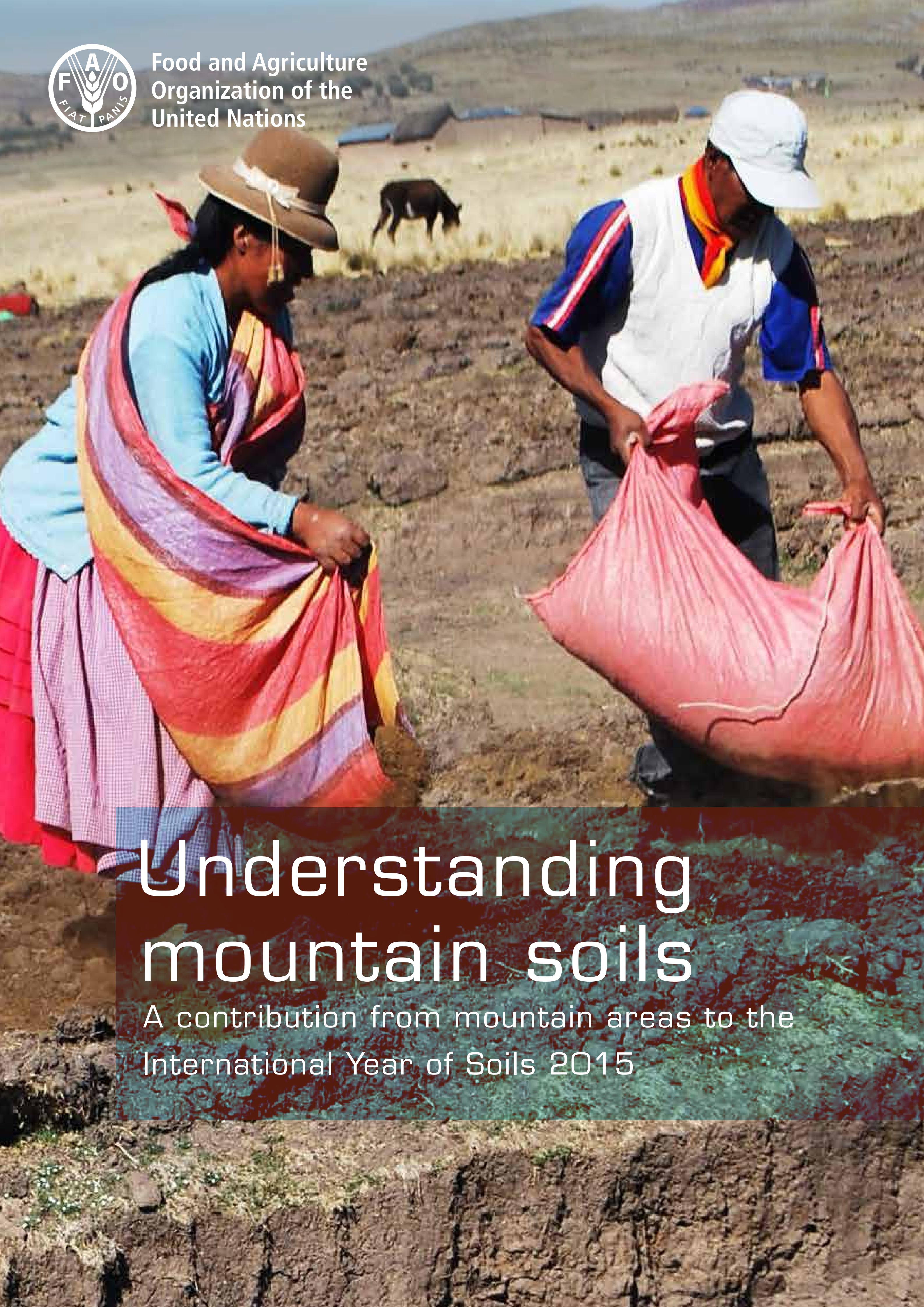

Food and Agriculture
Organization of the
United Nations

Understanding mountain soils

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

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2015

Published by the Food and Agriculture Organization of the United Nations,
the Mountain Partnership Secretariat,
the Global Soil Partnership and
the University of Turin

ISBN 978-92-5-108804-3

FAO information products are available on the FAO website (www.fao.org/publications)
and can be purchased through publications-sales@fao.org

Authors of case studies and introductory texts: international group of experts (for the names see list of authors)
Concept: FAO Mountain Partnership Secretariat, University of Turin
Layout: Roberto Cenciarelli
Editing: Nancy Hart
Proofreading: Caroline Lawrence

Citation:
Romeo, R., Vita, A., Manuelli, S., Zanini, E., Freppaz, M. & Stanchi, S. eds. 2015. Understanding Mountain Soils: A contribution from mountain areas to the International Year of Soils 2015. Rome, Italy, FAO, MPS, UNITO.

This publication is available from:
FAO information products are available on the FAO website (www.fao.org/publications)
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Electronic version can be downloaded from:
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Cover photo: Community partners of Caritamaya, Pruno, Peru planting and composting potato in rehabilitated Sukaqollos (@FAO/Alipio Canahua)

Contents

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.

Ermanno Zanini

Thomas Hofer

Ermanno Zanini, Director, Research Centre on Natural Risks in Mountain and Hilly Environments (NatRisk). Department of Agriculture, Forest and Food Sciences, University of Turin

Thomas Hofer, Coordinator, Mountain Partnership Secretariat, Food and Agriculture Organization of the United Nations

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
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

Introduction

Farmers clear weeds from a contour ridge and trench. The trenches and ridges retain water and prevent soil erosion during rains. Kiroka (@FAO/Daniel Hayduk)

Atacama Region, Chile (Corporación Nacional Forestal Region de Atacama)

Ermanno Zanini and Rosalaura Romeo

Introduction

Throughout the millennia, mountain peoples have learned to survive at high altitudes, developing resilient systems and solutions to adapt to their difficult environments. Most mountain peoples base their livelihoods on diversification, practising farming, forestry, pastoralism and fishery at family level. Global changes, including climate change, land-use change, deforestation and overgrazing, are affecting mountains in an unprecedented way. Mountain soils are vulnerable to these changes and, in turn, so are mountain peoples, their livelihoods and food security. Hazards such as floods, landslides, debris flows and glacial lake outbursts are on the rise in most mountain regions, especially those with rapidly expanding populations and poor infrastructure. Climate change is amplifying the impact of hazards as it increases the frequency of extreme events, causing heavy rainfall, droughts and glacier melt.

Soil is a limited resource that has a crucial role in sustaining ecosystem services and human life, and ensuring environmental stability and agricultural productivity. It is essential for life on Earth as it provides nutrients, water and minerals to plants and trees and is home to an infinite array of insects, bacteria and small animals. Soil, the top layer of the Earth's surface, is produced by the weathering of rocks, mainly due to temperature, precipitation and wind, and consists of minerals, gases, organic matter and micro-organisms.

Soil also has the capacity to retain water – absorb it, filter it and, in turn, improve its resilience to floods and droughts. More carbon is found in the world's soils than in the combination of the atmosphere and all plants, which indicates the crucial role that healthy soils have in storing carbon and reducing emissions therefore contributing to mitigating climate change.


French Alps (Carole Bastianelli)

The composition of the "parent" material – the material from which the soil is formed – as well as climate, elevation, slope, aspect and the activities of living organisms, contribute to defining each type of soil. Indeed, soils are dynamic and are in continuing evolution, driven by the effects of physical, chemical and biological processes.

Several soil classification systems exist based on their characteristics and uses. Also, each kind of soil consists of layers called "horizons" which have specific morphological, physical and chemical features and vary according to the area and the type of vegetation. The upper horizon, which is more exposed, is the more biologically active and is richer in organic matter. A soil profile is determined from a vertical section of the soil – from the upper horizon downwards to where the soil meets the underlying parent material. For agricultural purposes, the two key soil features are its water holding capacity and the quantity of its nutrients and organic matter that sustain plant growth.

Most mountain soils evolve slowly and are shallow because the low temperatures limit the biological activities and the soil genesis and evolution. Mountain soils are generally defined as poorly developed, skeletal, shallow, acidic and relatively infertile. They are also highly diverse and can vary significantly within limited areas due to different exposure and steepness. In general, they become less fertile and less developed as elevation increases. In cold mountain areas, freeze-and-thaw cycles reduce the aggregation of soils and, as a consequence, their stability, fertility and water retention. Many plants, including crops, have adapted to grow on mountain soils and numerous mountains are covered with lush vegetation that has several fundamental roles, including controlling erosion.

In most cases, mountain soils are less productive than lowland soils and agricultural activities are more labour intensive and less productive. Where the land is very steep, farmers build terraces and similar structures to limit erosion and land degradation. Agricultural activities generally take place in intermediate elevation classes while grazing is found at higher altitudes (Box 1).

Box 1: Mountain definition according to elevation class

In this publication, mountains are defined according to a topographic criterion that combines metres above sea level (masl), steepness of slope and local elevation range. This classification was developed in 2000 by the United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC) in order to represent the environmental gradients that are key components of mountain environments.

- Class 1: elevation ≥ 4 500 m.
- Class 2: elevation 3 500–4 500 m.
- Class 3: elevation 2 500–3 500 m.
- Class 4: elevation 1 500–2 500 m and slope ≥ 2°.
- Class 5: elevation 1 000–1 500 m and slope ≥ 5 or local elevation range (LER) > 300 m.
- Class 6: elevation 300–1 000 m and LER > 300 m.

Slopes and altitude form a landscape where soils evolve according to the environment in which they were formed. Their evolution is a continuous process of topsoil erosion, profile truncation and burying, which are the main driving changes in space and time. On steep slopes, soil can be washed away or blown away more easily. This means that instead of building up a thick layer of topsoil over time, the topsoil on steep slopes is eroded more quickly than new soil can form. These deposits flow down the mountain, where they collect and stay in flatter, more level areas. This is why the soil on the steep parts of a mountain is thinner and less fertile than on the flatter parts.

From this dynamic process derives the fascinating complexity and pedological variability that characterize mountain environments. However, this ongoing change and variability means that mountain soil has restricted biomass productivity and, at the same time, vulnerability to human settlements.

The relationship between mountain people and soil is fundamental. Unsustainable farming and forest management practices increase the pressure on this fragile ecosystem, accelerating erosion, decreasing fertility and triggering natural hazards. Although mountains are characterized by high vulnerability to natural hazards, the risks can be somewhat lower when the areas are not densely settled. However, when mountain areas are densely populated the impact of natural disasters can be very disruptive with consequences on people living in the lowlands.

Understanding mountain soils, their composition, dynamic and value can help to address the challenges related to sustainable mountain development and ensure better, more resilient livelihoods for mountain peoples.

The "Andenes" are ancient stepped terraces, used by Andean farmers to plant their crops. Cusco, Peru (@FAO/Liana John)

Inca terraces in the Sacred Inca Valley, Peru (@FAO/Antonello Proto)

1

Mountain soils and ecosystem services

Woman on theback of a truck, captured during corn harvesting. Djalal-Abad province in the south of Kyrgyzstan (Alma Karsymbek)

Ronald Vargas, Aracely Castro and Feras Ziadat

Mountain soils and ecosystem services

View of a mountain range and river. Jalal-Abad Oblast, Kyrgyzstan (@FAO/Sergey Kozmin)

Soils of the mountain landscapes have the potential to generate a significant diversity and magnitude of ecosystem services needed to support life on Earth. Soils are fundamental for human well-being at all levels, generating a host of ecosystem services, including those that are life supporting, regulating, provisioning or cultural (Box 1). In all cases, whether supporting natural vegetation or managed crops, mountain soils must be properly managed.

Box 1: Ecosystem services of mountain soils

Life supporting: multiscale physical, chemical, biological and genetic support
- Provides physical support to plants.
- Facilitates nutrient cycling by renewing, retaining and delivering nutrients.
- Sustains biological activity, diversity and productivity.
- Provides habitat for dissemination of gene pools.

Regulating: multiscale water, nutrient, biodiversity and global climate regulation
- Buffers, filters and moderates the hydrological cycle.
- Mediates the cycles of carbon and oxygen and plant nutrients (such as nitrogen, phosphorus potassium, calcium, magnesium and sulphur), affecting plant production.
- Facilitates climate change adaptation (through resilience) and mitigation (through carbon storage).
- Sustains one-quarter of global biodiversity activities and their functions.
- Supports micro-organism processes for pest, disease and pollution prevention and suppression.

Provisioning: water, food and medicine provision
- Provides the basis for production of food, feed, fibre, bioenergy and medicines.
- Holds and releases water for plant growth and human consumption.

Cultural: amenities and habitat
- Offers spiritual or heritage value (in some cultures).
- Provides the basis for landscapes that provide recreation and ecotourism.
- Provides support for urban settlement and infrastructure.
- Provides material for construction.

Through their provision of these ecosystem services, soils can contribute to four of the Sustainable Development Goals (SDGs) under consideration by the United Nations (UN): food security (Goal 2), water for human consumption (Goal 6), climate change adaptation and mitigation (Goal 13), and protection and sustainable management of terrestrial ecosystems to halt biodiversity loss, land degradation and desertification (Goal 15). Ecosystems services mediated by mountain soils extend far beyond terrestrial support – they can sustain livelihoods of smallholder mountain farming communities who often produce food in vulnerable lands and marginal soils predominantly in the tropics. This creates human-induced pressure on already aggravated naturally fragile soils.


Colorful chuquirequa flowers bloom at high atlitudes in the Andes. Las Cajas National Park, Ecuador (Jesse Lewis)

In all terrestrial ecosystems – but in mountain landscapes in particular – the area of fertile soil is limited and increasingly under pressure stemming from competing land uses. In addition, inadequate governance, increasing population demands, land-use planning and unsustainable management, among other factors, have significantly facilitated land-use conversion, mostly from forests to agriculture, which has increased degradation in general but soil degradation in particular. As a result, mountain soils increasingly face problems such as water erosion, loss of organic matter, nutrient mining, loss of biodiversity, landslides, and soil and water contamination which, in turn, affect and reduce productivity, provision of goods and services, and resilience.

All this indicates that soil degradation needs to be prevented and reversed. Through appropriate rehabilitation techniques, degraded soils can, in some cases, be rehabilitated to continue performing their core functions and contributions to ecosystem services. Although avoiding soil degradation in the first place is vastly more cost-effective than their eventual rehabilitation/restoration, the latter increases the area available to generate ecosystem services without necessitating additional land use conversion.

Soils in mountains are highly diverse and, thanks to recent efforts to improve their management and governance, some sound technologies for sustainable foodproduction are now available that can be adapted and disseminated using diverse approaches and tools. However, more urgent actions are needed to implement appropriate land-use planning together with sustainable management and protection of soils.

During and beyond the International Year of Soils, global efforts should be made to raise today’s population awareness about the fundamental roles that soils play in mountain ecosystems by enabling life-critical ecosystem services.

Agroforestry generates multiple ecosystem services on hillsides of Central America

Aracely Castro, Mariela Rivera, Oscar Ferreira, Edgar Amézquita, Luis Alvarez-Wélchez and Idupulapati Rao

On Central American hillsides, traditional slash-and-burn (SB) agriculture has led to extensive resource-base degradation. A smallholder farming community located in the region with lowest development index of one of the poorest countries of Latin America has shown that by replacing SB with sustainable management technologies such as agroforestry systems, it is possible to rehabilitate soils and lands to enhance food production and other key ecosystem services provided by mountain landscapes.

Rehabilitated agro-ecosystem in mountains of Southwestern Honduras, mostly as a result of the Quesungual Agroforestry System to replace traditional slash-and-burn agriculture (CIAT/Edwin García)

Traditional smallholder agriculture on Central American hillsides is based on the ancient practice of SB – clearing lands of vegetation in preparation for planting before the onset of the rainy season. This practice improves short-term soil fertility to support crop development through fast nutrient release (as result of the burning) of fresh organic materials (from the slash activity). SB, the base of shifting cultivation, can be sustainable if the fallow length between agricultural cycles in a production plot is sufficient to allow the recovery of natural balances (*e.g.* biomass accumulation, soil biota). However on steep slopes this practice can lead to rapid soil degradation and reduced productivity through (i) nutrient depletion from loss of vegetation and biodiversity (fauna, soil organisms as well as vegetation), (ii) significant increase soil erosion, together with (iii) poor investments in soil conservation. In addition, higher pressure on mountain landscapes due to population growth, land use regulations or scarcity of suitable land are leading to shorter fallow periods.

In the early 1990s, smallholder farming communities in southwestern Honduras faced a perfect storm: lands degraded as result of SB agriculture and three consecutive years of irregular rainfall which led to a shortage of ecosystem services. Productivity and resilience were lost, leaving soils without the capacity to produce enough food for subsistence and the whole agro-ecosystem unable to produce other key benefits for livelihoods. As a result, the Food and Agriculture Organization of the United Nations (FAO) and other organizations worked together with local farmers and technicians to develop technological options to restore the sustainability (based on productivity and resilience) of the agricultural landscape.

The following identifies some of the output of their efforts.

One of the options developed – the Quesungual Slash and Mulch Agroforestry System (QSMAS) – is based on planting annual crops (maize, common bean, sorghum) with naturally regenerated trees and shrubs. The set of technologies and tools responsible for its success can be summarized in four synergistic principles that contribute to the sustainable management of vegetation, soil, water and nutrient resources:

- no SB, but a rational management of natural vegetation;
- semi-permanent soil cover, through the continual deposition of biomass from trees, shrubs and weeds, and through crop residues;
- minimal disturbance of soil, through the use of no tillage, direct seeding and reduced soil disturbance during agronomic practices;
- efficient use of fertilizer, through the appropriate application (type, amount, time, location) of fertilizers.

Studies conducted from 2005 to 2007 by the International Center for Tropical Agriculture (CIAT), FAO and other partners in Latin America, found that production practices applied in the Quesungual agroforestry system can contribute to local economic growth, environmental sustainability and social development through improved food (maize and bean) production. Compared with SB agriculture, a Quesungual system has more potential to provide supporting, regulating, provisioning and cultural ecosystem services through the sustainable use of renewable natural resources (Box 1).

Agricultural landscape in mountains of northern EL Salvador (CIAT,FAO/Aracely Castro)

Box 1: Ecosystem services of Quesungual agroforestry system

Supporting

- Physical support for crop production and natural regeneration of local vegetation.
- Rehabilitation of soil functions through improved structure, biological activity, organic matter, nutrient cycling and fertilizer-use efficiency, and restoration and conservation of above-ground biodiversity.[1]

Regulating

- Improved water cycling by protecting water sources through reduced susceptibility to soil erosion (Figure 1), runoff and surface evaporation, and increased infiltration.
- Enhanced nutrient (nitrogen and phosphorus) and organic matter cycling.
- Climate regulation by reducing the global warming potential at production plot scale through lower methane emissions and improved carbon accumulation, and at landscape scale by reducing deforestation (Figure 2).
- Conservation of local biodiversity (in Honduras mountains, 14 local species of tree and shrub at plot scale and 50 at landscape scale).

Provisioning

- Increased food production through improved soil health, use of green water and water productivity.
- Improved water availability for crops through enhanced soil water storage capacity.

Cultural

- Improved quality of life through regeneration of the landscape.
- Enhanced potential for attractiveness of ecosystem services compensation to convince other countries to initiate policies to protect or rehabilitate ecosystems.

[1] No studies were conducted on belowground diversity.

The Quesungual agroforestry system is currently practised by smallholders in Honduras, Nicaragua and Guatemala. More than 10 000 resource-poor farmers have successfully adopted the system on more than 10 000 ha in the three countries.

Figure 1: Improved water recycling with Quesungual agroforestry system, partially as a result of protection of water sources through reduced soil erosion.

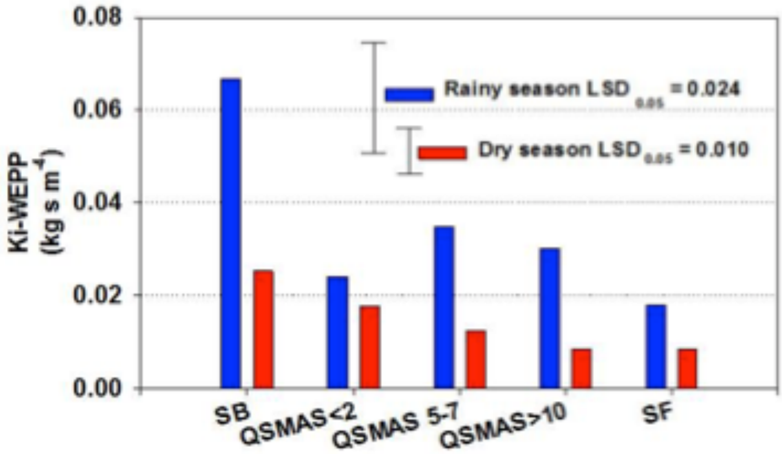
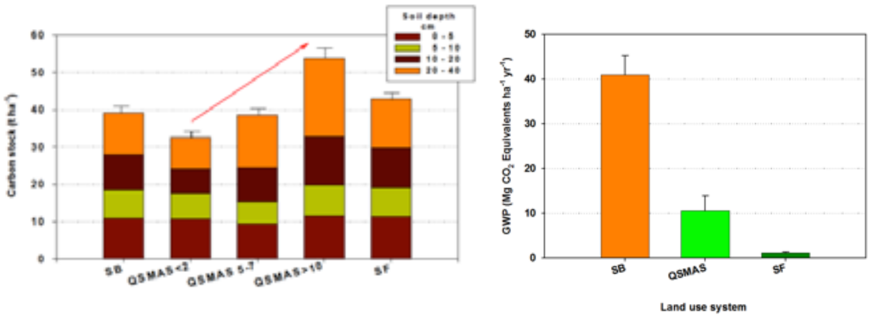


Figure 1 shows that soil erosion in SB traditional plots was 5.6 times greater in the Quesungual system. As a result, the SB system also had the highest nutrient losses (in kg per ha) of nitrogen – N (9.9), phosphorus – P (1.3), potassium – K (6.9), calcium – Ca (22.8) and magnesium – Mg (24.2). SF = secondary forests.

Figure 2: Climate regulation with Quesungual agroforestry system, mostly through the improved management of the soil and tree components



Regulating services provided by the Quesungual improved carbon accumulation (left), in young middle age and mature plots (0–2, 5–7 and 10+ years old, respectively) and lower average methane emission (right) expressed in global warming potential (GWP), compared with SB agriculture. Bars indicate standard error

As shown in Figure 2, a reduction of 42 percent in GWP was projected for the communities of southwestern Honduras using Quesungual over an estimated 20-year period starting from 2006, based on the rate of adoption of the system and consequent expected regeneration of secondary forests, compared with continued use of SB agriculture.

Lessons learned

- Soil degradation is a severe problem for sustainable agriculture in rural areas, particularly in developing countries. Therefore, it is urgent to develop land management strategies enhancing food production and other ecosystem services while preserving natural capital.
- Smallholder communities on hillside agro-ecosystems of the sub-humid tropics can use Quesungual as a land use management strategy to generate multiple ecosystem services, including food production, soil health, resilience, rehabilitation of agro-ecosystems and protection of the environment.

Sustainable mountain ecosystem results from participatory community planning: a story from the Syrian Arab Republic

Feras Ziadat

In some landscapes, mountain soils are naturally at risk, due to unfavourable biophysical conditions aggravated by improper land-use practices that lead to a decrease in the provision of ecosystem services. Climate change also contributes to the problem, particularly where scenarios predict both a decrease in rainfall amounts and an increase in the frequency of heavy rainfall events. This would increase runoff and soil erosion, and reduce food and feed productivity, particularly on vulnerable mountainous agricultural lands that already exhibit high rates of soil degradation. The aim of this study was to design and implement soil conservation to reduce further soil erosion on threatened areas based on a participatory community planning.

Severe land degradation and ecosystem services loss. Rill and gully erosion can increase losses of water, sediments, nutrients and organic carbon, reducing provision of ecosystem services (Feras Ziadat)

Soil erosion by water is a persistent problem in the mountainous areas of southern Syria, where topography is highly rugged, deforestation is common, steep lands are cultivated and, as a result, erosion rate is high. Farmers try to reduce erosion by implementing conservation practices such as physical structures (continuous and semi-circular stone walls), reduced tillage, manipulating vegetation cover, or crop residues input. In this region, where intensive olive cultivation without proper soil conservation measures is the underlying cause, farmers realize the extent of erosion, but claim that the investments demanded to conserve soils are too costly. In general, a targeted and cost-effective conservation intervention is needed to sustain ecosystem services from mountainous soils, which calls for identifying the most vulnerable landscapes and setting the priorities for implementing these interventions. In addition to adopting conservation practices, achieving tangible impact on protecting fragile ecosystems calls for farmers' participatory monitoring and evaluation of soil erosion risk assessments.

This study took place in Maghara village located within a mountainous watershed northwest of Aleppo, Syria (Figure 1). Soils are generally less than 30 cm deep, and native forests have been replaced by olive groves without sustainable means of protecting the uncovered soils.

Figure 1: Location of Maghara village

Vulnerable landscapes and erosion prone areas were mapped by spatial analysis using topographic parameters generated from a 30 m digital elevation model (DEM). Flow accumulation, classified into three categories (0–2, 3–5 and >5 pixels), land curvature into two categories (convex and concave/linear), and slope steepness into three categories (0–5, 5–10 and > 10 percent) were used to classify the whole village area into three erosion risk classes (high, moderate and low). Local residents participated in mapping the farms' boundaries, ownership and current conservation practices. Once completed, the land ownership map was overlaid with the DEM-based erosion risk map to show the erosion status of each field (Figure 2). Farmers indicated that soil and water conservation interventions implemented on fields which are located at lower positions within the hillslope

Severe land degradation (Feras Ziadat)

are not effective because these fields receive erosive runoff from the upper fields. Therefore, farmers upstream should play a role in protecting downstream fields from eroded soil during heavy rainstorms. Discussion with farmers highlighted the need for rules and/or criteria that prioritize implementing soil conservation practices to ensure obvious impact. The idea of collective action to implement measures according to the erosion risk of farmers' fields was accepted and the priority map was used by the community.

To support the implementation of soil conservation interventions, the community, with assistance from the International Center for Agricultural Research for the Dry Areas (ICARDA), secured a fund from the Small Grants Programme (SGP) of the Global Environment Facility – United Nations Development Programme (GEF-UNDP) in Syria. An elected Land Management and Diversification Community Committee assumed responsibility for distributing loans to establish soil conservation measures. The committee endorsed using the map as a base to determine the priority of each field and to distribute loans based on this priority. A community watershed

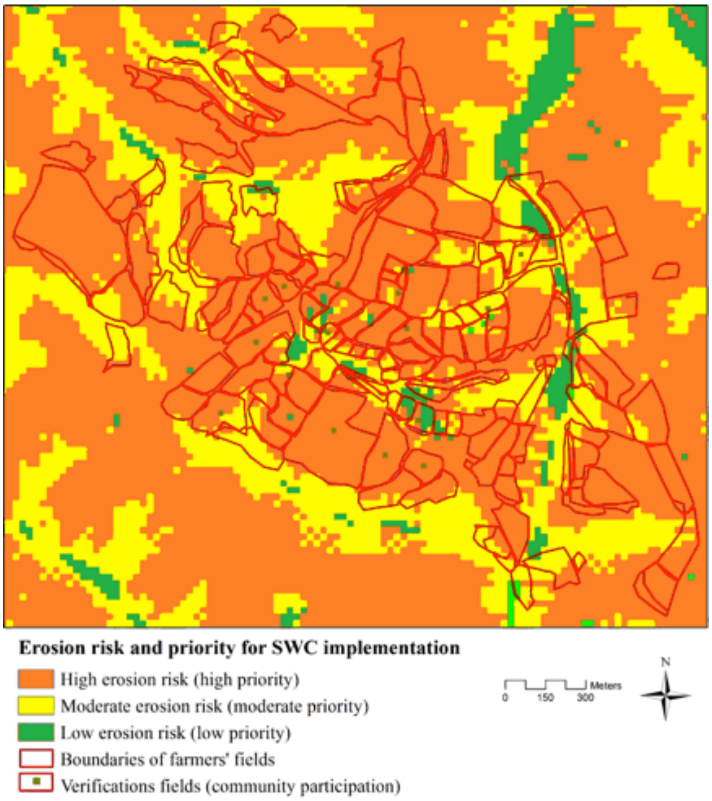


Figure 2: Erosion risk and priority for implementing soil and water conservation. A map of erodible land was created for Maghara village, using topographic parameters for the small catchment. Susceptible areas for erosion were targeted with suitable soil and water conservation measures to improve productivity and enhance environmental sustainability

plan was established, revised and approved by the community. Incentive loans to implement soil conservation measures were distributed to 222 farmers based on the priorities of their fields. After two years, the conservation measures led to marked improvement in soil conservation.

However, farmers were reluctant to apply soil and water conservation options because they would not generate enough direct benefits for them to repay their loans in two years. After discussion, the committee and the farmers decided that 50 percent of the loan should be used for soil conservation and the rest for some income-generating diversification options, such as cultivating herbal and medicinal plants, raising livestock at household level, or introducing home gardening, mushroom farming or beekeeping. In addition to supporting provision of ecosystem services, these options helped to empower local families to diversify their income sources and generate short-term benefits which, in turn, would partially cover the costs of the long-term benefits of land degradation mitigation activities. Adopting other production sources and ecosystem services improved the livelihoods of the community and therefore reduced the pressure on soil resources (soil is not the only source of production).

Lessons learned

- Participatory identification of areas under high risk of soil erosion and targeted implementation of soil conservation interventions, coupled with an enabling environment such as micro-credit system, ecosystem-friendly diversification options and the support of public policies, are necessary to maintain the provision of ecosystem services in fragile mountains.
- The approach explained here is easy to implement, uses available information, and thus could be applied in other mountainous areas facing similar challenges.

Alpine soils and forests: securing ecosystem services in the Pamir mountains of Tajikistan

Farrukh Nazarmavloev, Gulniso Nekushoeva, Pjotr M. Sosin and Bettina Wolfgramm

Farming for subsistence in high-altitude locations, such as the Gunt valley in the Pamir mountains of Tajikistan, requires specific attention to managing the soils in harsh mountainous environments. While fertile soils have developed in valley bottoms and especially under forest cover, land-use changes in these semi-arid ecosystems may critically affect soil conditions and lead to desertification. However, if soils are managed well, the ecosystem can provide multiple benefits.

Cultivating potato fields in Jamoat Vanqala, Tajikistan (Marcel Reinhard)

People in the remote Pamir villages rely on food, fodder and fuel produced from their land for their livelihoods. However, they face many challenges including harsh climate, high disaster risk (*e.g.* avalanches, snowstorms, droughts), shortage of arable land, difficult access to irrigation water and lack of financial resources. Forests play a major role in providing fuelwood and non-timber forest products such as berries, mushrooms, nuts, honey, medicinal plants, foliage, seeds and seedlings. Forests are also used for grazing animals, the number of which has increased greatly over the last 20 years.

The large and dense forest covering the floodplains in the Tajik Pamirs were teeming with wildlife, as mentioned by many expeditions before and in the first decades of the Soviet era (for example Korzeniewski 1903). It is estimated that forest cover in Tajikistan in 1910 was still around 25 percent. Today, official data state that forest cover in Tajikistan is only around 3 percent.

Land-use changes affecting the high alpine natural ecosystems in the Tajik Pamirs increased with the independence of the Republic of Tajikistan in 1991 and the cut in imported goods, including wheat, fodder such as hay, but also coal and wood. Food and energy scarcity during and after the Tajik civil war in the 1990s led to severe land degradation, with a reduction in soil functions, such as regulation of soil nutrients, water and temperature. It also affected soil-related ecosystem services, such as soil nutrient availability, control of erosion by water and wind, length of the growing period and, consequently, biomass production and plant diversity. Overgrazing, deforestation and expansion of cropland to forest areas are

Riverine forests along the Gunt river, Jamoat Vanqala, Tajikistan (Bettina Wolfgramm)

the main pressures on land and, especially, forest resources. In this same period, coal imports have become rare, and therefore costly, which has led to continuous cutting of the forests, bush lands and trees along rivers and on mountain slopes. As the winter is long (October to May), there is an extremely high demand for fuelwood for heating and cooking. Climate conditions are unfavourable for fruit trees, but poplar trees and buckthorn grow well.

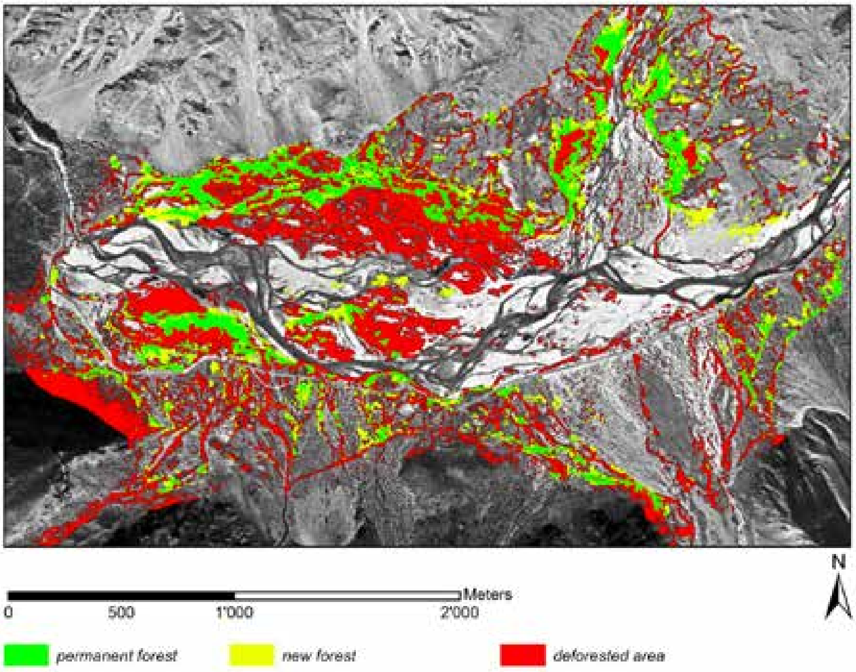
The information presented here resulted from an applied research study conducted in the Vanqala municipality, located in the Gunt valley at 3 100 masl, that identified limitations of agricultural production such as the need for irrigation, constant temperature fluctuations during the growing season that may cause crops to freeze, and cold winds that affect plant growth and lead to erosion. In general, local farmers who cultivate mainly fodder crops, such as lucerne (*Medicago sativa*) and sainfoin (*Onobrychis*), need to apply land management technologies to increase land productivity under these soils, water and temperature conditions, while reducing erosion processes and maintaining soil quality.

The study aimed to identify forest cover changes as well as the specific soil conservation practices in this area, and to estimate their impact on soil resources and related ecosystem services. Soil organic matter was used as a health indicator to assess the impact of the management practices. The information on sustainable land management (SLM) technologies was documented using the World Overview of Conservation Approaches and Technologies (WOCAT) standardized questionnaire. The land use change since the mid-1970s was analysed using satellite imagery, Corona imagery from 1968 and RapidEye imagery from 2010, covering around 130 km^2 of study area.

Overall, the study found a 54 percent increase in arable land and a 34 percent decrease in forest and bush land in the study area. In specific cases, such as the village of Patkhor, it detected a 53 percent forest cover change, indicating that its forest area had been reduced to less than half of the forest area in the 1960s. Other villages were able to protect their forest resources better.

While forest resources were generally heavily degraded, some families managed to improve the tree cover by, *e.g.* planting a dense buckthorn forest belt to shelter fields from temperature fluctuations, cold winds and frost or planting poplar forests in the flood plains of the high mountain river areas. The low temperature in the study area is not favourable for most trees species. The natural forest mainly consists of slow growing trees. However, plantations of poplar (*Populus Pamirico*) and willow trees (*Salix Schugnanica Coerz*) can be established fast with a good water supply, which can be provided by rivers or by irrigation systems. Around 10 ha of low productive pasture land in alluvial sandy soils along the river was turned into a poplar forest by creating an irrigation canal and planting seedlings along it. In the first year, the area needed to be protected from grazing cattle and from neighbours cutting trees.

The soil analysis found that soil under the poplar trees has more organic matter (3.88% in the first 30 cm) compared with other surrounding plots (2.58-2.78%).



Corona imagery of the village of Pathkur, with forest cover change classification between 1968 and 2010. A misclassified area is marked with a white arrow (Selina Studer)

Lessons learned

- Agroforestry and forestry systems for producing food, fodder and fuel can also contribute to improved management of soil resources and enhance long-term provision of ecosystem services in temperate areas.
- These systems can protect soils from wind and water erosion, contributing to sustainable nutrient supplies. The tree cover creates a micro-climate and reduces the impact of temperature extremes in order to increase production in these harsh mountainous environments, it is also crucial to protect soils from cold winds and cold spells during the summer season.
- The benefits resulting from agroforestry plots are manifold and include significant improvements of soil fertility, productivity, biodiversity and carbon stocks, compared with the surrounding arid desert landscape.

Plantation of poplar forest in the flood plains of the high mountain river areas. Gunt valley, Tajikistan (Gulniso Nekushoeva)

Pedodiversity and ecosystem services of mountain soils in Southwestern Europe

Juan-Antonio Pascual-Aguilar, Vicente Andreu, Juan-José Ibáñez and Rufino Pérez-Gómez

Within mountain environments, it is possible to find a huge variety of soils in relatively small areas. However, the provision of ecosystem services is not the same among the different mountain ranges of the world. Factors that contribute to the great variety of soils (pedodiversity) at local level include altitudinal differences and their associated climate belts from the lowlands to mountain tops, the roughness of the topography and the lithological substrate.

Panoramic view of Almería (@Flickr/Rubén)

The mountainous climatic zone is highly peculiar due to steep altitudinal gradient – meaning that mountainous regions have many climatic belts in small areas that contain a large variety of soil-forming factors and, therefore, soil types (pedotaxa) and soilscape belts. Major climatic differences among the world's mountain regions offer a variety of benefits. For example, mountain ranges are especially important in hot arid and semi-arid regions as their provide water (irrigation), wood, grass.

At global level, mountain areas achieve the highest pedorichness of all the different world biomes. Mountains have also the highest richness density in terms of number of soil types per unit area.

Almeria Province, located in the Andalusia Region of Spain at the southeast end of the Iberian Peninsula, is an arid mountainous land overlooking the Mediterranean Sea that extends from sea level to 2 500 m in a horizontal distance of 35 km. Some 60 percent of Almeria is mountainous, with six mountain ranges and an average altitude of 700 masl and 7° slope gradient (Figure 1). Altitudinal differences affect both temperature and precipitation, with less than 200 mm annual average rainfall along the shoreline and more than 600 mm in the top mountains.

Almeria Province hosts seven Mediterranean climatic belts ranging from hot arid to periglacial, as well as more than 44 soil types. There are salt-rich soils in the lower arid mountain areas, but as the altitude increases, salts leaching occurs, with salts re-precipitated in deeper horizons of the soil profile and in the highest altitudes salts are leached out of the soil. There are nine reference soil groups with soil-ecosystem services that can be classified according to three main categories: provision services

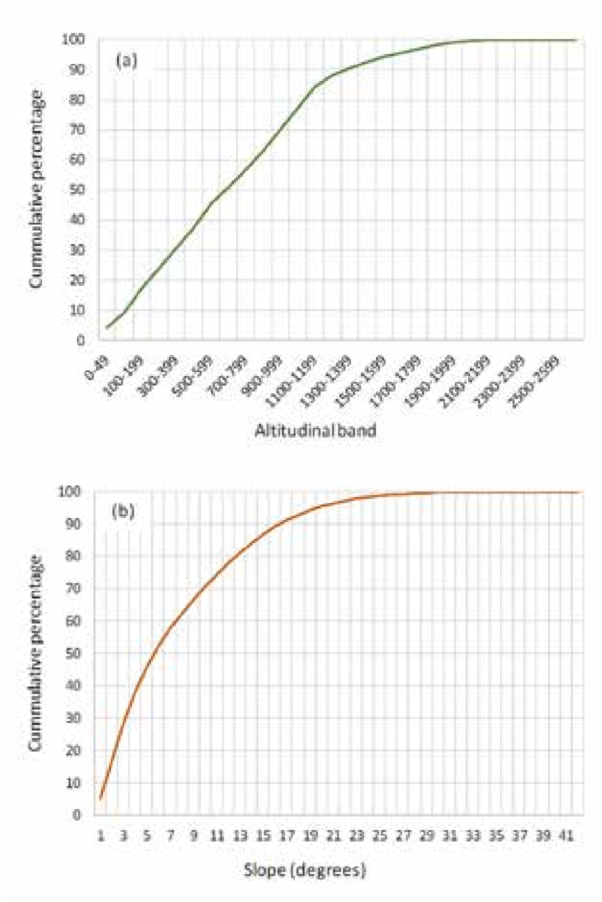


Figure 1: Topographic characteristics of the Almeria Province: (a) Altitude, (b) Slope. (Juan José Ibáñez)

Panoramic view of Almería (@Flickr/Rubén)

such as providing substrate of both cultivated and natural vegetation and providing fresh water; regulating functions such as control of climate, pests, erosion and natural hazards (*e.g.* flooding), and also of water flow and water purification, and cultural services that support cultural and heritage sites, as well as area recreation, geo/ecotourism, education and research.

The natural vegetation of Almeria has been used as fuel for mining activities for five millennia. Most of the land in high altitudes and steeper slopes of the mountain ranges is home to plant ecosystems (natural vegetation) with only a small portion taken up by human settlements, infrastructure and food production (Table 1). Arable land for food production is mainly restricted to lower mountainous areas which account for 15 percent of the land. Traditional cultivation systems, mainly bench terraces, are rainfed but some small plots are irrigated with water harvested from underground supplies coming from the mountains.

Dominant natural vegetation covers consist of arid, semiarid and dry Euro-Mediterranean shrubs including some species of African origin. Sparsely vegetated areas are extensive in most mountain areas of Almeria (30-82% of the total mountainous area, Table 1). Sparsely vegetated sites interspersed with "islands of fertility", which is typical of arid lands, appear in locations where soils productivity is limited by climatic and lithological (*e.g.* badlands) features or overexploiting activities. *Sclerophyllous* vegetation, which is able to survive the pronounced hot, dry Mediterranean climate, is dominant in the highest mountains (above 2 500 m), forming dense vegetation associations composed of numerous shrubs species on siliceous or calcareous soils.

Coniferous forests (mainly pine species including shrub and bush understoreys) are the dominant natural vegetation in mountain areas located between 1 500 and 2 500 masl and slopes >5°.

There are 40 plant communities in Almeria. Because many edaphophylous plant communities (whose presence in a site depends more on the soil type than climatic conditions) are endemic, the conservation of this rich biodiversity depends on soil preservation is another invaluable ecological service.

Climate regulation is one of the major ecological services provided by soil in Almeria. Carbon dioxide (CO_2) stocks are stored in plant biomass or in form of soil organic carbon. CO_2 contents in the mountain area range between 20 and 80 Mg ha-1 as is showed in Table 1, while in the lower lands, plants and bush vegetation store higher amounts of atmospheric carbon in their biomass. Although CO_2 contents depend on several factors (such as soil moisture regime and texture) well-structured vegetation cover (with or without tree storeys) is important. Studies have found that among the dominant reference soil groups, the highest average soil organic stocks are found in typical soils of arid lands as well as in clay rich pedotaxa covered by shrub or herbaceous plant communities.

Altitude	**Ecosystem services**			
	Biomass production: % total natural vegetation cover	Biomass production: dominant natural cover (%)	Biomass production: % crops cover	Climate regulation: CO_2 (Mg ha-1)
>2500m	100	Sclerophyllous vegetation (64%)	*0*	20-60
1500-2500 m, slope 2°-5°	97,5	*Sparsely vegetated areas (46%)*	2,3	20-60
1500-2500 m, slope >5°	99,1	*Coniferous forest (34%)*	0,7	20-60
1000-1500 m, slope >5°	84,3	*Sparsely vegetated areas (30%)*	15,6	20-60
300-1000 m, slope >5°	83,7	*Sparsely vegetated areas (67%)*	15,6	20-80
100-300 m, slope >5°	87,3	*Sparsely vegetated areas (82%)*	10,5	40-80

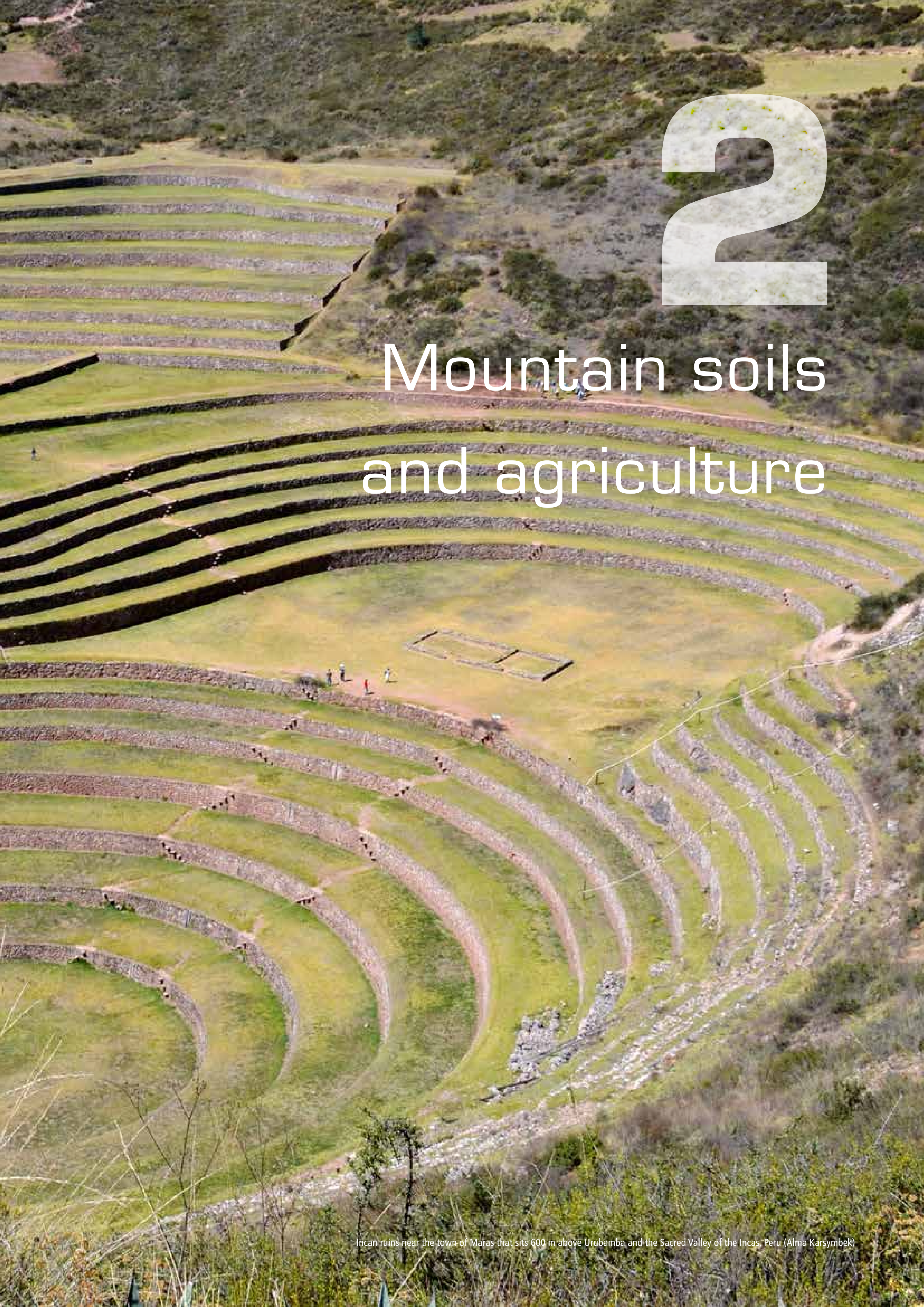
Table 1: Ecosystems services provided by plant communities and soils in Almeria

Lessons learned

- Due to the climatic gradient, from the arid coastal lowlands to the mountains tops, there are multiple bioclimatic belts that form sequences rich in soil and vegetation types offering diverse products and ecological services to the local rural communities that would otherwise live in very hostile environments.
- Water coming from the mountains' tops irrigates the surrounding arid lowlands increasing their productivity.
- In the Almeria province, mountain soil erosion was not caused by the traditional agricultural farming practices and grazing, but from the intense mining activity of the last centuries.
- The pedodiversity and biodiversity of the study area occurs mainly in dispersed and small waterlogged soil hotspots located in lower drylands, which attract eco-tourism.

2

Mountain soils and agriculture



Incan ruins near the town of Maras that sits 600 m above Urubamba and the Sacred Valley of the Incas, Peru (Alma Karsymbek)

A farmer working the land along the banks of Burera Lake. Burera, Rwanda (@FAO/Giulio Napolitano)

Sally Bunning, Ronald Vargas and Alessia Vita

Mountain soils and agriculture

Soils are the foundation of agriculture, supporting crops, livestock and trees vital to feed the 7 billion people currently on Earth, a population expected to grow to 9 billion by 2030. Already, more than half of those people live in cities, which means they depend on others to produce their food – food that comes from an increasingly limited and pressured land area suitable for agriculture.

This includes the world's mountainous and highland areas that support some 900 million people but present the farmers and livestock keepers with challenging, often marginal, conditions in which to live and work. Mountain peoples have to cope with high runoff rates from steep slopes and associated soil erosion and landslides. They also face challenges of highly differentiated climatic conditions due to altitude, large daily and seasonal temperature fluctuations and changes in aspect and exposure within short distances, and they are vulnerable to climate change with its associated extremes in precipitation such as rain, snow and mist. Crop growth is slower due to the lower temperatures at high altitudes, so many farmers have only one harvest per year. Also soils in mountain areas are often degraded due to leaching of nutrients and erosion by water on steep slopes and erosion by wind on exposed areas.

Moreover, mountain peoples often live in remote areas that are not easily accessible. They have poor access to health, education and markets, and may have to travel long distances with their pack animals to collect water, fuelwood and basic supplies.

However, the variations in soil, terrain and climate also provide opportunities. The world's mountainous areas have the capacity to store water in upstream reservoirs and to supply users downstream through gravity fed systems. Mountains host approximately 25 percent of terrestrial biodiversity as well as vital genetic resources for locally adapted crops and livestock crucial for food security.

Many of the world's staple food crops, such as maize and potatoes, and a large share of domestic animals originate in mountain areas. Indeed indigenous livestock breeds – such as yak, mountain goats and sheep – are usually well adapted to the harsh mountain conditions and able to cope with the extreme and alternating hot and cold, wet and dry conditions.

The Food and Agriculture Organization of the United Nations (FAO) has estimated that around 45 percent of the world's mountain areas is not, or only marginally, suitable for growing crops, raising livestock or carrying out forestry activities. Thus mountain peoples, who are largely family farmers and livestock keepers, have had to develop different ways of averting or spreading risks to survive. They have adapted, adopted or conceived complex and diversified farming systems on croplands, pastures and forests that make use of different soil types at different altitudes and at different times of the year. For example, they grow sun-loving plants on the warmest slopes and move livestock to graze on high summer pastures after the snow has melted.

Across the generations, mountain people have developed survival or subsistence strategies and have become important custodians of indigenous knowledge and local innovations that shape and protect the soil, vegetation, water resources and landscapes on which they depend. Moreover, these livelihood strategies contribute to the provisioning of crucial ecosystem services that benefit not only peoples living in the mountains, but billions more living downstream.

Unsustainable soil management practices such as overgrazing, deforestation, monocropping, and up- and down-slope ploughing, as well the sprawling of urban settlements cause serious soil degradation, which accelerates erosion, reduces soil fertility and increases the potential for natural hazards.The degradation of mountain soil and vegetation cover may happen gradually and imperceptibly, or rapidly if there is a change in land use or management practices or a natural disaster. The restoration of degraded lands is very costly in human and financial terms and in severe cases, the degradation is irreversible.


A shepherd keeping an eye on a herd of sheep at the former National Feedlot. Maseru, Lesotho (@FAO/Gianluigi Guercia)

Some mountain areas are more prone to landslides due to earthquakes or volcanoes or due to mass movements of rock and sedimentary materials and mud flows. The combination of steep slopes, varied topography and often alternating dry and wet spells in mountainous areas requires a combination of biological and structural soil and water conservation measures to provide a protective vegetation cover and minimize the downward transport of soil (by splash, rill and gully erosion). Measures are needed that factor in the safe storage and diversion of excess runoff water as well as for downstream erosion and flood control and reducing risk of landslides when building roads, terraces or valley dams, or for ensuring sustainable forest logging. In addition, restoration of soil organic matter is needed on sloping lands to replenish nutrients that are lost through the harvesting of crops and erosion and thereby to sustain plant growth and land productivity over the years.

Mountain peoples have adopted, adapted or developed a host of agricultural systems that help them manage their land, especially their soil, sustainably.

Contouring. Growing crops on sloping land is a major cause of accelerated erosion, unless soil and water conservation measures are widely practiced. On gentle slopes, this requires contour farming (*i.e.* ploughing, planting and weeding across rather than down the slope). In higher rainfall areas, it requires construction of permanently vegetated contour bunds or ridges with retention or diversion ditches to break up the slope, increase rainwater capture and infiltration, reduce runoff volume and velocity and hence minimize erosion.

Terracing. For sustainable cropping on steep slopes, progressive or bench terraces are required which are costly and require substantial labour for their construction and maintenance. The resulting change in landscape, however, can be extremely productive as shown by breathtaking terracing systems worldwide, many of which are recognized and designated as Globally Important Agricultural Heritage Systems (GIAHS). For example, in the Andes, the terracing systems provide soil conservation which induces the formation of deeper soils and enlarges cultivated areas, ensures sunlight for longer periods during the day, increases water storage, and allows for a more efficient use of water for irrigation. It also contributes to protecting agricultural fields from possible landslides, because the use of rocks in the building of the faces of the terraces strengthens the mountain slopes.

Organic mixed farming. Due to low levels of technology available, mountain agriculture generally has a low impact on the environment. In many mountain areas of the world, family farms are organic, in part because they do not have access to costly inputs (seeds, fertilizers and other chemicals). These farmers must adapt local farming practices to build and maintain soil fertility, to manage diversity and natural predators for pest and disease control, and to maintain habitat for pollinators as well as shade and watering points for livestock and wild animals. By emphasizing a holistic mixed-farming approach, where crop rotations and animals play an integral role, mountain farming is able to tap into a growing demand for high value, organic products.

Terraced rice fields that march up the slopes of Toraja Land, Sulawesi, Indonesia (Jesse Lewis)

Conservation agriculture. Conservation agriculture is another management approach that can be used on sloping land to sustain crop yields and soil health through its three main principles: minimal soil disturbance, permanent soil cover and crop rotation. This can include alternating staple food crops with nutritious legumes (*e.g.* beans and chick peas) and fodder crops (*e.g.* lucerne and radish) to restore nitrogen and organic matter and encourage deep rooting of plants for optimizing access to moisture and nutrients.

Forests and trees. Forests and trees make an essential contribution to mountain agriculture by helping to maintain the environmental conditions needed for agricultural production while providing food, fuelwood and fodder as well as building materials and timber. With their diverse ground cover and highly developed root systems, trees and forests stabilize the soil, protect it from erosion and landslides, improve soil fertility, enhance the capacity of the land to store water, and moderate air and soil temperatures. Sustainable forest management and, as required, restoration of degraded forests and reforestation of mountain tops, steep upper slopes, and steeply incised rivers, streams or gullies are a crucial part of watershed management systems that regulate hydrological flows and provide a constant water supply downstream. Traditional agroforestry techniques, which can provide canopy cover, have been successfully used for centuries in mountain regions and areas vulnerable to cyclones and frequent storms to enhance resilience to such shocks.

Pastoralism. Sustainable pastoralism is a low input-low output approach to keeping marginal rangelands productive, many of which are in mountains and highland regions. It does this through adaptive use of pasture, rangeland, water, salt and forest resources, and by maintaining mobility of herds to cover vast distances between the dry and wet seasons, or between summer and winter grazing lands. Pastoralists also manage high genetic diversity and variations in herd composition to cope with the harsh environments. Through herd management, pastoralists deliver a wide range of economic and social benefits from areas of low biomass productivity that are ill-suited to intensive management or cropping. They provide food and fuel and also contribute to climate regulation, flood and erosion control and nutrient cycling. Some examples of Globally Important Agricultural Heritage System (GIAHS)-designated mountain pastoralism systems are the traditional yak-based pastoral system in Ladakh and the high Tibetan plateau of India and China, and extensive rangeland management in the highlands of Mongolia, Yemen and the Atlas mountains of Morocco.

Volunteers unload forage trees and ready to plant them.
Upper Mazar watershed, Cañar, Ecuador (Alec Morton)

These varied examples of sustainable crop, pasture and forest management in mountain agricultural landscapes demonstrate the need for increased awareness and greater recognition of the importance of maintaining the multi-functional role of the soil and wider landscapes in mountain areas. Good soil management contributions include the production of food and other products; water regulation and purification; climate regulation; erosion, landslide and flood control; and conservation of biodiversity. In addition, many mountain landscapes also attract visitors for recreation and tourism, are sources of cultural heritage and folklore, and provide supplementary income and employment based on local foods (dairy, meat), medicinal plants and artisanal products (*e.g.* made from animal hair, fleece and hides).

The History of terracing

Carmelo Dazzi and Edoardo A.C. Costantini

Terracing, an agricultural technique developed over thousands of years, has transformed landscapes and soils in many parts of the world (Table 1). Early terracing systems trace back to approximately 3000-4000 years BCE (Figure 1).

Figure 1: Terraces that date back to the Inca period along the Colca Canyon, Peru

Table1

Area	Development of (years before common era)	
	Agriculture	**Terracing**
China	8500 - 11000	3000
Japan/Korea	3000 - 5000	2000
India	5000 – 7000	3000
Philippines	3500 – 5000	2000
Papua New Guinea	9000	?
Polynesia	1000 – 3500	1100
Near East	10000 – 13000	3000 - 6000
Europe (Mediterranean)	8000	2500 - 4000
Europe (East)	5000 – 7000	?
Europe (West)	5000 – 7000	2000 - 3500
North Africa	6500	3000
Meso America	5000 – 10000	2500 - 3000
South America	4000 – 10000	2500 - 4000
North America	3000 – 5000	1000 - 3000

Before the development of terracing, agriculture in mountain areas was a risky activity as farmers tried to cultivate a slope while hanging from the side of the mountain in a harness. (Figure 2)

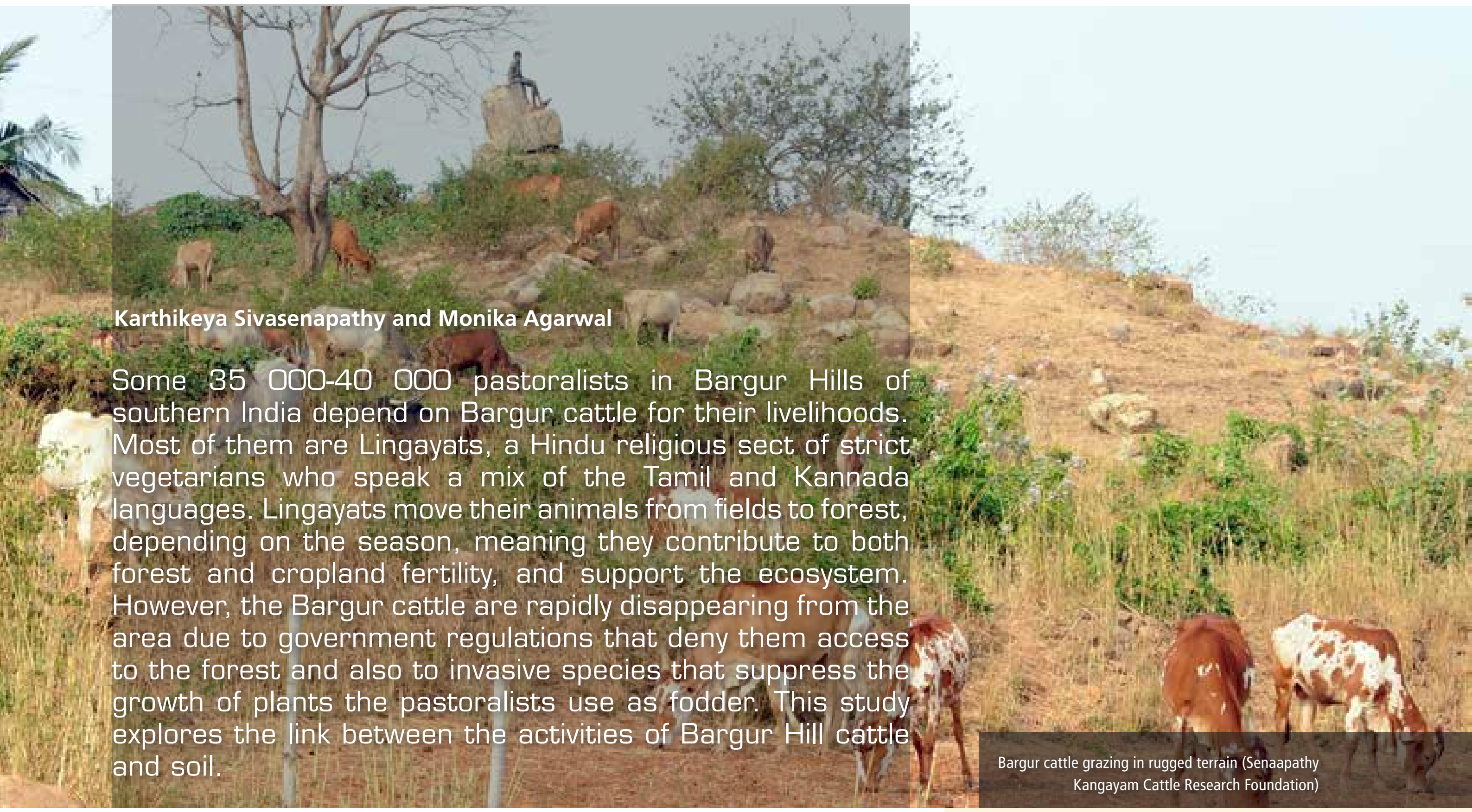
Figure 2: Example of farming in mountainous area with steep slopes, before the development of terracing (scale model in the Anthropological Museum of Mexico city)

Terracing was a revolutionary approach in steep mountainous areas. Success in this activity requires substantial knowledge about soils and how to conserve and manage them on steep slopes, since mountain soils are commonly thin and vulnerable to erosion.

Even after the diffusion of mechanization and intensive agriculture, terracing is not only widely practiced in mountain areas, but also extensively studied and researched upon, as an example of the ongoing human struggle to adapt to these harsh environments (Figure 3).

Figure 3: Modern terracing for new vineyard plantation in the Priorat region, Tarragona (N-E Spain)

Pastoralists, mountains and soils



Bargur cattle grazing in rugged terrain (Senaapathy Kangayam Cattle Research Foundation)

Karthikeya Sivasenapathy and Monika Agarwal

Some 35 000-40 000 pastoralists in Bargur Hills of southern India depend on Bargur cattle for their livelihoods. Most of them are Lingayats, a Hindu religious sect of strict vegetarians who speak a mix of the Tamil and Kannada languages. Lingayats move their animals from fields to forest, depending on the season, meaning they contribute to both forest and cropland fertility, and support the ecosystem. However, the Bargur cattle are rapidly disappearing from the area due to government regulations that deny them access to the forest and also to invasive species that suppress the growth of plants the pastoralists use as fodder. This study explores the link between the activities of Bargur Hill cattle and soil.

Bargur village consist of 36 hamlets most of which are scattered inside the Bargur reserve forest areas. The total area of breeding tract, comprising of deciduous forests with undulating topography, is about 34 043 ha most of which is under the reserve forest. Bargur cattle, found in Erode district, are bred extensively in and around Bargur Hills in Andhiyur taluk in Tamil Nadu. Bargur Hills, 1 078 masl, are a part of Western Ghats situated on the Tamil Nadu-Karnataka border.

The cattle have compact size and a distinct brown colour with white patches (therefore called *Semmarai*). The bullocks, famous for speed and trotting, are maintained for dung and breeding, and are good draft animals and suitable for all agriculture operations in hills and also in plains. Their hooves are hard and water resistant (hence can be used for wet land ploughing) and do not need to be shoed. They are highly resistant to disease and normally no vaccination practice is followed. These bullocks are used by small farmers because of their low maintenance and feed requirements.

The forest and cattle have coexisted in Bargur Hills for centuries, thereby, conserving each other. The pastoral practices of seasonal grazing in the forest conserved the Bargur Hills. The pastoralists in Bargur do not take their cattle to forest for penning in dry season. Instead they take them to their agriculture fields after the harvest and allow them to graze on grass and fodder. The herders only take their cattle to graze in the forest from mid-August to mid-January – after they have sown their fields – which checks the excess growth of grass and forest fires. As a policy, they do not collect the dung fallen during grazing, thus leaving it to act as a good fertilizer. Compared to chemical fertilizers, dung manure has a higher prevalence and a slower nutrient release because the soil nutrients are


Bargur hills (Senaapathy Kangayam Cattle Research Foundation)

not fully mineralized and are accompanied by a gut microbiota that catalyses the slow nutrient release. Dung also has a positive effect on increasing water holding capacity on soils, as it has a sponge effect that allows for capture of water during rains and slow release during dry times. Cow dung and urine and dung mixed with leaves of the nimtree (*Azadirachta indica*) are being used by local people as pesticide and weedicides. Farmers in Bargur Hills have traditionally never used chemical pesticides, weedicides and fertilizers and have preferred dung over chemical fertilizers.

The presence of pastoralists has also prevented the poaching and hunting of animals in the forest, thereby maintaining the ecosystem in the hills. The current decline in pastoralism may lead to disruption of balance between soil, trees and cattle in the Hills. It can already be seen that, with a decline in cattle population and expansion of cropping, the use of chemicals for farming is rising, which in the long run will affect the soil fertility and water availability in hills. For example, a lower sustained organic matter content may cause higher erosion rates in such a hilly environment.

Pastoralism is declining rapidly in hills. More than 50 percent of Linagayats have already given up pastoralism and migrated to the plains, seeking any available labour. A 2003 census found 9 091 Bargur cattle in the area, which represented a decline of around 90 percent from 1977, when there were 95 400. Now, a 2010 estimate done by Tamil Nadu Veterinary and Animal Sciences University (TANUVAS) found that the hills are left with only 3 000 cattle, a number that continues to decline significantly, mainly due to restriction on the grazing imposed by the forest officials of both Tamil Nadu and Karnataka States. Denial of grazing and penning permits by the forest department since 1994 has created a major situation leading to an increasing number of cattle being sent to the slaughterhouses.

The pastoralists also are dealing with the invasion of *Lantana camara* and *Prosopis juliflora*, both invasive alien species which suppress the growth of native flora and fodder grasses such as *alampul* or *malampul* and *naalepul*, which support the ruminants. In addition, a special police task force assigned to the area to search for the forest brigand Veerappan since 1990, led to the harassment of the locals in the search of information to bring him to court, which resulted in loss of cattle and livelihood of the pastoralists.

India enacted a National Biodiversity Act in 2002 which supports *in situ* conservation and also calls for including traditional communities in joint forest management. Alienating the pastoralists and livestock keepers from the decision making mechanism would lead to loss of bio diversity. The cattle keepers demand that their right to graze in the forests should be secured as per the national policy outlined in the National Biodiversity and Forest Rights Act 2006.

Senapathy Kangayam Cattle Research Foundation (SKCRF), a non-governmental organization (NGO) based in Tamil Nadu working on *in situ* conservation of native cattle and pastoralist systems appealed to the Government of Tamil Nadu in 2013 and an *in situ* breeding centre for Bargur cattle has been sanctioned and is currently in progress. The struggle to save the Bargur cattle goes on, but without access to the forests of Bargur Hills it may not be possible and without Bargur cattle the hill soil will not be the same.

Sustainable soil management options in the Nepalese mountains

Bishnu Kumar Bishwakarma, Shiva Kumar Shrestha, Juerg Merz and Richard Allen

A Swiss-funded Sustainable Soil Management Programme in the Nepalese Himalayas introduced sustainable soil and farm management technologies to improve soil fertility and farm productivity through the use and recycling of locally available farm resources. All this combined to provide alternative cropping options, enhance food security, and improve livelihoods.

Monitoring of an on-farm vegetable demonstration plot by a group of district officials (Richard Allen)

The Sustainable Soil Management Programme (1999-2014) was launched to combat the decline in soil fertility and productivity in the mid-hills of Nepal and then evolved to include technologies that responded to the ever evident impacts of climate change in the mid-hills. The programme was implemented by HELVETAS Swiss Intercooperation and funded by the Swiss Agency for Development and Cooperation (SDC) in close collaboration with government agencies, local non-governmental organizations and farmers at central, district and village development committee levels. From its initial implementation in 20 mid-hill districts, it was up-scaled by Nepal's Ministry of Agricultural Development to all mid-hill and some terai districts.

The programme focused on optimal use of local resources and methods to improve the preparation and management of farmyard manure and compost, and the systematic collection of cattle urine which can be used as both a liquid fertilizer and as a base for bio-pesticides. Adoption of these practices has contributed to increased productivity, enhanced income, improved food security, and has had a beneficial impact on the workload of women. In fact, it is almost always the women's job to carry the manure to the fields: being the improved manure lighter, more friable, less wet and being fodder crops grown on waste or nearby land, the burden on women was alleviated. The approach also includes options to improve general farm management techniques, such as topsoil nutrient monitoring,

A husband and wife farming team using bio-pesticides, based on cattle urine, on their cauliflower and citrus in a farmer-led experiment. Okhreni village, Ramechhap district, eastern Nepal (Richard Allen)

soil organic carbon and crop productivity surveys that indicate enhanced levels of soil nutrients, and improved soil carbon storage, soil structure, workability, moisture characteristics and crop resilience to changes in weather patterns. With the adoption of improved farmyard manure management techniques and the systematic collection of cattle urine, farmers gained around 18.6 kg of additional nitrogen each year from one mature cow. This represented a significant contribution through on-farm recycling of local resources, as much of this nitrogen would otherwise have been lost through volatilization and leaching. Adoption of these practices has contributed to increased productivity, enhanced income, improved food security, and had a beneficial impact on the workload of women.

The soil and farm management technologies introduced by the programme were based on locally available resources and alternative solutions, and included:

- improving methods of preparation, management and storage of farmyard manure and compost, focusing on the protection of the manure from rain and sun to reduce leaching and volatilization of plant nutrients;
- making cost-effective improvements to cattle sheds to permit the collection and utilization of cattle/buffalo urine as a base for on-farm production of bio-pesticides and as a liquid fertilizer (replacing urea);
- using on-farm composting, vermicomposting and mulching;
- introducing crop rotation and integrating legumes into the cropping systems;
- using on-farm fodder and forage production to reduce the time and drudgery of collecting cattle feed;
- introducing integrated plant nutrient management;
- setting up collection and use of on-farm waste and runoff water.

These technologies are linked with the production of high value vegetable and cash crops and improved varieties of cereal crops, and incorporate establishment of low-cost polyhouses and value chain marketing to increase farm incomes. They have been adopted in the policies of the Ministry of Agricultural Development and are being promoted through on-farm demonstrations and experiments, documenting and sharing innovations, on-farm coaching and training, and through mobilizing experienced leader farmers for the farmer-to-farmer extension approach. In each of the more than 2 000 farmer groups the project worked with in the period 2011-2014, the best or most innovative farmer was elected the leader farmer, *i.e.* she/he was the leader of the farmer group and contact person.

In order to adopt and mainstream these activities at the local level, and in government policies and regular programmes, the Sustainable Soil Management Programme engaged successfully with senior government staff at local and national level for policy development and capacity building. These soil management technologies were adopted by over 150 000 farmers in 20 districts during the time of the programme (1999-2014). Now, through upscaling by the Ministry of Agricultural Development to more than 50 more districts, many other farmers will also adopt the improved practices. At the local level, more than 400 village development committees have mobilized their government grants and experienced leader farmers have promoted these sustainable soil management technologies among the farmers.

Lessons learned

- Use of the improved farmyard manure resulted in the soils' organic matter contents increasing over periods of one to three years, at rates varying from 2 to 27 percent. Overall, the increase from 3.3 percent organic matter to almost 3.8 percent was highly significant.
- Sustainable land management and improved farmyard manure quality significantly increased the total nitrogen levels which resulted in reduced fertilizer applications, increased moisture-holding capacity and drought resistance, and enhanced soil erosion control.
- Due to the improved farm and soil management, together with the use of improved seed and adoption of innovative technologies, all farmers who adopted the practices have improved productivity, drought and pest/disease resistance, household income, food security and resistance to climate change.

Tackling soil erosion with nuclear techniques in Viet Nam

Miklos Gaspar

Currently, 65 percent of the Earth's soil resources – or 1.9 billion hetares – are considered degraded. Soil erosion, the main contributor to land degradation, leads to loss of 75 billion tonnes of fertile soil each year with an economic cost of about US $400 billion per year. Nuclear techniques have been developed that can help protect soil from degradation by pinpointing and measuring erosion which enables targeting conservation practices and treatments that can control the erosion.

Sampling of soil for FRN analysis to quantify soil erosion rates from a coffee farm. Lam Dong province, Viet Nam (Phan Son Hai)

The International Atomic Energy Agency (IAEA), through its Technical Cooperation Project on Improving Soil Fertility, Land Productivity and Land Degradation Mitigation and in partnership with the Food and Agriculture Organization of the United Nations (FAO) through the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, helps scientists and farmers in over 60 countries measure and control soil erosion through the use of various nuclear techniques. These include tracking fallout radionuclides (FRNs), which help assess soil erosion rates, and using compound specific stable isotope (CSSI) analysis, which assists in tracing hot spots of land degradation (Box 1).

Box 1: Fallout radionuclides and compound specific stable isotope analysis

Fallout radionuclides mostly originated with the fallout from nuclear weapons testing that was done in the 1950s and 1960s and from nuclear accidents, such as the 1986 explosion at the Chernobyl Nuclear Power Plant in Ukraine. Fallout from the testing and the accidents, dispersed throughout the world and, in addition to being present in the atmosphere, the FRNs have been deposited on the soil surface through rainfall.

Measuring the presence of FRNs in the soil can help i) identify changes in soil redistribution patterns and rates in large catchment areas and ii) evaluate the efficiency of soil conservation measures in controlling soil erosion. FRNs can be measured non-destructively and relatively easily using modern high-resolution gamma spectrometry.

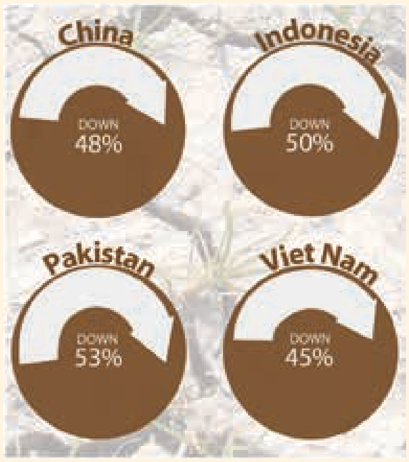
CSSI analysis is used to identify where eroded soil originated because CSSIs are specific to different plants. By studying the CSSI make-up of the eroded soil, scientists can trace it back to its origins. Combining the two approaches provides information that links the sediment in the catchment to its source of erosion.

Coffee plantation farm site for monitoring soil erosion study using nuclear techniques. Lam Dong province, Viet Nam (Phan Son Hai).

Erosion affects the fertile top layer of the soil, carrying away much of the essential plant nutrients and making it difficult for plants to grow and thrive. Environmental problems also occur when these nutrients are deposited in freshwater – algae feed on them which greatly increases their presence and, in turn, sharply decreases water quality. Intensive agriculture, along with deforestation, is a common cause of erosion. Aggressive farming removes the organic matter that binds the soil particles, leaving the soil vulnerable to erosion during heavy storms and rainfalls. Nuclear techniques help identify erosion hot spots, enabling follow-up mitigation measures to target treatment on areas most at risk, which increases effectiveness and reduces cost. After introducing the project in various Asian countries, the FAO/IAEA partnership is now working to replicate its success in other parts of the world and is forming a network of national experts to share best farming practices and know-how to address land degradation.

In Viet Nam, where three-quarters of the country's territory is sloping land, erosion is a major problem. An FAO/IAEA pilot project in the Lam Dong province measured soil erosion rates using nuclear techniques at 27 sites. As a result, the Centre for Environmental Research and Monitoring at Viet Nam's Dalat Nuclear Research Institute, which has participated in the project since 2012, reported that farmers were able to adopt appropriate and targeted conservation practices – such as introducing intercropping, creating basins near coffee trees to trap water, and building terraces – which led to a 45 percent reduction in soil erosion. Similar results were achieved throughout the region (Figure 1). The Centre is now assisting other institutes across the country in introducing nuclear techniques for erosion monitoring nationwide.

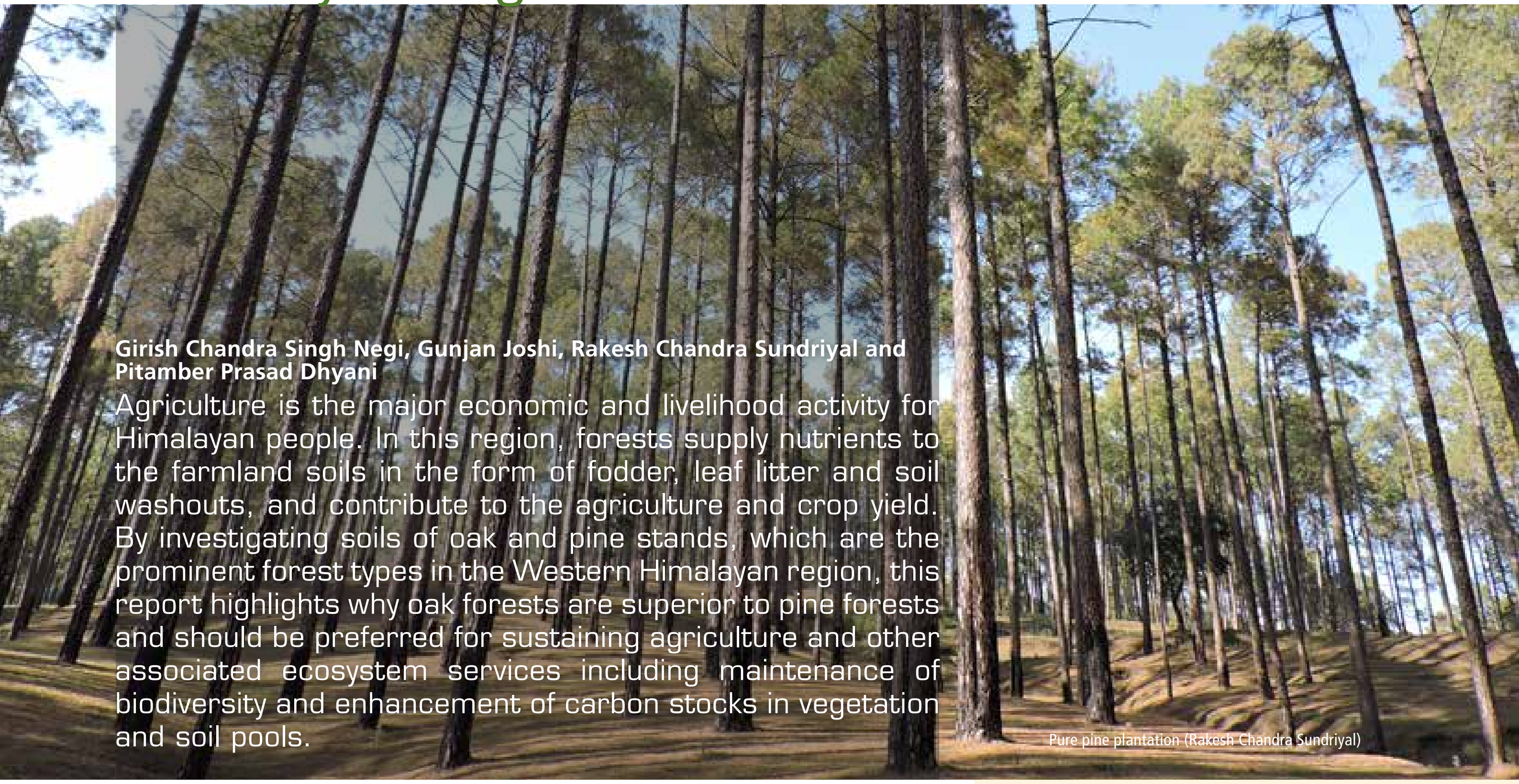
Figure 1: Reduction in soil erosion in target areas since 2012



An erosion-prone area of Perlis State in northern Malaysia, which is also part of the project, has been monitored for over ten years. The monitoring team, from the Sultan Idris Education University, switched to nuclear techniques two years ago which enabled them to obtain much more detailed information. Previously, the team could measure sedimentation rates in lakes, but could not identify the exact source of the sediments. With the nuclear measurement techniques, the team can identify precisely the erosion source and, thus, know where to undertake proper mitigation measures. The next step is to organize a training programme for farmers on techniques to reduce soil erosion.

A Vietnamese farmer, who has seen his income increased by over 20 percent, now grows tea plants and animal fodder in erosion hot spots among his coffee trees. The new plantings not only curtail the erosion, they also provide extra income.

Oak and pine forests soil in the Western Himalayan region of India



Pure pine plantation (Rakesh Chandra Sundriyal)

Girish Chandra Singh Negi, Gunjan Joshi, Rakesh Chandra Sundriyal and Pitamber Prasad Dhyani

Agriculture is the major economic and livelihood activity for Himalayan people. In this region, forests supply nutrients to the farmland soils in the form of fodder, leaf litter and soil washouts, and contribute to the agriculture and crop yield. By investigating soils of oak and pine stands, which are the prominent forest types in the Western Himalayan region, this report highlights why oak forests are superior to pine forests and should be preferred for sustaining agriculture and other associated ecosystem services including maintenance of biodiversity and enhancement of carbon stocks in vegetation and soil pools.

Forests perform an important contribution to food production by helping maintain soil fertility and other ecological services (*e.g.* pollination) necessary for crop production. In the Himalayan region, agriculture is the mainstay of local inhabitants and livelihoods are largely dependent on forest-based resources. Forests are generally maintained at hilltops or on slopes above agricultural fields. The nutrient rich washout from the forests also contributes to the soil fertility. Fodder collected from forests is stall-fed to domestic animals and the farm yard manure, prepared from composting animal dung with forest leaf litter, is applied to agricultural fields. In addition, forests stabilize the soil, control erosion, improve the soil's water holding capacity and moderate air and soil temperatures. Thus, there is a direct relationship between forest soil fertility and agricultural land fertility. Studies on soil are extremely relevant, enabling better choices for conservation and management of forests. The soils' physiochemical characteristics – those which depend on the joint actions of both physical and chemical processes – vary in space and time because of variation in vegetation cover, topography, climate, weathering processes, microbial activities and several other biotic and abiotic factors. Vertical patterns of soil organic carbon (SOC), total nitrogen (N) and C/N ratios are crucial for understanding biogeochemical cycles, and for insights into nutrient inputs, outputs and cycling process in ecosystems.

Uttarakhand State in India's Western Himalayan region has two major forest types - oak (*Quercus leucotrichophora*) and pine (*Pinus roxburghii*) – which spread over some 10 000 km^2. The Oak, known also as banj oak, is a deep rooted and moderate sized evergreen tree that grows in the moist and cool aspects between 1 000 and 2 300 masl, whereas pine is a shallow rooted, and large evergreen conifer that grows between 800 and 1 700 masl. Oak forests mostly occupy deep, moist and fertile soils whereas pine forests do better on shallow and nutrient poor

soil and dry habitats. In an area between 1 000 and 1 500 masl, these two forest types overlap and form mixed forests. Generally, oak forests require protected sites while pine forests endure biotic stress such as fire and grazing. About 150 year ago, pine forests were planted for their commercially important resin and timber, occupying the habitats suitable for oak forests. Biotic disturbance such as lopping for fuel wood and fodder and foraging by livestock is common in both the forests. In these forests, soil quality (particularly N) deteriorates along the disturbance gradient, and tree growth is most commonly limited by shortage of mineral nutrients. As the hardy pine has replaced oak forests, it has affected the N cycle. These forests also offer a large sink for atmospheric carbon dioxide (CO_2). In this case study, an effort has been made to present physicochemical properties of soils (up to 1 m depth) among oak and pine forests located in Chamoli and Champawat districts of Uttarakhand across winter and rainy seasons. Data indicated that the physicochemical properties of soil in both the forest types varied significantly (Table 1, Figures 1 and 2).

Soil parameters	**Winter season**		**Rainy season**	
	Oak forest	**Pine forest**	**Oak forest**	**Pine forest**
Moisture content (%)	15.0±0.90[a]	7.0±0.48[a]	33.0±2.25[a]	17.0±1.76[a]
Water holding capacity (%)	65.0±2.9[b]	49.0±2.0[b]	66.0±2.0[b]	48.0±1.94[b]
pH	5.26±0.48	5.34±0.44	5.37±0.03	5.44±0.12
Organic carbon (%)	1.83±0.39[b]	0.94.±0.19[b]	2.11±0.31[c]	1.31±0.10[c]
Total nitrogen (%)	0.35±0.04[a]	0.12±0.02[a]	0.36±0.07[c]	0.18±0.03[c]
C:N ratio	5.2	7.8	5.86	7.28

Table 1: Mean values of physicochemical properties of soil of oak and pine forests across two different seasons in the Western Himalayan Region, India (N = 18 for all parameters). For both forest types in each season, if the values are denoted by the same letter, the difference is significant as: a<0.001; b<0.01; c<0.05 level

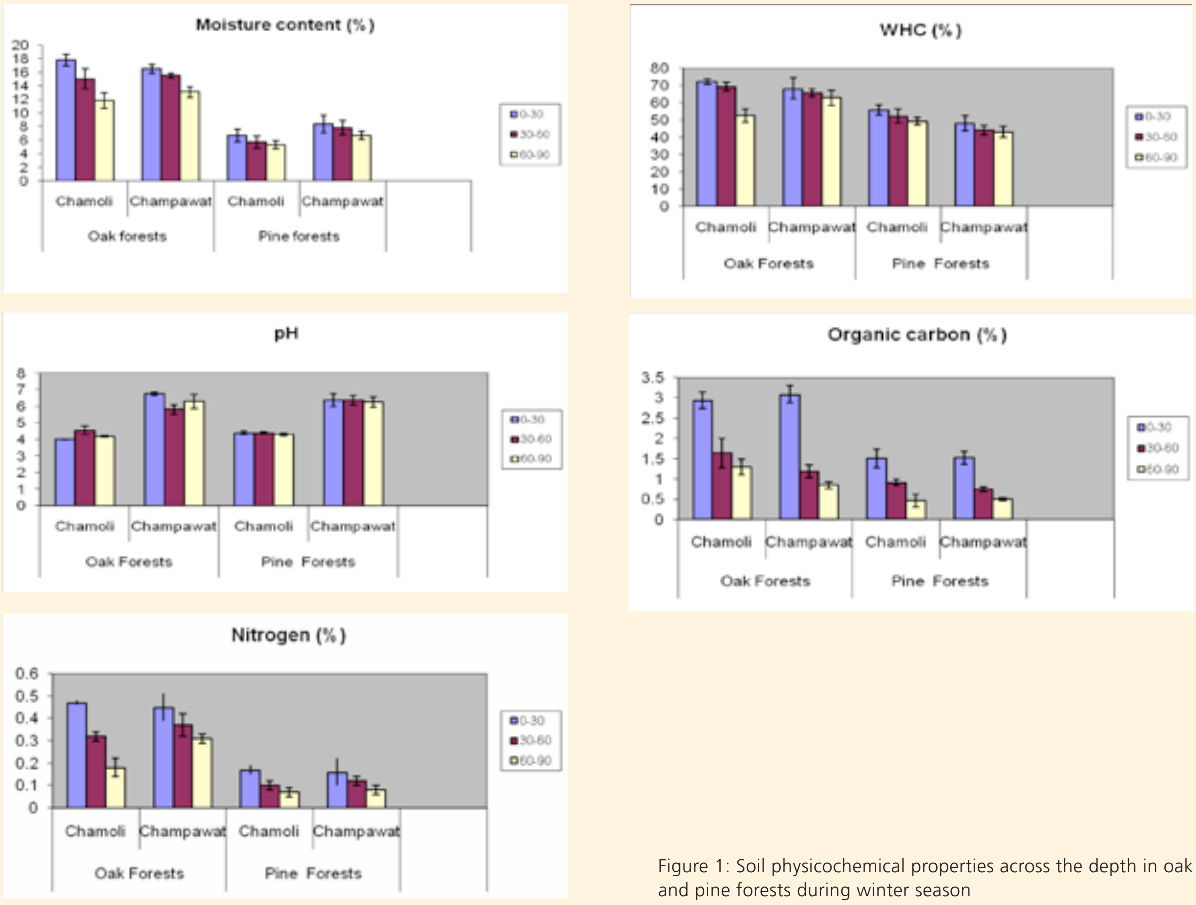


Figure 1: Soil physicochemical properties across the depth in oak and pine forests during winter season

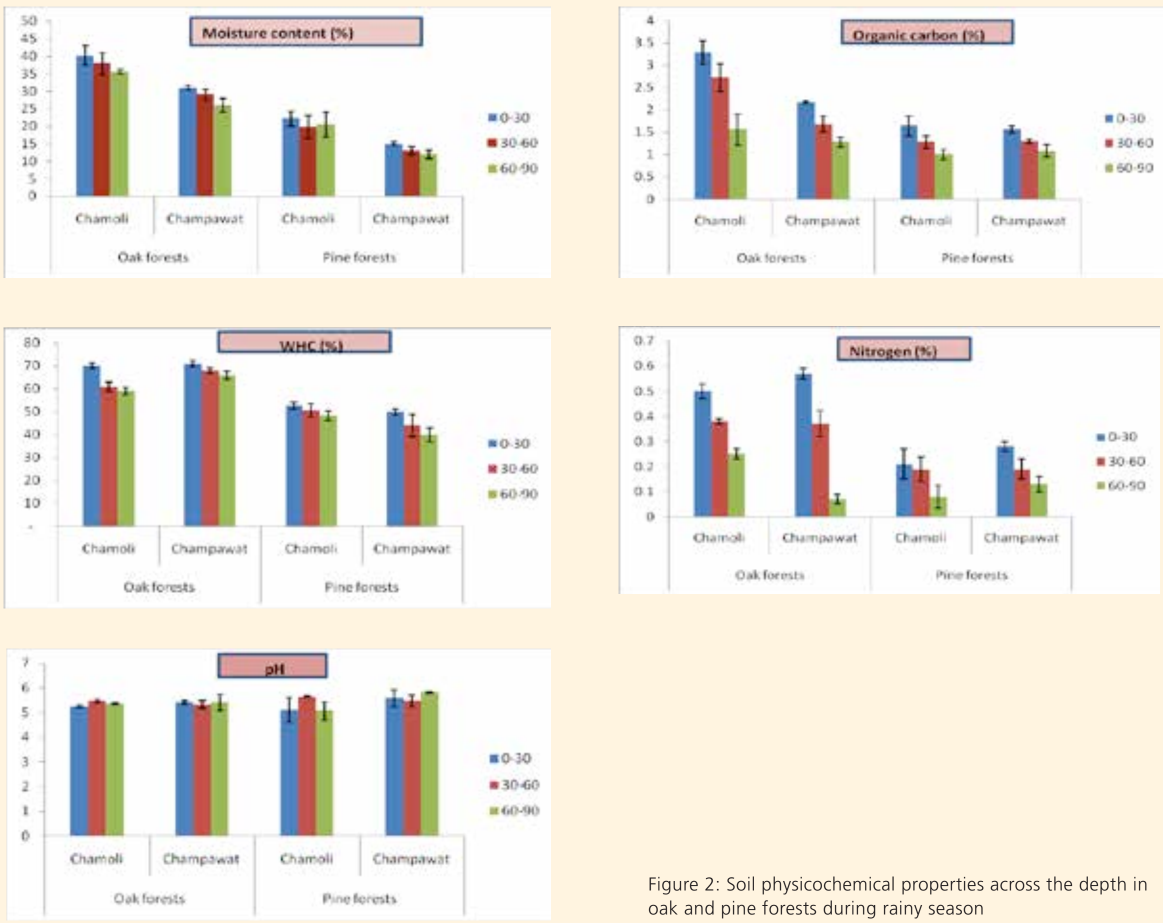


Figure 2: Soil physicochemical properties across the depth in oak and pine forests during rainy season


A panoramic view of western Himalayan landscape (Rakesh Chandra Sundriyal)

The topsoil layer (0-30 cm depth) in both the forests studied had high concentration of SOC and total N, and concentration of these nutrients decreased significantly with increasing soil depth. In both the forest types, about half of the SOC and total N stock was distributed in the topsoil layer. Shallower distribution of the most limiting nutrients for plants (those required by plants in high amounts relative to soil supply) such as N was in general agreement with earlier reports. Considering that SOC stored in surface layer is more vulnerable and less stable than that in deeper layer, the topsoil of these forests should be protected to minimize the risk of large C release.

In the Western Himalayan region, oak forests are socially valued as they provide a range of ecosystem services for the rural communities – they hold high soil moisture and have the water holding capacity and soil fertility that support higher density, biomass productivity, diversity, species richness and under-storey vegetation year-round than the pine forests. In the oak forests, deep soil rich in detritus layer and organic matter coupled with higher clay content (oak 22 percent vs pine 17 percent) promotes absorption of dissolved organic carbon in deeper soil layers. Thus, the role of healthy soil for the growth and sustainability of forests is implicit through this research. Recently, the role of soil C pools for mitigation of greenhouse gas emission has highlighted the need for more knowledge on tree species and forest type, and enhancing natural sinks for C sequestration to mitigate climate change impacts.

Lessons learned

- The report highlights that oak forests hold more fertile soil than pine forests, and the topsoil layer of these forests is particularly nutrient rich, hence needs to be protected, particularly for C stocking.
- The SOC and total N stock in oak forests was significantly higher than in pine forests. Maintaining broad-leaved oak forests will not only provide higher biodiversity, fodder, fuelwood and carbon sink, but also control fire and enhance ecosystem services.
- Oak forests should therefore be protected and given priority in afforestation programmes to contribute to mitigation of climate change impacts.

Addressing the knowledge gap on mountain soils

Luciana Minieri, Fabio Terribile and Simona Vingiani

When dealing today with mountain soils it is important to understand that very little is known about mountain soils, because most of the world's soil survey programmes are oriented towards arable agricultural production. Therefore an integrated ecosystem management is very much lacking.

Soil structure (Christian Prat)

An example of this tremendous knowledge gap refers to some peculiar soil properties, such as andic properties of mountain soils. It is noteworthy that andic soils have unique morphological, physical and chemical properties that induce considerable soil fertility and resilience to land degradation processes such as erosion and landslides. In recent years several reports from all over the world have addressed soils with andic properties in Non-Volcanic Mountain Ecosystems (NVME), including Nepal, India, Austria, North Appalachians (Canada, United States), Kyushu (Japan) and the Alps (Europe). Despite all these findings there is a huge lack of knowledge about the spatial extent of these soils and why they occur over different types of parent materials and climatic conditions.

In the Italian mountains altitude (> 700 masl), slope (< 12°) and active green biomass (maximum Normalized Difference Vegetation Index (NDVI) value > 0.5) have been used as preliminary criteria to identify potential sites where andic soil processes may occur. From this analysis, 42 sites were investigated over a large range of geographical and geological features throughout Italy. All soils were morphologically, micromorphologically and chemically fairly homogeneous, indicating similarities of pedogenetic processes towards andosolization, whereas the podzolization was negligible. A further analysis concerning soil genesis showed that these soils exhibit a parent material of "autochthonous eolian deposits" (loess) in Aluandic Andosols, Cambisols, Phaeozems and Podzols (67 percent, 63 percent, 44 percent and 73 percent, respectively), which also exhibited lower andic features, whereas eolian volcanic deposits accounted for about 90 percent of the parent material in the most andic soil type (Silandic Andosols). The outcome of this study shows the lack of knowledge of mountain soils and the need for improvement in their sustainable management.


A small village in Northern Italy in the Dolomite Mountain Range (Flickr/Andrew Langdal).

An "integrated" mountain ecosystem management is very much lacking. The multifunctional role of soils calls for a holistic approach to address mountain agriculture and mountain ecosystem management. This role includes water regulation, food and no-food production, source of raw materials, climate regulation, flood control and water flow regulation, water purification, erosion control, stock of biodiversity, recreation and tourism.

In this respect, it is now evident that there are many contrasting demands on mountain landscape such as tourism, primary productivity, leisure, etc. but also land degradation issues, as well as new risks and opportunities provided by climate change such as the expansion of viticulture towards higher altitudes. All these issues must be considered and managed holistically if we aim to protect mountain ecosystems.

A new approach is offered by the use of Spatial Decision Support System based on Geospatial Cyber-Infrastructure (GCI).[1] One example is given by the SOILCONSWEB-LIFE+ project. This system allows dynamic, multidisciplinary, multiscale and multifunctional answers to agricultural, forestry and urban planning issues to be obtained online through the web. The system has been applied and tested in an area of approximately 20 000 ha in the south of Italy (Valle Telesina – in the province of Benevento) within a large mountain ecosystem (altitude ranging from 35 to 1 390 masl). The system has been developed with the help of end users and is starting to be adopted by local communities. Indeed, it has the benefit of having abolished current disciplinary fragmentation which is rather common in mountain ecosystem (habitat, forestry, agriculture, etc.) offering – through a smart web-based system – a truly integrated geospatial knowledge that may be directly and freely used by any end user. For example, the forestry module of the system can provide answers such as (i) forest types, (ii) the average height of forest stands, (iii) the growing stock, (iv) above ground carbon stock, etc. This is also an example which may help to bridge the divide between scientists working on the landscape and end users.

1 The Geospatial Cyber-Infrastructure SOILCONSWEB is a platform that supports advanced geospatial data acquisition, data storage, data management, data integration, data mining, simulation modelling, data visualization and other computing and information processing services distributed over the web. It is a technological and sociological solution to the problem of efficiently connecting data, computers and people with the goal of land planning and land conservation.

3

Mountain soils and healthy food production

Life in Bhutan (Pan Himalayan Grassroots Development Foundation)

Peter Schmidt

Mountain soils and healthy food production

Agrobiodiversidad – Quinoa. Perú (@FAO/Alipio Canahua)

Efforts to reduce poverty of people in remote mountainous areas by responding to growing demand for mountain agricultural products can often incorporate more intensive use of natural resources, in particular soil and water. Yet, across the globe, communities living in mountainous areas have developed unique and sustainable production systems adapted to their local environments, and consumers are willing to pay higher prices for high-value products produced in such ways.

Successful soil management in mountainous areas calls for ensuring these locally adapted production and processing techniques maintain their focus on ecologically sound production and incorporate fair market relations. Recognizing this has increased the focus on identifying and further developing the locally adapted sustainable production systems that provide food, generate income and conserve scarce natural resources.

The following looks at some of these systems.

Staple crops. Through tradition, indigenous knowledge and continuous adaptation, low fertilizer-demanding staple crops evolved in mountain areas, such as buckwheat in the Himalayas, quinoa in the Andes, teff in the Ethiopian highlands and wheat landraces in the Alps. Today, due to a growing demand for these nutritious and healthy crops in northern countries, they are often marketed through organic or fair-trade channels and sold as speciality foods.

Radhia Abdul Kulunge's onions and tomatoes at the Kiroka market. Kiroka, Tanzania (@ FAO/Daniel Hayduk)

Livestock production. Traditional livestock production practices – such as migrating herders making use of remote pastures and applying ingenious traditional processing techniques to conserve food – are at the origin of characteristic mountain agro-ecosystems. The resulting livestock products include *kymys*, a fermented mere milk in Kyrgyzstan, dried yak meat in the Himalayas, and *kurut*, balls of dried protein-rich milk in the Hindu Kush. They not only have growing markets in urban centres, their traditional production techniques have now been complemented with semi- and fully industrialized cheese production, promoted by, for example, the Swiss Agency for Development and Cooperation (SDC) in the Andes, Nepal, India and Central Asia to name a few. In view of ecological sustainability needs, such as maintaining soil fertility, livestock production systems need to pay attention to solid pasture management (management committees and pasture rotation), fodder production (stall feeding and fodder trees) and nutrient management (farmyard manure and urine collection).

Non-timber forest products. Non-timber forest products such as berries, nuts and mushrooms are also potential income sources in mountainous areas because, whether collected or cultivated, they are high value and are comparatively easily to transport. For example, raspberries from the Balkans (*e.g.* Serbia) or mushrooms from the deep forests in Eastern Europe (*e.g.* Kosovo or Albania) find their way to Western European supermarkets.

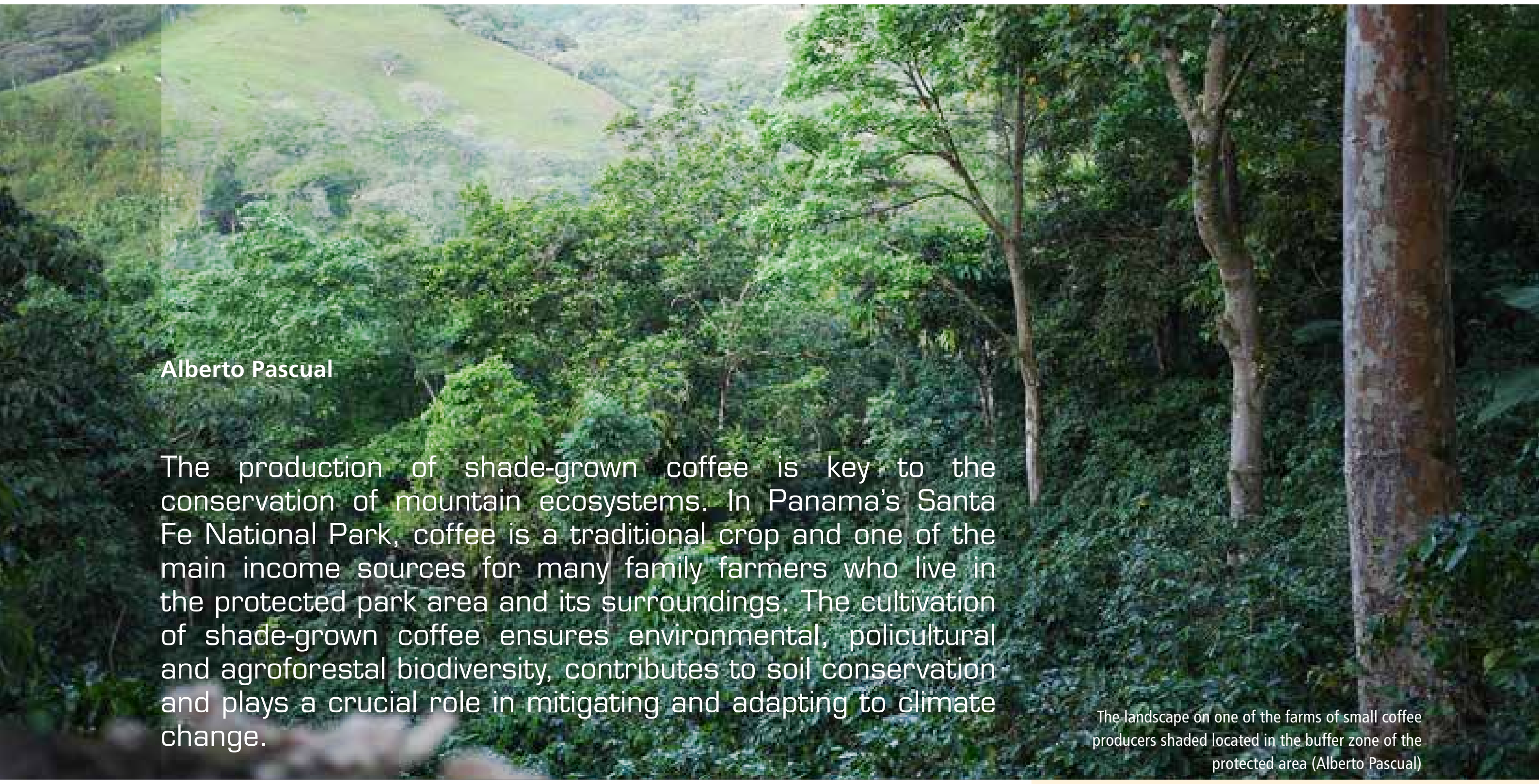
Aromatic and medicinal herbs. Aromatic and medicinal herbs are fast growing compared with trees and, in addition to a quick economic return, growing them also provides producers with a permanent soil coverage. With support from the Swiss State Secretariat for Economic Affairs (SECO), HELVETAS Swiss Intercooperation is engaged in the "bio-trade" of medicinal plants in the Mekong area – linking producer groups to national and regional processors. The sustainable trade benefits mountain peoples and contributes to conservation of tropical forests. With herb collection, it is particular important to avoid over-exploitation of the resource, requiring for example the application of respective standards such as those of the Union for Ethical BioTrade which promotes "sourcing with respect". Semi-processing and the adherence to standards such as organic production can increase value addition and income for the producers, even in the most remote areas, and ensures that sustainability principles, including the maintenance of soil fertility, are followed.

Viticulture. The traditional production system for wine takes advantage of the steep slopes' higher sun-radiation. In addition to inexpensive mass production of wine, there is a growing demand for special wines with a certified origin of a specific region, for which consumers are ready to pay higher prices. The conscious choice of particular grape varieties and grape blends, special pressing techniques and, again, the adherence to sustainability labels increase consumers' readiness to pay a higher price which, in turn, provides an incentive to producers to apply sustainable production techniques. For example, wine producers in Georgia have revived the ancient *kvevri* technique whereby fermentation takes place slowly and naturally within large earthenware vessels with no chemical preservatives.

In very fragile ecological contexts, such as arid and semi-arid areas, the quality of soils is particularly vital for the sustenance of rural communities. In such situations, the organic matter content of soils is of primary importance because it controls their water holding capacity. All measures to maintain and increase organic matter – for example, crop rotation, green manure, mulching and compost making – can also contribute to maintaining, promoting or even introducing soil fertility. In certa*in situ*ations, changing cropping patterns or even introducing new crops may be appropriate measures for erosion control and soil fertility. For example, simple management measures such as planting and pruning transformed the beles cactus (*Opuntia ficus-indica*) – originally an invasive species in Tigray, Ethiopia – into a welcomed multi-purpose plant, providing food for humans, fodder for livestock, and fruits and flowers for sale on urban and international markets. At the same time, beles contributes to erosion control and enriches soils with organic matter.


Taroudannt, Morocco (Migrations & Développement)

Family coffee farmers improve mountain soils



Alberto Pascual

The production of shade-grown coffee is key to the conservation of mountain ecosystems. In Panama's Santa Fe National Park, coffee is a traditional crop and one of the main income sources for many family farmers who live in the protected park area and its surroundings. The cultivation of shade-grown coffee ensures environmental, policultural and agroforestal biodiversity, contributes to soil conservation and plays a crucial role in mitigating and adapting to climate change.

The landscape on one of the farms of small coffee producers shaded located in the buffer zone of the protected area (Alberto Pascual)

Located in the highlands of the Panamanian Central Cordillera in the Santa Fe district of Veraguas province, the 72 636 ha Santa Fe National Park has proven critical for conveying the need for investment in the conservation and sustainable management of natural resources. It belongs to the Mesoamerican Biological Corridor, a highly biodiverse region that encompasses seven Central American countries and Mexico. In addition, it contains a strategic water reservoir for the major human settlements of the country, and the water streaming from its watershed and the related rivers has great potential to generate hydropower. Thanks to the elevation and steepness that characterize the geomorphology of the park, all the springs of the major rivers originating within the protected area may potentially generate renewable energy.

The non-governmental organization (NGO) Fundación CoMunidad works with family farmers engaged in small-scale coffee production in the protected area and its surroundings. A buffer zone outside the natural park is a forested area with trees such as *Cedrela odorata* and *Cordia alliodora* up to 30 m high and an understorey with many fallen leaves. Hence, this area is a productive system with natural or significant spontaneous woody vegetation. These lands are suitable for the production of coffee, and their humid tropical climate also allows for the production of complementary crops such as citrus, beans and vegetables. With constant rain throughout the year and favourable soil features, the area also has good agricultural potential for various forest and fruit plantations.

The park has mountain ranges with narrow valleys and elevations ranging from 600 to 1 400 masl. Mountains slopes are steep, especially in the southern section of the Santa Fe National Park and its buffer zone, and soils are thin with good internal drainage. The predominant soils of this mountain region have a pH that tends to range from acidic (<6.5) to very acidic (4.5). This is because the rainfall has historically induced a strong phenomenon of nutrient leaching and soils are exposed to wind erosion and other atmospheric agents.

The work of family farmers engaged in shade-grown coffee generates multiple benefits due to the use of native species, soil conservation and improvement practices, reduced dependence on petrol and derivatives through agro-ecology, practice of polyculture and silvopastoralism, terraced coffee plantations and crop rotation. One of the salient features of the traditional farming systems is their high degree of biodiversity thanks to polyculture and agroforestry. Diversified systems support several ecosystem services such as soil carbon sequestration, regulation of the hydrological cycle, provision of habitat for natural pollinators and control of pests and diseases through natural enemies. All this, in turn, promotes dietary diversity and improves the long-term productivity of soils, even with low levels of technology and limited resources.

The techniques the family farmers have implemented for shade-grown coffee have reduced soil erosion and nutrient loss, while also respecting the ground cover, the trees and their extensive root systems which are key elements for agriculture to conserve and improve soils in mountains.

All components and joint actions of this project are framed and legitimized within the Management Plan of the Santa Fe National Park published in September 2014 by the Panamanian Ministry of the Environment which calls for:

- reducing the pressure on natural resources by promoting sustainable production techniques, restoring degraded areas, strengthening local capacities, income generation and use of native species, identifying crops that are suitable to the park's soil and overall improvement of livelihoods;
- promoting understanding and analysis of the human-environment interaction in the park and its buffer zone, with special emphasis on indigenous communities;
- promoting knowledge sharing on the biophysical, ecological and cultural features of the region;
- ensuring participative management of the park involving local communities, institutions, NGOs.

In this framework, Foundación Comunidad works with local producers to establish shade-grown coffee as a finished brand product. This has potential to open new markets, build public and private partnerships, and identify new strategic partners, always ensuring sustainable use of natural resources and soils conservation and improvement within the Santa Fe National Park and its buffer zone.


Coffee is one of the main source of income for peoples living in the central mountains of Panama (Alberto Pascual)


Sebastián Fernández, one of the thirty members of the association of coffee producers, prepares the next bag for the drying process (Alberto Pascual)

Thyme for Port-au-Prince

Peter Schmidt

Only 2 percent of the surface of disaster-prone Haiti is covered with forest. For more than a decade, the non-governmental organization (NGO) HELVETAS Swiss Intercooperation has engaged on behalf of the Swiss Agency for Development and Cooperation to protect Forêt des Pins, one of Haiti's few large tracts of forest located at the mountainous top of the island. It has supported farmers in the area through promoting production of crops for both family consumption and for markets – crops that do not put pressure on the area's fragile environment.

Due to the karst underground, water retention is among the key problems for agriculture in this area (HELVETAS Swiss Intercooperation/Flurina Rothenberg)

Forêt des Pins is located at an altitude from 1 500 to 2 500 masl on the top of an east-west passing ridge of Hispaniola. It forms part of the Caribbean Biological Corridor. Steep and erosion-prone slopes reach down to Haiti's south coast, and weather conditions are known for extreme precipitation and hurricanes. The high pressure on the land due to the area's rapidly growing population and its remoteness, combined with poor infrastructure and weak governance, makes it one of the world's most poverty-stricken spots. Soils are poor and water retention for both human consumption and agriculture is a key problem in the karst of the area.

In order to reduce the pressure on farmers to clear the little remaining forest in order to increase crop land, HELVETAS has encouraged in the buffer zone around the forest – among other interventions – the production of vegetables for family consumption and thyme for sale. Thyme is a crop well suited to fragile mountainous agro-ecosystem: it is perennial, covers the soil well, and is easy to transport, not too perishable, high value and – most important – demanded by the market as thyme is a traditional spice in the Haitian kitchen.

The promotion of vegetable and thyme production in Forêt des Pins is just one example of an intervention that fosters sustainable livelihoods in mountain areas because it responds to three fundamental needs: food, income and conservation of natural resources. HELVETAS began promoting thyme production in 2008, based on a market analysis, and today, about 1 000 of the most disadvantaged families in Haiti are involved. As in so many development interventions, there have been challenges. For example, because of presence of soil-borne diseases, producers have had to change the location of the perennial crop every couple of years. The farmers' tradition of growing thyme in rows required additional anti-erosion measures such as stone walls to protect the scarce soil.

Natural disasters, scarce resources, remotness and poor govenrance makes the Forêt des Pins poverty stricken area (HELVETAS Swiss Intercooperation/ Flurina Rothenberg)

Thyme cultivation is only one of many interventions to reduce the pressure on the forest and to protect its unique biodiversity. Compared with vegetable production, thyme cultivation is the most profitable activity. Farmers report that the income generated from the sale of thyme allows them to send their children to quality schools. There are primary schools in the Forêt des Pins area, but when it comes to secondary schools the families have to send their children to towns in the plains or even the capital, Port-au-Prince. Truly an investment in the future. And with the urban market demand, the students may enjoy the taste of thyme – perhaps from their parents' fields – in their food, even in Port-au-Prince.

Beles – from an invasive plant to a blessing

Peter Schmidt

The Beles SUNRise Project (BSP) in northern Ethiopia's Tigray region aims to improve food security and income generation by promoting the use of the beles cactus (*Opuntia ficus-indica*, also known as prickly pear). Once viewed as an invasive species, BSP has promoted the fact that it can be used for human consumption and animal feed as well as to improve soils, reduce disaster risks and contribute to climate change mitigation. Initiated as a "cactus initiative" in 2003, the project today operates in the Eastern Tigray Beles Belt including five districts with a total population of approximately 20 000. The project is funded and implemented by the Swiss development non-governmental organization (NGO) HELVETAS Swiss Intercooperation.

Beles (*Opuntia ficus-indica*) is an invasive plant growing in northern Ethiopia. Properly managed beles provides food to humans and livestock (HELVETAS Swiss Intercooperation)

The dry season is long around Mek'ele, the capital city of Tigray in Ethiopia, and rainfall is becoming increasingly scarce due to climate change. The landscape is a patchwork of greys and browns and, for many months, the beles cacti are the only spots of green.

The plant, which stores water during the rains for the long dry season ahead, was first introduced by Roman Catholic missionaries around 150 years ago and spread quickly, turning out to be invasive. In collaboration with an array of institutions from the state, research, private sector and civil society organizations, the BSP undertook to make better use of beles and through their efforts, beles is now cultivated for fencing and planted along contour lines to stop soil erosion. Its remains enrich the soil's organic matter content and consequently its water holding capacity, a vital characteristic of soils in semi-arid and arid areas such as Tigray. Astonishingly, in an area with chronic hunger, people did not consume the edible parts of the plant, even though its fruit and leaves can be used for human consumption as well as animal feed. Today women in Tigray prepare delicious side dishes and salads from the young leaves of the cactus.

The orchestrated interventions to make better use of beles is only one of the project's many contributions to comprehensive watershed management and improving livelihoods.

At household level, the overall goal of BSP is to promote economically viable family farms that are able to manage their natural resources in a sustainable way, to increase their food security and adapt to climate change.

Cut in time, beles leaves serve as welcome fodder for livestock (HELVETAS Swiss Intercooperation)

At community level, the project aims to contribute to the empowerment of rural communities through establishing watershed associations and community development funds. These can pave the way for future self-initiative and attract local government bodies and direct donor funding for the implementation of watershed development plans. Ultimately, this should enable communities to develop and manage their natural resources through community-induced initiatives and resources. Furthermore, it should restore community capacity and self-reliance to develop community-based safety nets that can look after disadvantaged and vulnerable households.

The project also focuses on the development, expansion and strengthening of beles cactus value chains including the potential of establishing a beles processing industry in Tigray for the local or regional markets. In collaboration with women's organizations, the project promotes beles dishes as a means of enhancing food security among target communities. As a result, beles has become a source of hope for many families in the remote and mountainous area of Tigray where it not only provides food and income, it also prevents soil erosion and improves soil fertility.

Today local women prepare side dishes and salads from the edible parts of beles (HELVETAS Swiss Intercooperation)

Crop-Nu – a phone app to calculate crop nutrient requirements

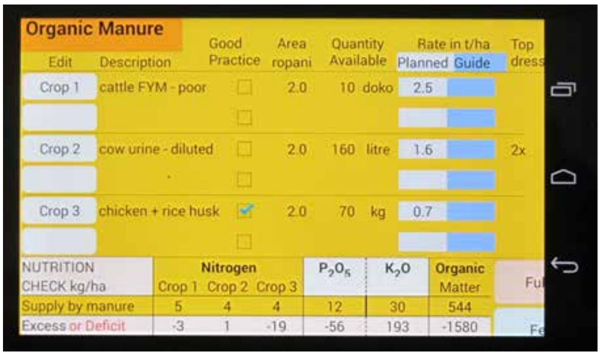
Bishnu Kumar Bishwakarma, Stephen Hemming, Richard Allen, Juerg Merz and Shiva Kumar Shrestha

Most Nepali farmers lack knowledge about the nutrient requirements of the crops they grow. HELVETAS Swiss Intercooperation in Nepal has developed a smartphone app, Crop-Nu, which calculates the soil nutrients required by any given crop in any given location in Nepal. The app recommends a variety of ways to apply the required nutrients, while maintaining or improving soil organic matter levels, soil fertility and productivity.

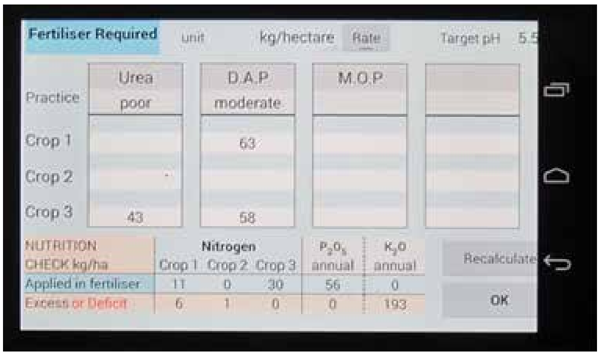
Two experienced HELVETAS field staff testing Crop-Nu for the first time,. Dhabaha village, Nawalparasi district, Nepal (Richard Allen).

Both small- and large-scale farmers in Nepal's highlands and lowlands have little knowledge of the nutrient requirements of the crops they grow or of the existing balance of nutrients in their soil. This means they also do not know whether they need to apply more or less fertilizer or recycled material for optimal yields. They often apply too much, too little or the wrong fertilizer and are unsure of how to adjust for the manures and other recycled materials that are applied. Even if productivity improves, the potential of higher yielding varieties is variable and often low throughout Nepal, where low levels of organic matter, nitrogen and phosphorus are commonplace. All of this was taken into consideration when developing the Crop-Nu smartphone app to help farmers make more informed soil management decisions.

Crop-Nu takes into account climate and location, current soil nutrient status (based on soil analysis when available or on the local experience of the operator), traditional conservation and green manure practices, all the crops to be grown in one year, the expected or desired crop yield, and inputs of both recycled materials and commercially available fertilizers. It then calculates the amounts of the major crop nutrients (nitrogen – N, phosphorus – P and potassium – K) and soil organic matter required for optimal growth, and provides a recommendation as to how much nutrient to apply to the soil, and in what form – either as additional organic matter or as commercial fertilizer.



The Crop-Nu screen showing the organic manure additions to each crop, with the excess or deficit nutrition check at the bottom of the screen (Richard Allen)



This is the final screen of Crop-Nu where, on the basis of the data entered, a recommendation is made for the additional soil nutrients that are required for optimal production (Richard Allen)

In addition, the app can answer many common questions: *e.g.* which land or crop requires further nutrient top-up, what rates of N-P-K fertilizer are actually needed to ensure no loss of production and no decline in soil fertility, and how can the use of organic manure be optimized to fulfil more of the crop's nutrient need, and maintain or increase soil organic matter levels? For example, a farmer in Dhobaha village who grew three crops on one parcel of land in a single year (spring maize, summer rice and winter wheat) only applied farmyard manure to one of the crops. Crop-Nu clearly showed her that the productivity on her land was low because all crops were not receiving sufficient N, P or K for optimal yields.

Crop-Nu, developed by Nepali programmers and based on Nepali conditions and research, builds on the comprehensive work of the HELVETAS Sustainable Soil Management Programme (1999-2014), which was funded by the Swiss Agency for Development and Cooperation to combat the decline in soil fertility and productivity in the mid-hills of Nepal, and develop an integrated plant nutrient management system for mid-hill farmers. Available in both English and Nepali, it is designed to be modified for use in other countries, in other languages, for many crops, and to be updated to include new research findings.

When the app development was completed at the end of 2014, field testing began in February 2015 in two communities in south Nepal's Nawalparasi district on a first version of Crop-Nu in Android app format, with encouraging results (see lessons learned, opposite). Farmers and field extension staff were very interested in Crop-Nu, took part enthusiastically in the tests, and identified and recommended areas that needed improvement. It is envisaged that a system will be developed to link the mobile phones on the farm to databases in relevant government departments and with private sector partners where the operators responsible can provide real-time advice and assistance to extension workers in the field.

Lessons learned

- Using Crop-Nu, it takes about 30 minutes to provide a recommendation to farmers and discuss options with them as to how to best fulfil the crop nutrient requirement for optimal yields and maintenance of soil fertility.
- The app works equally well for a single crop or a series of three crops to be grown on a single parcel of land over the cropping year, and for both small and large areas of land, providing that they are under the same cropping and management regimes.
- Crop-Nu reported sound results whether soil analysis results were available or not, and provided farmers with sensible recommendations in terms of soil nutrient applications, potential yields and management of soil fertility.

Testing Crop-Nu after training on sustainable soil management practices with farmers. Dhabaha village, Nawalparasi District, Nepal (Richard Allen).

Shivapuri is one of the main sources of drinking water for the densely populated Kathmandu, Nepal (@FAO/Giuseppe Bizzarri)

4

Soil variability in mountain areas

Llano del Leoncito with a view over Piedra Parada volcano, 3 600 masl. Provincia de Chañaral Atacama region, Chile (Jorge Carabantes Ahumada)

Ermanno Zanini, Michele Freppaz, Silvia Stanchi, Eleonora Bonifacio and Markus Egli

Soil variability in mountain areas

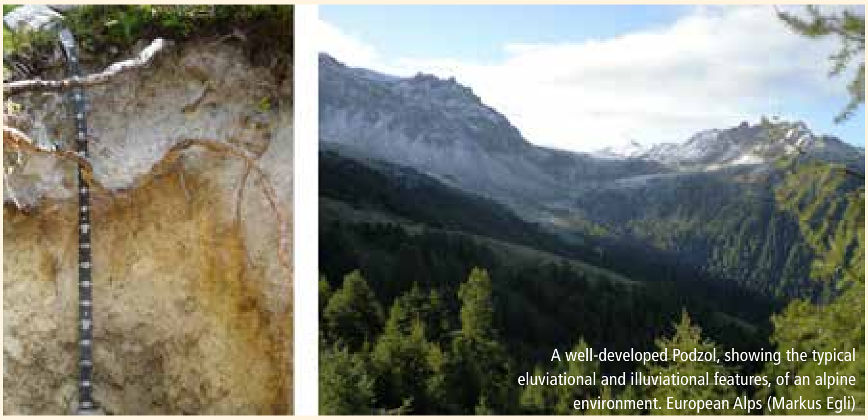
Farmers tilling soil for crops aiding post-conflict districts so they can begin growing crops again. Kirimetiyawa, Sri Lanka (@FAO/Ishara Kodikara)

The high spatial variability of soils is a relevant issue at local and global scales, and determines the complexity of soil ecosystem functions and services. This variability derives from strong dependencies of soil ecosystems on parent materials, climate, relief and biosphere, including human impact. Although present in all environments, the interactions of soils with these forming factors are particularly striking in mountain areas.

Principle patterns of soil distribution can be found in the work of natural scientists across the decades. Writing in 1899, Dokuchaev mentioned that spatial changes in moisture and temperature conditions (*i.e.* in climate) determine soil properties. This gave rise to the Laws of Horizontal Soil Zonality (for plain regions) and Vertical Soil Zonality (for mountain regions).

In mountain areas, altitude and relief strongly affect the soil's energy balance and, as a consequence, the soil temperature. These two variables influence snow cover duration and the amount of precipitation, which can for example differ between windward and leeward sites. The thermal conditions and availability of water in soils are the main drivers of chemical and physical weathering. The relief has additional impact due to geological uplift, the differing hardness of parent material and its resistance to erosion and weathering. Vegetation is linked to the prevailing climatic conditions, but also to the parent material as its composition determines which plant species can grow and, thus, indirectly influences soil development.

At alpine sites, the bare surfaces left by retreating glaciers offer the opportunity to observe early stages of soil development, which validates existing theories about ecosystem evolution and makes it possible to determine the speed of soil-forming processes. On silicatic parent material, chemical weathering, acidification and soil formation proceed very fast in mountainous areas due to the often relatively young surfaces and the availability of fresh mineral surfaces. With surface age, these rates usually decrease. In some cases, aeolian deposits may also be an important soil-forming factor in mountainous and alpine soil pedogenesis. In addition, wind-blown materials, such as carbonates, may contribute to reducing the acidity of soils.



A well-developed Podzol, showing the typical eluviational and illuviational features, of an alpine environment. European Alps (Markus Egli)

Often, soil morphology and properties cannot be related to surface age directly, because soils may exhibit progressive and regressive evolutional stages. At geomorphologically active sites, where erosion or accumulation are under way, soils are often polygenetic. Mountain soil development is often characterized by the redistribution of soil material along the slopes.

Soil can only persist at a given location if erosion does not remove it faster than it can be produced. Erosion leads to a rejuvenation of the soils and increases their weathering rates. This means that, to a certain extent, erosion and chemical weathering rates are positively correlated. Larsen *et al.* showed that, under undisturbed conditions, soil production enables even rapidly eroding landscapes to retain a cloak of soil. However, a delicate balance exists between soil production and erosion that may become very intense and endanger the persistence of fertile soil.

A Vertisol from the Iblei mountains in a Mediterranean environment. Sicily, Italy (Markus Egli)

Mountain soils are highly dynamic and sensitive systems that react to environmental changes such as climate change and intense land use. Human-induced erosion rates are, in some mountain areas, much beyond (maximum) soil production rates. Extensive erosion rates lead to rapid soil degradation and loss of areas for plant growth which, in turn, also negatively affects carbon sequestration.

The environmental and site variables have considerable effects on pedogenesis, organic matter input and its turnover, leading to soils that under undisturbed conditions are thick and anisotropic, and develop clearly distinct horizons. For example, at cooler sites or at sites with ample water (having anoxic conditions), the decomposition of organic materials may be hindered. As a consequence, the rate of biomass production is often greater than the rate of decomposition (plant and soil respiration). This results in a net accumulation of plant and animal remains which eventually causes paludification (*i.e.* waterlogging of terrestrial soils by organic materials) with the formation of histosols, which are characterized by thick organic horizons.

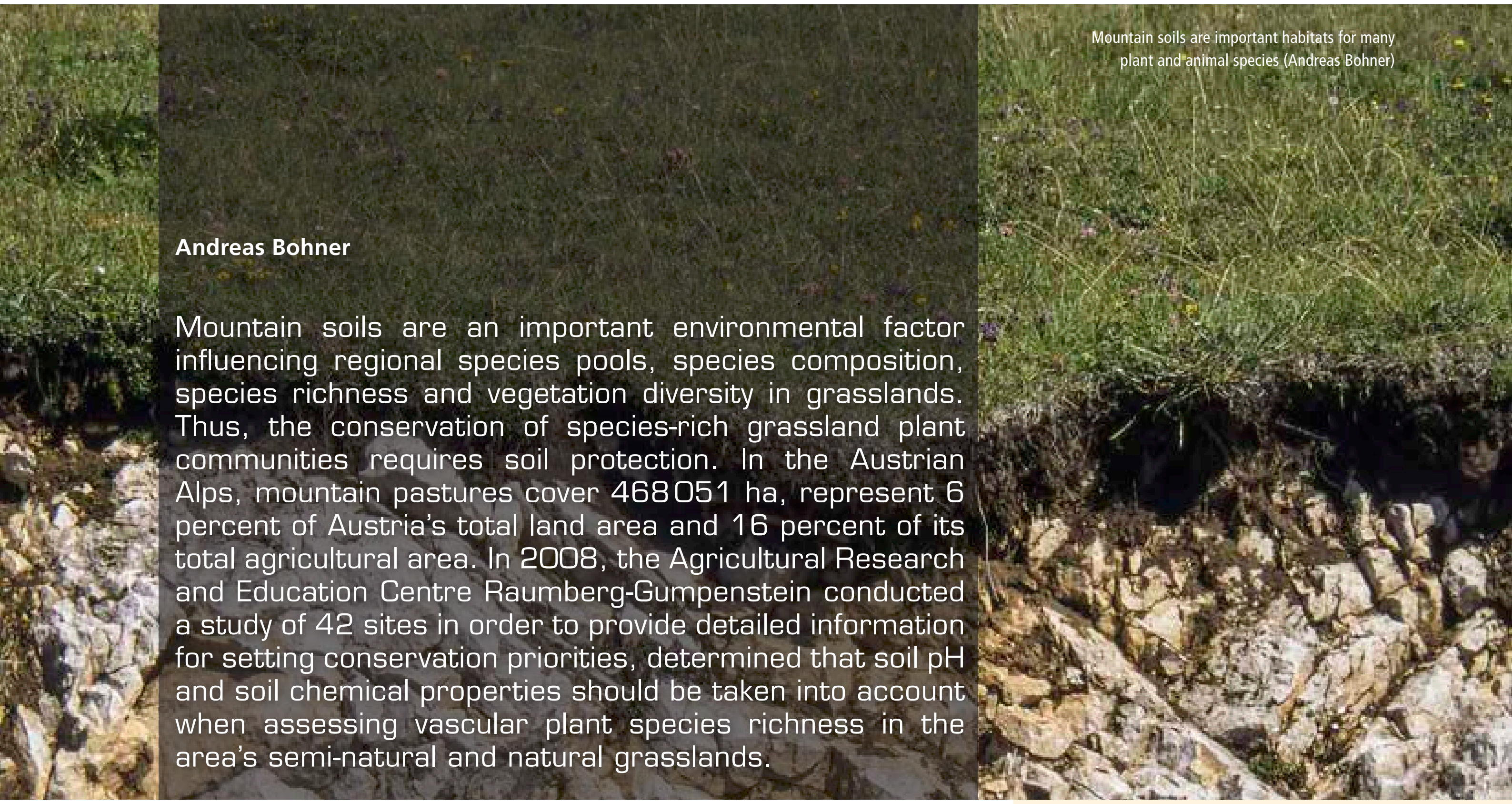
In cold areas dominated by siliceous rocks, on slopes with conifers or in the alpine dwarf-shrub zone, Podzols are quite widespread. Leptosols dominate at higher elevations in the alpine tundra while, at lower elevations, they only occur at geomorphically active sites (*e.g.* shallow landslides, snow avalanches) where erosion/accumulation and other disturbances inhibit further evolution. In these areas, buried soils, often truncated by erosion, are frequently overlain by younger soils developing on colluvium, debris flows and detrital slope deposits.

A soil (Calcisol) of an aridic mountain environment shwoing a substantial accumulation of secondary carbonates. Wind River Range, Wyoming, United States (Markus Egli)

The “catena” (chain) approach is a useful tool to detect common rules of soil development even in such diverse environments. The rugged and abruptly changing topography affects soil evolution in multiple ways, including the redistribution of the soil material along the slopes to valley floors. The exposure, for example, may have a tremendous effect on chemical weathering: north-facing slopes are often characterized by a higher element of leaching and consequently a higher weathering degree than south-facing slopes at the same elevation. At high altitudes, exposure and relief influence prevailing winds or snow distribution. This is the base concept of the “synthetic alpine slope model”, which suggests that soil development across an alpine slope is at least partially governed by the number of snow-free days per year which, in turn, affects soil temperature and moisture.

Although research at the regional level is needed, theories and experiences from elsewhere can greatly reduce efforts, as can modelling. However, transferring models and technology to field conditions can present serious difficulties, particularly in heterogeneous environments, and the effect of scale emerges as one of the main problems. Soil variability also means pedodiversity which is part of local and cultural heritage. This heritage includes the human impact which has widely and dramatically changed the soil cover. Now, with the knowledge of the origin, the significance and degree of soil variations in space and time, pedologists can contribute to support conservation of soil as a primary and nearly non-renewable resource. Because mountainous soils developed in a strongly dynamic landscape, are highly variable and react very sensitively to environmental change, they deserve particular protection.

Mountain pasture soils and plant species richness in the Austrian Alps



Mountain soils are important habitats for many plant and animal species (Andreas Bohner)

Andreas Bohner

Mountain soils are an important environmental factor influencing regional species pools, species composition, species richness and vegetation diversity in grasslands. Thus, the conservation of species-rich grassland plant communities requires soil protection. In the Austrian Alps, mountain pastures cover 468 051 ha, represent 6 percent of Austria's total land area and 16 percent of its total agricultural area. In 2008, the Agricultural Research and Education Centre Raumberg-Gumpenstein conducted a study of 42 sites in order to provide detailed information for setting conservation priorities, determined that soil pH and soil chemical properties should be taken into account when assessing vascular plant species richness in the area's semi-natural and natural grasslands.

Most of the mountain pastures of the Austrian Alps are lightly grazed by cattle, sheep, horses or goats. Depending on the type of landscape and altitude, grazing takes place from May to September. In general, mountain pastures receive no manure or mineral fertilizer other than from grazing animals. Most of the vegetation is considered semi-natural (below the climatic timberline) or natural (above the climatic timberline). With few exceptions, the direct human influence on soil is marginal. Consequently, soil development and processes in the soil system, including their impacts on the environment, can be studied under near-natural conditions.

The area offers many different rock types, mountain soils and associated grassland plant communities. The mountain soils Rendzina, Para-rendzina, Ranker and Cambisol are widespread and crucial components of the near-natural terrestrial ecosystems, providing important habitats for many plant and animal species, and water and nutrients for plants and soil organisms. Their chemical, physical and biological soil properties and processes usually regulate plant species composition and species richness in the terrestrial ecosystems. Biodiversity in the Austrian Alps is threatened primarily by habitat loss or degradation. Consequently, mountain soils play a central role in the conservation of biodiversity, including both diversity of species and habitat types.

In order to set priorities in nature conservation, protected area managers, conservationists, land-use planners and nature conservation authorities need more detailed information about the relationship between soil properties and floristic diversity in different ecosystems and landscapes. Therefore, the primary aim of this study was to investigate the importance of soil chemical properties in influencing plant species composition and species richness in semi-natural and natural


Para-rendzina (Andreas Bohner)

grasslands of the Austrian Alps. The altitude of the 42 carefully selected study sites ranged from 1 340 to 2 220 masl with negligible browsing by wild animals or human trampling, unfertilized mountain soils and lightly grazed grassland plant communities.

Soils. The studied soils were more or less completely covered by grassland vegetation, the proportion of bare ground was small (< 5 percent) and the soil moisture regime was generally well balanced or periodically moist in topsoil.

Plant communities. The studied grassland plant communities represented a vegetation and soil gradient from plant communities on very strongly acid soils to grasslands on slightly alkaline soils. Only vascular plants were taken into consideration. To determine vascular plant species richness (species density), the total number of vascular plant species within a homogeneous investigation area of 50 m² was recorded.

At each site, soil samples were collected from the 0-10 cm soil layer. The pH of air-dried soil samples was measured in a calcium chloride ($CaCl_2$) solution. Regression analysis was used to describe the relationship between vascular plant species richness and soil pH. Across all sites investigated, species richness varied between 16 and 96 vascular plant species per 50 m², and soil pH ranged from 3.4 to 7.6.

Grassland plant communities on mountain soils derived from calcareous mica schist (Para-rendzinas) have the greatest floristic diversity. This grassland represents a biodiversity hotspot in the Austrian Alps. Surprisingly, there was no relationship between floristic diversity and altitude, and the sampling sites differed only marginally in the intensity of grazing. In the studied vegetation types, vascular plant species richness was mainly affected by soil pH. Figure 1 illustrates a hump-shaped relationship between floristic diversity and soil pH.

Nutrient-poor plant habitats are potentially rich in plant species if the mountain soils are moderately acid (pH 5.0-6.2). They are particularly poor in plant species if the mountain soils are very strongly acid (pH < 4.2). Under these conditions only a few calcifuge plant species are able to survive, forming a species-poor acidophilic grassland plant community. On moderately acid soils, especially on Para-rendzinas, both calcicole and calcifuge plant species can be present. This coexistence promotes floristic diversity and is primarily responsible for the peak in species richness in this pH range.

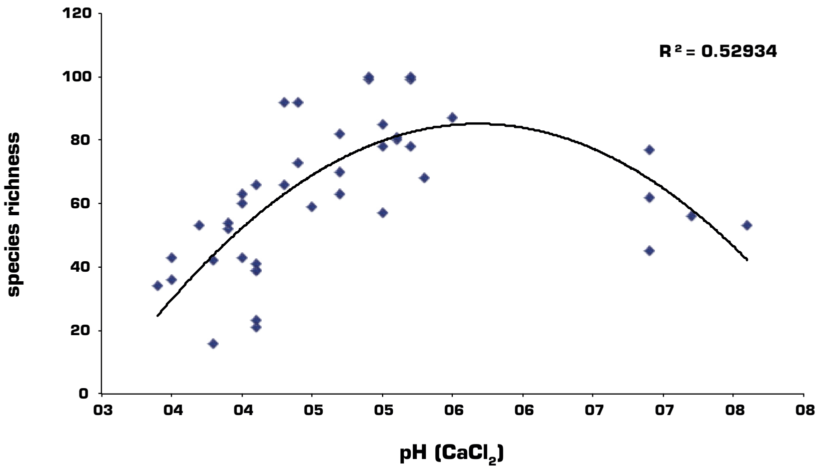


Figure 1: Relationship between vascular plant species richness (total number of vascular plant species within an investigation area of 50 m²) and soil pH (pH $CaCl_2$) in topsoil (0-10 cm)

Lessons learned

- The results of this study indicate that soil pH and the pH-dependent soil chemical properties have a major influence on vascular plant species richness and species composition in semi-natural and natural grassland communities of the Austrian Alps.
- They strongly influence the distribution of plant species and plant communities throughout the Alps. Moreover, they govern the size of regional species pools.

Major soil types in grasslands of the Austrian Alps according to the Austrian soil classification system

In the Austrian Alps, the following soil types are common and widespread.

Rendzinas

A single, dark-coloured, humus-rich soil horizon – the humus layer – overlies the calcareous bedrock, mainly limestone or dolomite. These shallow soils, which usually contain appreciable amounts of carbonates, are calcareous soils.

Rankers

A single, dark-coloured, humus-rich soil horizon overlies the non-calcareous bedrock, frequently composed of sandstone, mica schist, phyllite, gneiss or granite. These shallow soils are carbonate-free.

Para-rendzinas

Similar to Rendzinas or Rankers, a single, dark-coloured humus layer has been developed. In contrast, the parent material of Para-rendzinas mainly consists of marl or calcareous sandstone, mica schist or phyllite. Various unconsolidated sediments, composed of both calcareous and non-calcareous fragments, also serve as parent material. The humus layer usually contains carbonates. Soil depth varies from shallow (< 30 cm) to deep (> 70 cm).

Cambisols

These soils are characterized by their well-developed brown soil layer. Soil parent material is quite variable, though different types of non-calcareous rocks or various unconsolidated sediments usually dominate. Generally, the soil is carbonate-free, at least in the root zone. Soil depth varies from shallow (< 30 cm) to deep (> 70 cm).

Cambisol (Andreas Bohner)

Basophilic grassland communities dominated by calcicole species on calcareous soils with pH values above 6.2 are generally richer in species than acidophilic grassland communities dominated by calcifuge species on very strongly acid soils. This can be explained by differences in the species pool sizes at high and low pH values. Comparatively more plant species can inhabit calcareous soils, while a markedly smaller number of species tolerate strongly acid soils. Soil acidification is therefore a serious threat to vascular plant species richness in semi-natural and natural grasslands of the Alps.

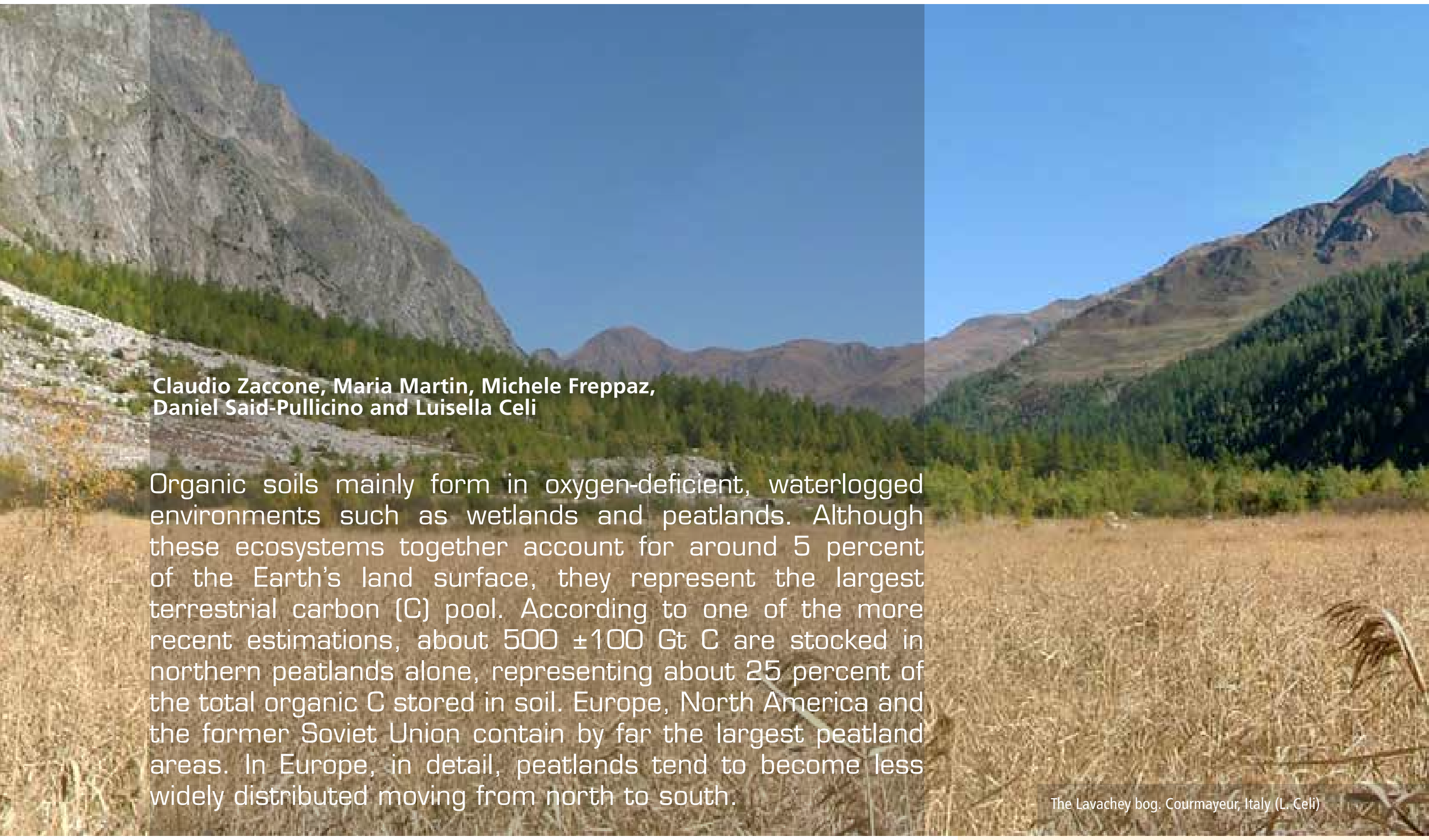
Soil pH

The pH values (measured in a $CaCl_2$ solution) of mountain grassland soils in the Austrian Alps usually range from 3.0 to 7.5 in topsoil (0-10 cm soil depth). In humid mountain regions, soil pH is primarily determined by the parent material, Calcareous soils, especially Rendzinas, generally have high pH values (pH > 6.2), whereas carbonate-free soils such as Rankers or Cambisols frequently have low pH values. Soil pH affects a number of soil properties and processes. In semi-natural and natural grasslands, soil pH largely controls the supply of soil nutrients and potentially toxic elements (e.g. aluminium – Al) to plants. Therefore, soil pH in the main root zone (0–10 cm soil depth) is an important soil parameter influencing plant growth, distribution of plant species, species composition and species richness in grasslands. Both very strongly acid soils with pH values below 4.2 and calcareous soils with pH values above 6.2 represent stressful habitats to plants, mainly caused by an unbalanced soil nutrient supply and/or by high levels of potentially toxic elements. On the other hand, moderately acid soils (pH[2] 6.2–5.0) are characterized by a balanced soil nutrient supply to plants. These soils represent favourable habitats for many plant species. There are no constraints on plant growth due to unfavourable soil chemical conditions.

Plants' pH preferences

Plants have specific soil pH requirements. They exhibit differences in tolerance to soil acidity and alkalinity. Calcicole plant species grow mainly or exclusively on calcareous soils such as Rendzinas. They are adapted to the disharmonic nutrient supply in these soils. If a mountain soil is calcareous and soil pH in the root zone is higher than 6.2, the basophilic grassland plant community is usually dominated by calcicole species. On the other hand, calcifuge plant species are restricted to strongly acid soils such as Rankers or carbonate-free Cambisols. They are adapted to the prevailing nutrient and acid stress in these soils. Under such conditions, especially if soil pH in the root zone is lower than 4.2, calcifuge species dominate and form an acidophilic grassland plant community. The acid-tolerant calcifuge species never occur on calcareous soils (Rendzinas). However, they are not absent in the Calcareous Alps, but within this region they inhabit exclusively deep, carbonate-free, acid Cambisols. Few vascular plant species can grow on both calcareous and carbonate-free, strongly acid soils.

Peatlands and organic soils



Claudio Zaccone, Maria Martin, Michele Freppaz, Daniel Said-Pullicino and Luisella Celi

Organic soils mainly form in oxygen-deficient, waterlogged environments such as wetlands and peatlands. Although these ecosystems together account for around 5 percent of the Earth's land surface, they represent the largest terrestrial carbon (C) pool. According to one of the more recent estimations, about 500 ±100 Gt C are stocked in northern peatlands alone, representing about 25 percent of the total organic C stored in soil. Europe, North America and the former Soviet Union contain by far the largest peatland areas. In Europe, in detail, peatlands tend to become less widely distributed moving from north to south.

The Lavachey bog, Courmayeur, Italy (L. Celi)

Organic soils may form in shallow open waters (*e.g.* lakes, ponds), poorly drained soils with high water tables, and imperfectly drained soils located in areas characterized by high precipitations, low evapotranspiration and cool temperatures. In mountain areas, peatlands occur where different soil morphologies ensure the presence of water, such as at the bottom of alluvial valleys, on flat summits and plateaux, close to springs, but also along slopes on seepage sites. In these sites, generally anoxic and acidic conditions hinder the decomposition of organic materials, hence the rate of biomass production is greater than the rate of decomposition. This results in a net accumulation of plant and animal remains eventually causing terrestrialization (*i.e.* the filling of shallow lakes by limnic sediments and vegetation) and paludification (*i.e.* the waterlogging of terrestrial soils by organic materials).

Terminology in peatland literature is particularly challenging. Investigators from different countries have developed distinct sets of terminology throughout the twentieth century to describe the peatlands of their respective areas. Often, a naming convention developed in one area did not adequately differentiate the peatland characteristics in other areas, and new names or redefinition of old names often occurred. In general, however, the terms "bog" and "fen" are the most commonly used to describe different types of peatlands. Bogs and fens can be thought of as describing a continuum of peatlands, rather than two distinct, separate groupings. In this continuum, the variables of vegetation (*sphagnum* vs sedge dominated), chemistry (acidic vs circum-neutral) and source of water (rainfall vs ground- and surface water) differ along gradients. These three variables have been the ones most often used by scientists to differentiate peatlands along the bog-to-fen continuum.

An example of Sphagnum peat core collected using a Wardenaar corer (C. Zaccone)

A peat bog. Danta di Cadore, Italy (C. Zaccone)

Peatlands show great variability depending on climate, topography, hydrology and geology. The same occurs for peat. Peat is a blond to black organic material (<25 percent by weight mineral matter) formed under waterlogged conditions from the partial decomposition of mosses and other bryophytes, sedges, grasses, shrubs, and/or trees. The structure of peat ranges from fibric to sapric, and the relative proportions of carbon (C), nitrogen (N), hydrogen (H), and oxygen (O) vary, depending upon the botanical composition and degree of decomposition. Typical abundances (moisture and ash free) are in the range 40-60 percent C, 0.3-2.0 percent N, and 5-6 percent H. *In situ*, peat may sum up 90-95 percent water by weight, rendering peatlands a unique kind of natural organic-rich water system.

In their natural, undisturbed state, peatlands support a unique biodiversity and regulate the flow and storage of water over areas that often extend well beyond the peatlands themselves. Although highly scattered in the mountain landscape, and normally limited to small areas, these ecosystems often control the nutrient status of drainage water with important implications on water quality at the catchment level. In fact, the waterlogging conditions also induce drastic changes in the cycling of several elements, such as iron and manganese. The formation of iron-organic complexes may involve the accumulation of highly reactive phases which can promptly undergo dissolution/precipitation cycles following seasonal changes in depth and duration of the flooding, snow coverage, and temperature. The dissolution or precipitation of these iron-organic phases drive, in turn, the solubility of other organic and inorganic compounds, with sudden, drastic changes of their concentration, supplying or subtracting substrates for micro-organisms, nutrients for plants, or xenobiotic, and thus contributing to determine the unicity of these systems, both in physical, chemical and biological terms.

Peatlands generally represent a net sink of atmospheric carbon dioxide (CO_2) but a net source of methane (CH_4). Although the role of peatlands in affecting climate change is widely recognized, there is however still a poor understanding of C dynamics in these ecosystems and across timescales.

Discussing only the spatial extent and variability of wetlands, in general, and peatlands, in particular, misses a very important point, *i.e.* the depth, that is the third dimension of these organic soils. In fact, for at least two centuries, ombrotrophic peat bogs have been recognized as excellent archives of the past. Rennie, for example, interpreted stratigraphic changes in Scottish bogs not only in terms of natural changes in palaeoclimate, but was also able to identify environmental changes induced by humans. The use of bogs as archives of climate change in the early twentieth century was accelerated by studies of fossil plant remains, and by systematic investigations of pollen grains pioneered by von Post in Sweden. In Denmark, Glob outlined the remarkably well-preserved remains of bog bodies. In Britain, Godwin provided an introduction to the use of bogs as archives of human history, vegetation change and Holocene climate. The characterization of peat bogs near glacier tongues in the Alps, for example, has contributed to the comprehension of changes in the climate of the past and the reconstruction of the sequence of past glacier advances.

In conclusion, organic soils in general, and peatlands in particular, are of paramount importance not only because they are unique ecosystems (in terms of landscape and wildlife habitat), but also because they perform other functions more related to economic (peat as fuel and horticultural medium), environmental (peat as C sink) and sociocultural (peat as archive of the past) aspects. At the same time, managing such conflicting values is not easy and often becomes a political and economic debate rather than a scientific and environmental issue. Finally, these organic soils are also particularly fragile, which makes their recovery from disturbances (like drainages, exploitations), when possible, extremely long.

Etang de la Gruère bog. Jura Mountains, Switzerland (C. Zaccone)

High-elevation soils in the Central Apennines

Giuseppe Corti, Stefania Cocco and Alberto Agnelli

As a consequence of the climate change responsible for the end of Würm, the last glaciation period that lasted from 110 000 to 9 000 years ago, most of the glaciers disappeared, leaving a surface that slowly transformed into proglacial or periglacial landscapes. Proglacial areas, which start from the margin of a glacier and extend until freezing/thawing cycles, are few, as the soil temperature regime is gelic. Periglacial areas are those characterized by numerous and intense freezing/thawing cycles that are able to produce drastic modifications of soil surface and soil horizons' turbation, and where the mean annual air temperature is usually less than +2 °C and snow-cover is scarce.

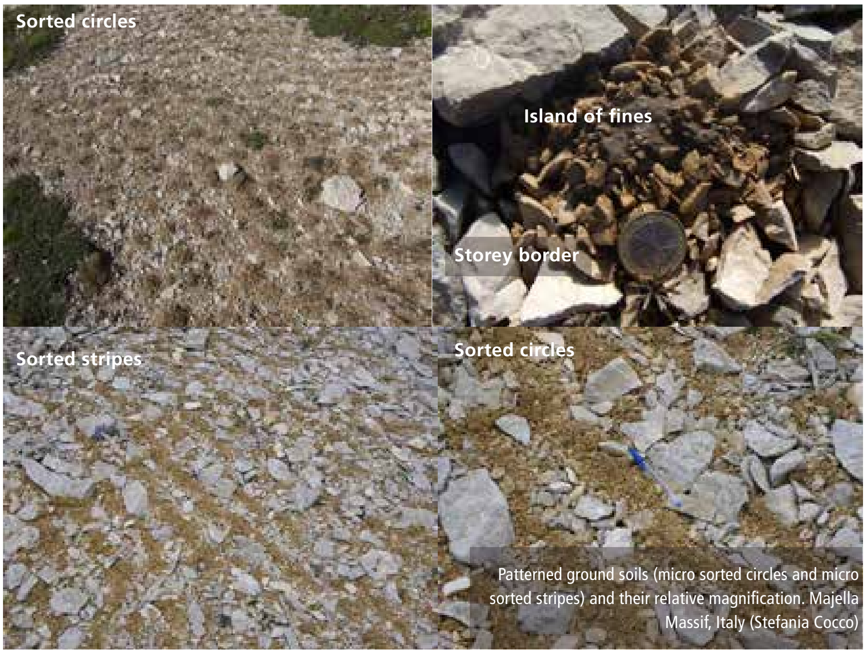
A U-valley with the bottom dotted by kettle holes. Cannella Valley, Majella Massif, Italy (Stefania Cocco)

During the twentieth century, the Earth's surface temperature increased about 0.74 °C, and a further increase of 4 °C has been projected for the twenty-first century. In this situation, the low-latitude ecosystems under periglacial conditions – which occupy restricted niches such as the mountain tops and may host discontinuous, sporadic or isolated permafrost – represent threatened environments of particular interest. Where a sporadic or isolated permafrost is present, the soil might not have sufficient thermal inertia to overcome the expected climate change, and the soil thermal regime warming could induce permafrost melting. Later on, the soils should evolve according to the newly acquired soil thermal and moisture regimes. Because of this, the landscapes at low latitude and their soils represent a sensitive proxy for the climatic warming.

Generally, periglacial landscapes have a rather complicated geomorphology with features of three types: (i) those inherited from the past glacial periods (*e.g.* glacial amphitheatres, U-valleys, roches moutonnées, moraines, eskers, kames); (ii) those formed during the receding of the glaciers (kettle holes and rock glaciers); (iii) those due to the freezing/thawing cycles, such as stone fields, patterned ground (sorted circles, sorted stripes, labyrinths), flagstones with biological zonation, mires with or without organic soils (Histosols). To complicate the landscape interpretation, the features of the first two groups could have been more or less modified following the new climatic conditions.

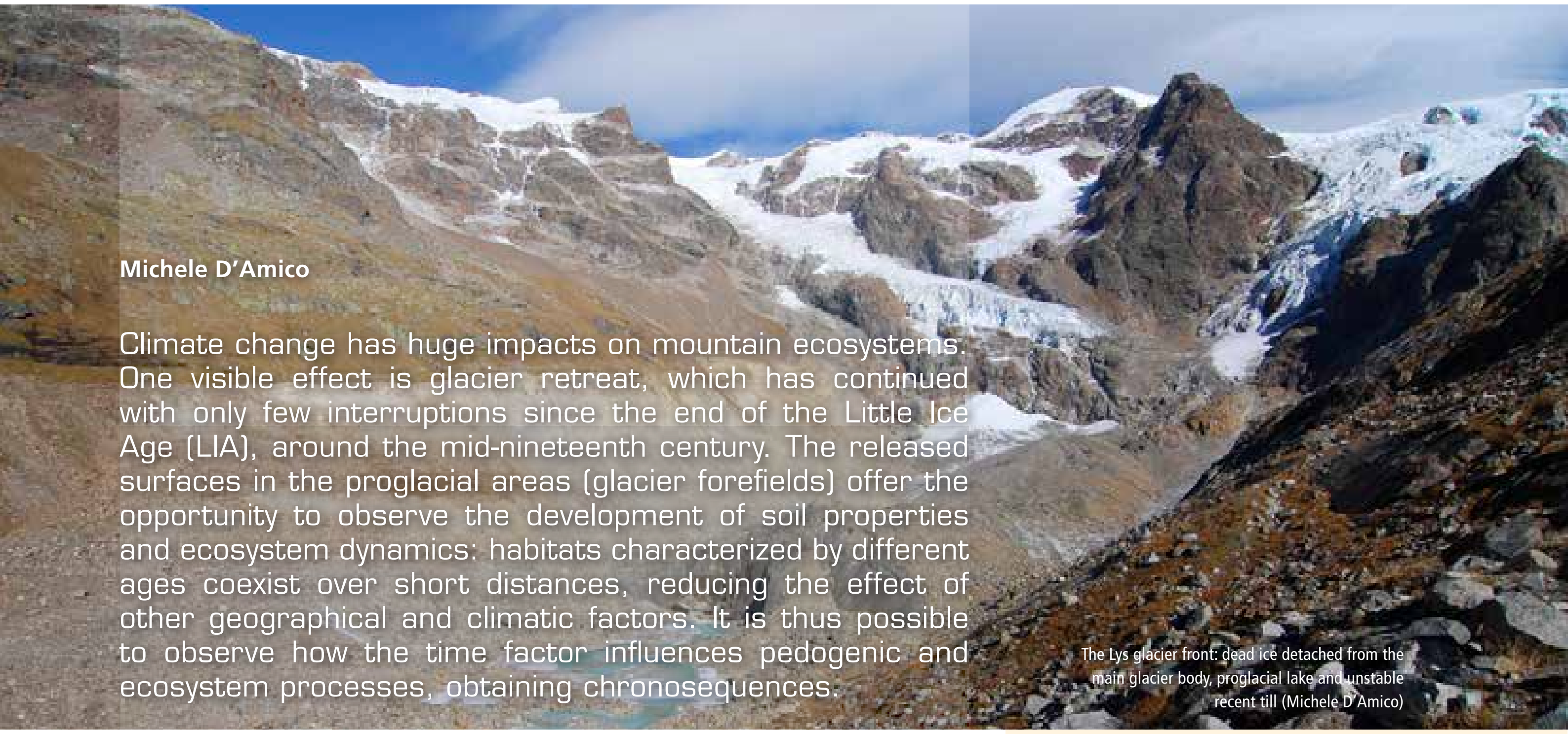
All these features are visible on the Majella massif (maximum height: 2 793 masl), which is part of the Central Apennines in Italy's Abruzzo region. The massif has a calcareous composition (limestone, dolostone, coralline limestone) and, at high elevations, shows the presence of several wide plateaux that are often covered by a thick (1–3 m) mantle of debris (glacial till). The most prominent soils on the plateaux are those with a patterned ground surface of either micro-sorted circles or micro-sorted stripes. These patterns result from cryo-selection of the skeletal particles, following freezing/thawing cycles of the water present in the saturated soil, and occur on moderate to null slopes with scarce vegetation and a sufficient amount of fines (earthy material made of particles with diameter less than 3, 4, or even 5 mm). If all these conditions are present, stones are pushed out and aside from the freezing area, so producing roughly segregated sorted circles (islands of fines surrounded by stony borders) and sorted stripes (alternated bands of rock fragments and fine earth).

Other particular soils present in the high elevated valleys of the Majella massif are those developed inside the kettle holes, which are shallow sediment-filled depressions formed by retreating glaciers. The kettle holes on the Majella massif, formed at the end of the Würm glaciation, are smaller and shallower than those reported elsewhere in the Northern Hemisphere, and do not contain bogs or lakes. These depressions are very effective as sediment traps and acted as sinks for materials washed in from the surrounding slopes or from more distant sources. Because of this, pedogenesis inside the kettle holes acted on a material much finer than the debris covering the plateaux, where drainage is from moderate to poor. Thus the main properties of the resulting soil horizons are mostly inherited from the amassed materials. The soils' main pedogenic process was the incorporation of organic matter that, as expected from the rather cold climatic conditions, was subjected to slow dynamics, as also indicated by the low ratio between humic C and total organic C. In the kettle holes of the Majella massif, some horizons developed from layers rich in volcanic material that was wind-blown from the volcanic complexes of Campi Flegrei (near Naples, about 140 km away from the massif). In these horizons, owing to the scarce presence of humic substances, the formation of short-range order minerals (allophane) occurred. As these soils also contain fragments of woody charcoal, the kettle holes pedons are a repository of geomorphic, pedogenic and palaeo-environmental information.



Patterned ground soils (micro sorted circles and micro sorted stripes) and their relative magnification. Majella Massif, Italy (Stefania Cocco)

Soil genesis in recently deglaciated areas



Michele D'Amico

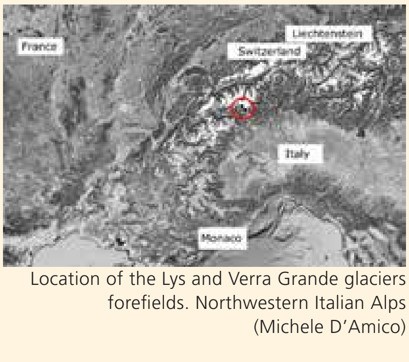
Climate change has huge impacts on mountain ecosystems. One visible effect is glacier retreat, which has continued with only few interruptions since the end of the Little Ice Age (LIA), around the mid-nineteenth century. The released surfaces in the proglacial areas (glacier forefields) offer the opportunity to observe the development of soil properties and ecosystem dynamics: habitats characterized by different ages coexist over short distances, reducing the effect of other geographical and climatic factors. It is thus possible to observe how the time factor influences pedogenic and ecosystem processes, obtaining chronosequences.

The Lys glacier front: dead ice detached from the main glacier body, proglacial lake and unstable recent till (Michele D'Amico)

After deglaciation, the till is attacked by many processes, such as loss of soluble compounds, acidification, weathering of primary minerals. They are enhanced after the onset of colonization by pioneer plants, when accumulation of organic matter initiates the differentiation in horizons characterized by different chemical and morphological properties.

The chemistry and mineralogy of the till and the phytoclimatic belt influence the development of soils and the associated ecosystem, while temperature and rainfall influence the speed of this development. In general, Podzols are the climax soils on sialic materials under subalpine vegetation, while Cambisols develop below other vegetation types. More humid climates favour quicker pedogenesis and plant community turnover. For example, in perhumid coastal Alaska high rainfall leads to the formation of weakly developed E and Bs horizons after only 70 years, and "real" Podzols after 230 years. Here, E horizons immediately appear after the establishment of spruce. In the Alps, Dystric Cambisols are normally found on 250–300-year-old surfaces, while more than 1 300-3 000 years are needed for the development of Podzols. However 500 years were calculated on stable slopes.

The Lys and Verra Grande forefields, located in contiguous valleys in the Monte Rosa massif, in the northwest Italian Alps, clearly exemplify the effect of parent material on soil development and vegetation succession. The Lys glacier forefield has a sialic till, dominated by gneiss, while the Verra Grande forefield is dominated by serpentinite, which represents more than 90 percent of the material in the eastern part of the forefield and the 100 percent in the western one. The effect of different vegetations on pedogenic trends and chemical properties development is also visible: in the Lys forefield, parts of the morainic system are colonized by subalpine forests, while others are covered by anthropogenic pastures or alpine grasslands above the timberline. The retreat of both glaciers started in 1821, but increased only after around 1860, with minor advances in 1922 and 1985.



Location of the Lys and Verra Grande glaciers forefields. Northwestern Italian Alps (Michele D'Amico)

The Lys glacier forefield, well colonized by subalpine larch forest, with a portion above timberline (Michele D'Amico)

Initial soils have near-neutral pH values, thanks to the abundance of freshly ground, highly reactive primary minerals. After the onset of vegetation, acidification proceeds quickly, together with the accumulation of organic matter. Base status was reduced to below 50 percent in more than 65 years.

Under grassland, organic matter accumulation in the soil surface leads to the formation of A horizons, with a maximum thickness and organic carbon content in 260- and 130-year-old soils, respectively above and below the timberline, while weathering in subsurface horizons led to the formation of cambic Bw in the same time frame. Well-developed pre-LIA soils were characterized by thick and well-developed brown Bw horizon with strongly acidic pH values (Dystric Cambisols (Humic)).

According to the World Reference Base (WRB) the soils up to 65 years in the forefield were classified as Skeletic Eutric Regosols. For the development of Dystric Cambisols under subalpine anthropogenic grassland, 190 years were necessary, whereas 260 years were needed in the less favourable environment above the timberline.

The soil changes were associated with vegetation succession: Skeletic Eutric Regosols supported a pioneer community rich in basophilous species, which tended to disappear below Skeletic Dystric Regosols. Quasi-climax grassland dominated by *Carex curvula*, *Nardus stricta* or *Festuca varia* colonized mature Dystric Cambisols.

Below timberline, where the grazing pressure is low, subalpine larch (*Larix decidua*) forests with *Rhododendron ferrugineum* colonize the moraines in around 60 years. After the establishment of subalpine forest, pedogenesis increases greatly in speed and radically changes direction: thin bleached E horizons appear in 90-year-old soils, evidencing an initial podzolization. Morphological and chemical data verify the incipient translocation of iron (Fe) and aluminium (Al) towards weakly developed Bs horizons. The calculation of chronofunction for Fe and Al translocation showed that around 500 years are necessary for the formation of Haplic Podzols. The soils under subalpine forest on the LIA materials were classified as Skeletic Dystric Regosols, while "climax" soils were Ortsteinic Podzols (Skeletic), developed on late glacial moraines.

The Verra Grande forefield, with the bare western lateral moraines and the eastern ones colonized by pioneer grassland (Michele D'Amico)

Despite the short distance from the Lys forefield, the Verra Grande forefield has a very different appearance. The western part of the LIA moraine system is almost devoid of vegetation: only a few trees and shrubs grow on bare soil. The eastern part is more vegetated, but the ground is covered by pioneer grassland species, with only a few scattered larch trees. Only limited flat and particularly stable surfaces have larch forests. The typical subalpine vegetation is developed on older surfaces.

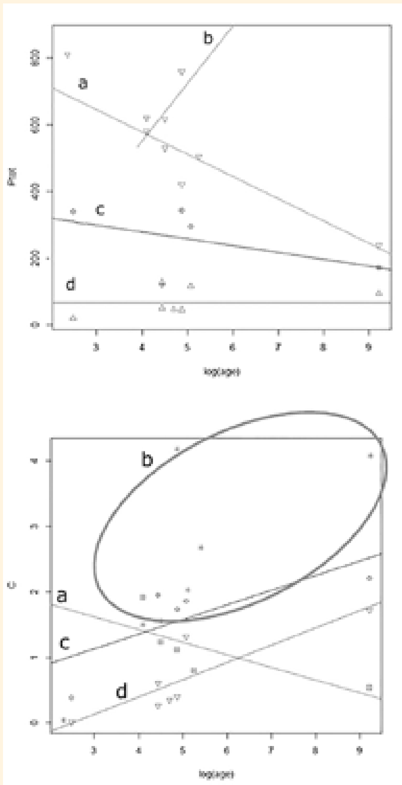
This great difference is due to the pure serpentinitic substrate on the western moraines and to small gneiss inclusions in the eastern ones. Typically, plant productivity is limited by high magnesium (Mg), low phosphorus (P) and by high heavy metal contents on serpentinite (the so called "serpentine syndrome").

The slow vegetation succession is tightly linked to the slow pedogenesis: soils younger than 190 years are classified as Skeletic Eutric Regosols, even if thicker and darker A horizons are developed on the eastern moraines. Soils developed on older Holocene materials are Podzols on the eastern moraines, Dystric Cambisols on the western ones.

Thus, a quicker pedogenesis can be observed where a small amount of gneiss is included in the serpentinitic till compared with where serpentinite is pure, but soil development and vegetation succession are much slower than on more "favourable" lithologies, in the Lys glacier forefield.

A complex net of mutual feedback relationships between chemical properties of parent materials, plant succession, speed and direction of pedogenesis can be observed on terrains released by melting glaciers since the end of the LIA. From the two former examples, it is possible to outline the following general rules on the main drivers of early pedogenic processes and speed:

- Initial chemical properties and nutrients of the unweathered substrate influence the speed of colonization by pioneer vegetation.
- Different early vegetation cover influences organic matter accumulation, soil acidification and leaching.
- Grassland soils tend towards Cambisols, forest soils towards Podzols.



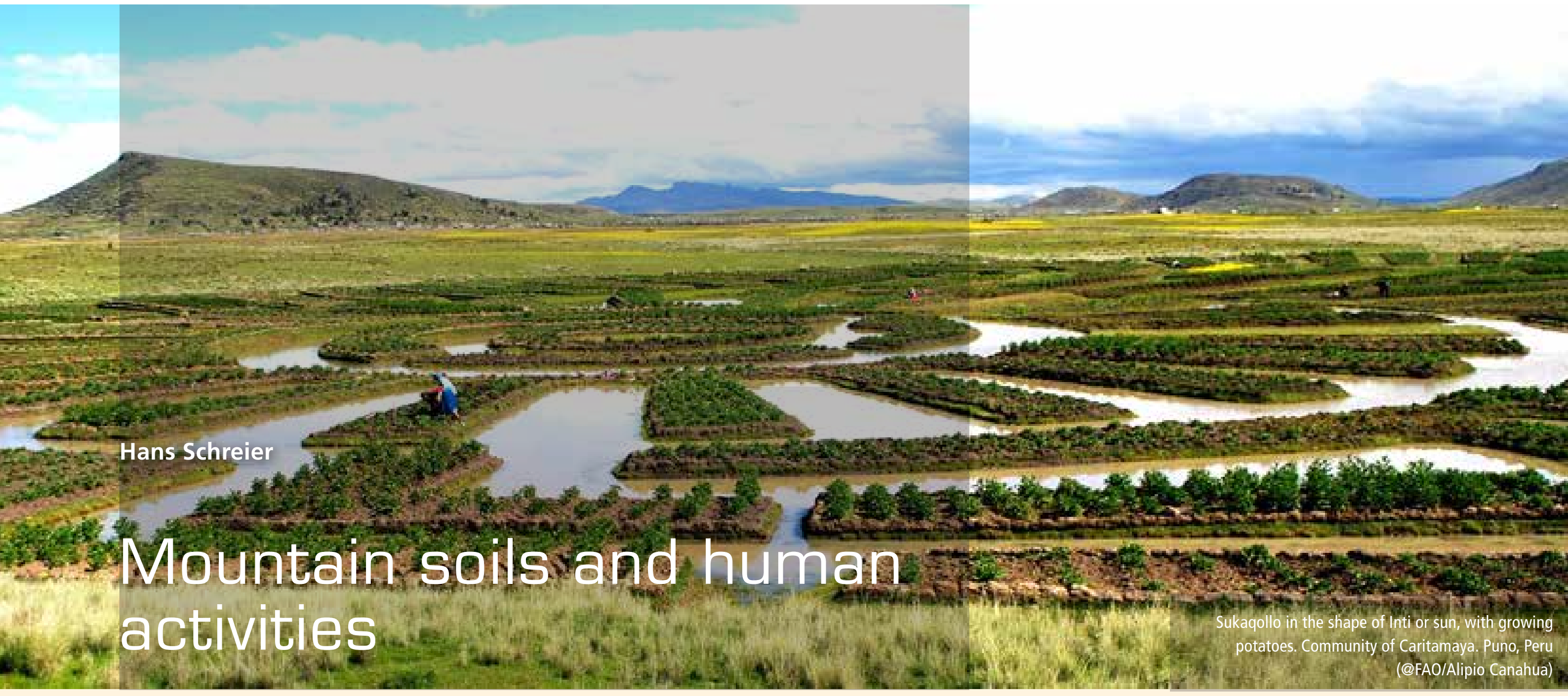
Total phosphorus and organic carbon contents in the soils developed on LIA moraines on gneiss, (a) under forest vegetation, (b) on gneiss under grassland, (c) on serpentinite with small gneiss inclusions, (d) on pure serpentinite. The age is log-transformed to better show the trends over time

- This different acidification induces a different speed in species turnover, slowing down or accelerating the entrance of subalpine *Ericaceae* and conifers (*Pinophytae*) which are associated with the onset of podzolization.
- Human activities, such as grazing, induce variations in plant succession which are correlated with variations in pedogenic trends and in the chemical development of soils.
- On harsh substrates (*e.g.* serpentinite), small inclusions of other rocks can dramatically improve the initial conditions by adding small quantities of nutrients, favouring quicker plant colonization.
- The small initial variations influence the pedogenesis throughout the soil development, soils around 11 000 years old are Podzols on slightly "richer" substrates, and weakly developed Dystric Cambisols on pure serpentinite.

5

Mountain soils and human activities

Grazing in Quebrada de Paipote, Atacama region, Chile (Corporación Nacional Forestal Region de Atacama)



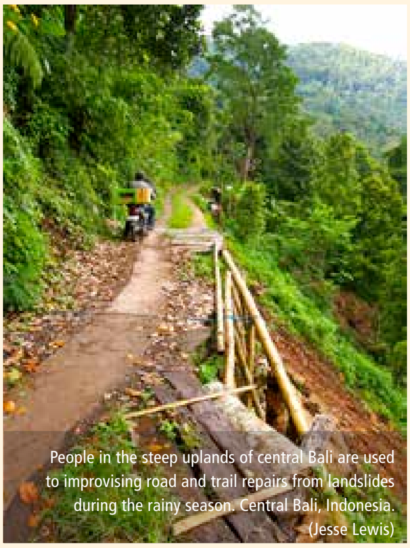
Sukaqollo in the shape of Inti or sun, with growing potatoes. Community of Caritamaya. Puno, Peru (©FAO/Alipio Canahua)

Hans Schreier

Mountain soils and human activities

Soils of the mountains serve as sentinels of the effects of land-use activities. Mountain soils have inherited very diverse mineralogical and chemical properties due to the great variety of geological formations that underpin the backbones of mountains. Because these soils develop under harsh climatic conditions, they develop slowly, are highly fragile and are considered pedologically youthful. Disturbances and degradation due to natural processes such as climatic events and fires are common, leading to land instability, soil loss by erosion, sediment transport and flooding.

Human activities have greatly accelerated the degradation processes that became evident during the Greek and Roman periods, when people accessed mountains to exploit forest resources to use for ocean shipping, construction and the industrial development of those days. This led to widespread soil erosion and, in many areas, the natural redevelopment of soils has remained insufficient to restore the productive capacity since that time. Today, human impact on mountain soils continues, with land-use activities, resource exploration and tourism contributing to, and often accelerating, these degradation processes. This is especially the case when accompanied by development of transportation infrastructure such as road construction which disturbs the natural slopes and can greatly change the hydrological regime, creating more concentrated surface runoff and resulting in accelerated landslide activities and soil erosion.



People in the steep uplands of central Bali are used to improvising road and trail repairs from landslides during the rainy season. Central Bali, Indonesia. (Jesse Lewis)

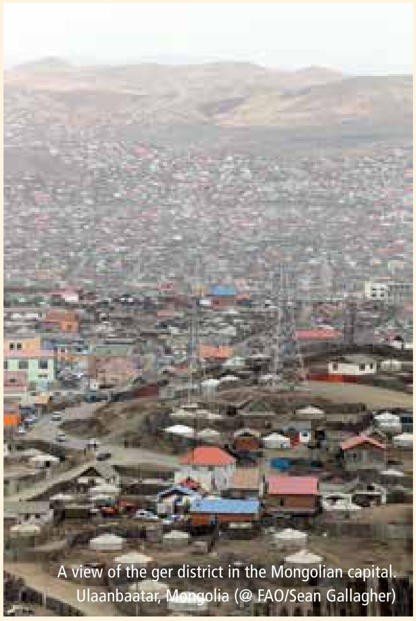
Transportation infrastructure. Transportation access enabled widespread forest exploitation in the European Alps at the turn of the last century which, in turn, led to severe soil degradation. It took several decades of natural and human-assisted reforestation efforts to restore the soil stability. Today, road construction in the world's mountains continues at an accelerated pace due to the increasing demand for mineral and energy sources, forest products, food and recreational activities.

British Columbia, the most mountainous Canadian province, has a network of around 500 000 km of unpaved logging and mining roads which were built quickly


Forest encroachment (slash and burn) by farmers for planting of agricultural crops. Cambodia (Masakazu Kashio)

and poorly maintained after the forests were harvested. Similar disturbances occur in the Andes and the Himalayas from access roads to mines and forests, which not only result in soil losses but are contributing to increasing sediment transport and deposition, and flooding in lowlands.

Tourism. As the world has urbanized, mountains have become a new frontier for recreation, prompting intensive development of infrastructure that services both summer and winter tourism. In the winter, when tourist sites take steps to maintain and make snow last longer, they are reducing the already short growing season that is essential for soil development. Maintaining this more ice-based surface means exposing it to rain-on-snow events in the spring, which increases erosive forces and soil losses. Increasing summer tourism, which has led to rapidly expanding trail construction for hiking and mountain biking, has resulted in new disturbances that influence infiltration and runoff processes which are detrimental to soil quality and development. In addition, as urban development expands in the mountains to accommodate tourism, it creates more impervious surfaces that lead to increased surface runoff, which adds to the erosion problem.


A view of the ger district in the Mongolian capital. Ulaanbaatar, Mongolia (@ FAO/Sean Gallagher)

Agriculture. In many developing countries, agricultural expansion into the mountains is accelerating due to population pressure, increasing food demand and, in some areas, more favourable growing conditions as the global climate warms. This has resulted in two different degradation processes: many forests on steep slopes were converted to agriculture to meet local food demands and many remaining forests were over-exploited by fuelwood, fodder and litter collection to support agriculture.

Converting mountain forests into cropland to support annual cash crops exposes the soils to rainfall events which lead to surface erosion. Without permanent plant cover, insufficient input from compost and manure, increased tilling has resulted in organic matter decline, reduced soil and nutrient storage capacity and soil erosion.

In forests that were subjected to extensive biomass removal, the carbon and nutrient recycling capacity was disrupted, the tree productive capacity declined and this also resulted in soil losses.

Mountains are also known to store large amounts of carbon in wetlands. The extensive *páramo* wetlands in the tropical Andes are increasingly threatened because of global warming, agricultural expansion and organic matter extraction to enhance the diminished carbon content in agricultural soils elsewhere.

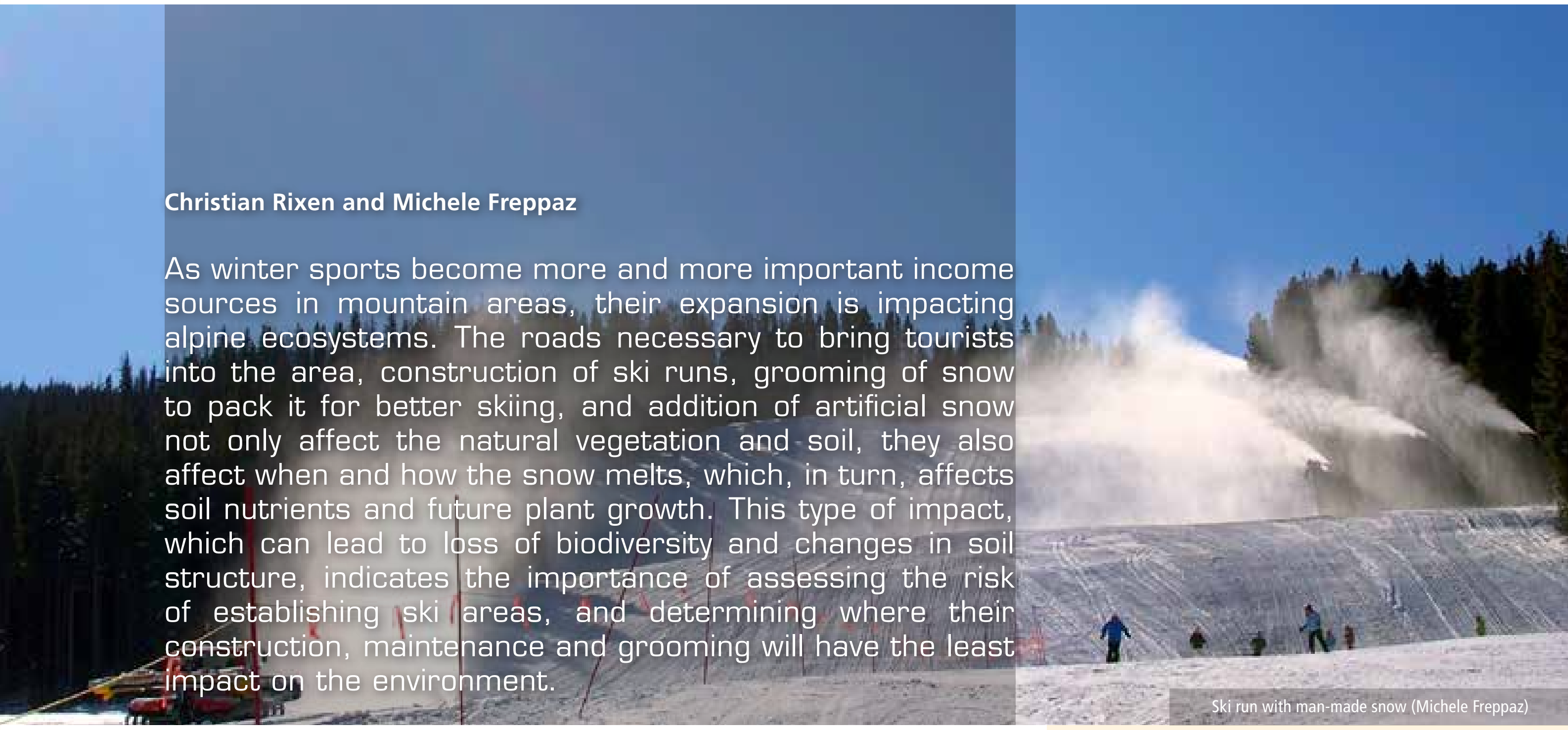
Air pollution. Mountain soils are subject to contamination from air pollution from mining activities, tourism and long-distance transport from industrial areas. Air inversions are common in mountain valleys during intensive traffic around ski holidays and from large mining operations. These generate acid rain that is particularly detrimental to those mountain soils that have little buffer capacity. In parts of Eastern Europe, heavy industrial development during the post-war period caused long-term damage to forests and soils in the mountains.

Climate change. The key human impact on soils is from accelerated climate change, particularly as there is evidence that the effect of global warming is probably more extensive in mountains and has greater impact on mountain ecosystems than on many other ecosystems in the world. The cold climate and period of water saturation enables mountain soils to effectively convert carbon dioxide (CO_2) into stable organic matter that accumulates and enhances their resilience and productivity. However, land-use activities may have negative effects on these ecological services. Protecting the most fragile soils and minimizing land conversions is the first step. Climate change can also have a positive impact because warmer climatic conditions will increase soil development processes.

In areas where land conversion has already taken place, it is essential to use the most effective beneficial management practices (BMPs). In areas where mountain agriculture is being practised, the introduction of agroforestry, planting trees in hedgerows between fields or terracing slopes is effective for protecting soils. Agroforestry is particularly pertinent because not only do the trees reduce the soil loss, they also use nutrients and water from deeper soil than field crops. In addition, they provide a permanent vegetation cover, yield useful products such as fodder and firewood, and sequester carbon. If the agroforestry scheme includes leguminous plants, it also enhances the nitrogen status of the soils. Finally, transportation infrastructure should be developed and maintained with much greater care to avoid widespread land instability, as the soil erosive forces will continue to heighten as a result of increased climatic variability around the world.

Wind turbines on a hillside at a wind farm in Frosolone. Italy (@FAO/Alessia Pierdomenico)

Winter sports: the influence of ski piste construction and management on soil and plant characteristics



Christian Rixen and Michele Freppaz

As winter sports become more and more important income sources in mountain areas, their expansion is impacting alpine ecosystems. The roads necessary to bring tourists into the area, construction of ski runs, grooming of snow to pack it for better skiing, and addition of artificial snow not only affect the natural vegetation and soil, they also affect when and how the snow melts, which, in turn, affects soil nutrients and future plant growth. This type of impact, which can lead to loss of biodiversity and changes in soil structure, indicates the importance of assessing the risk of establishing ski areas, and determining where their construction, maintenance and grooming will have the least impact on the environment.

Ski run with man-made snow (Michele Freppaz)

Winter sports have become prime contributors to mountain economies. France, Switzerland, Austria and Italy, major winter sports destinations in Europe, provide over 85 percent of Europe's skiing areas, with a combined skiing domain greater than 350 000 ha. The construction and management of ski resorts are expected to be impacted by global warming, as the predicted increase in temperatures will shift seasonal snowline towards higher elevations and, in turn, possibly pushing the ski industry to higher altitudes.

Constructions of ski runs in the Alps, particularly those above the treeline, have considerable impacts on alpine ecosystems. Natural vegetation cover and the organo-mineral topsoil are removed, boulders are rearranged to form ski runs and coarse materials from deeper horizons are mixed with finer upper soil to form the top layer. The original soil thickness is reduced due to the loss of previous soil horizonation, generally resulting in altered topsoil. Substantial alteration of ski-run soils is usually accompanied by an increase in pH values, organic matter impoverishment, and loss of both fine particles (clay) and aggregates.

The rapid establishment of a continuous plant cover after disturbance can protect and stabilize the substrate and hence minimize soil erosion, due to both its evident above-ground properties and its root systems. Roots not only stabilize the soil by simple mechanical effects, but the finer roots with fungal hyphae and the associated microbial communities aggregate finer soil particles and organic components into soil aggregates by means of both physical action and the production of organic compounds. The binding of soil particles into stable aggregates of various sizes provides a range of pore sizes for storage of organic matter (OM) and water, as well as root growth.

The snowmelt on ski runs with man-made snow is often two weeks delayed (C. Rixen)

Snow grooming on ski slopes, one of the management practices during the ski season, affects the snow properties but also the underlying soils. Groomed snow increases snow density and reduces snow depth compared with ungroomed areas. The snow compaction reduces the insulation capacity of the snowpack and, consequently, the underlying soil can experience considerable freezing with subsequent effects on soil nutrient dynamics and plant development.

Moreover, with the ongoing intensification of ski resorts, the use of artificial snow has become more prevalent, and the vegetation and soil properties have been influenced in an increasing area. Due to the greater snow mass, the beginning of the snow-free season can be delayed by more than two weeks. The late melting of artificial snow can hence alter the length of the growing season. The delay in the thaw delays plant growth to a degree that it cannot always be caught up during the course of the growing season and can bring about a change in the composition of the vegetation. Typically, there is an increase in plant species from snow beds that can grow, blossom and flower all within a few weeks, such as the soldanella (or snowbell).

Graded un-vegetated ski run in summer (C. Rixen)

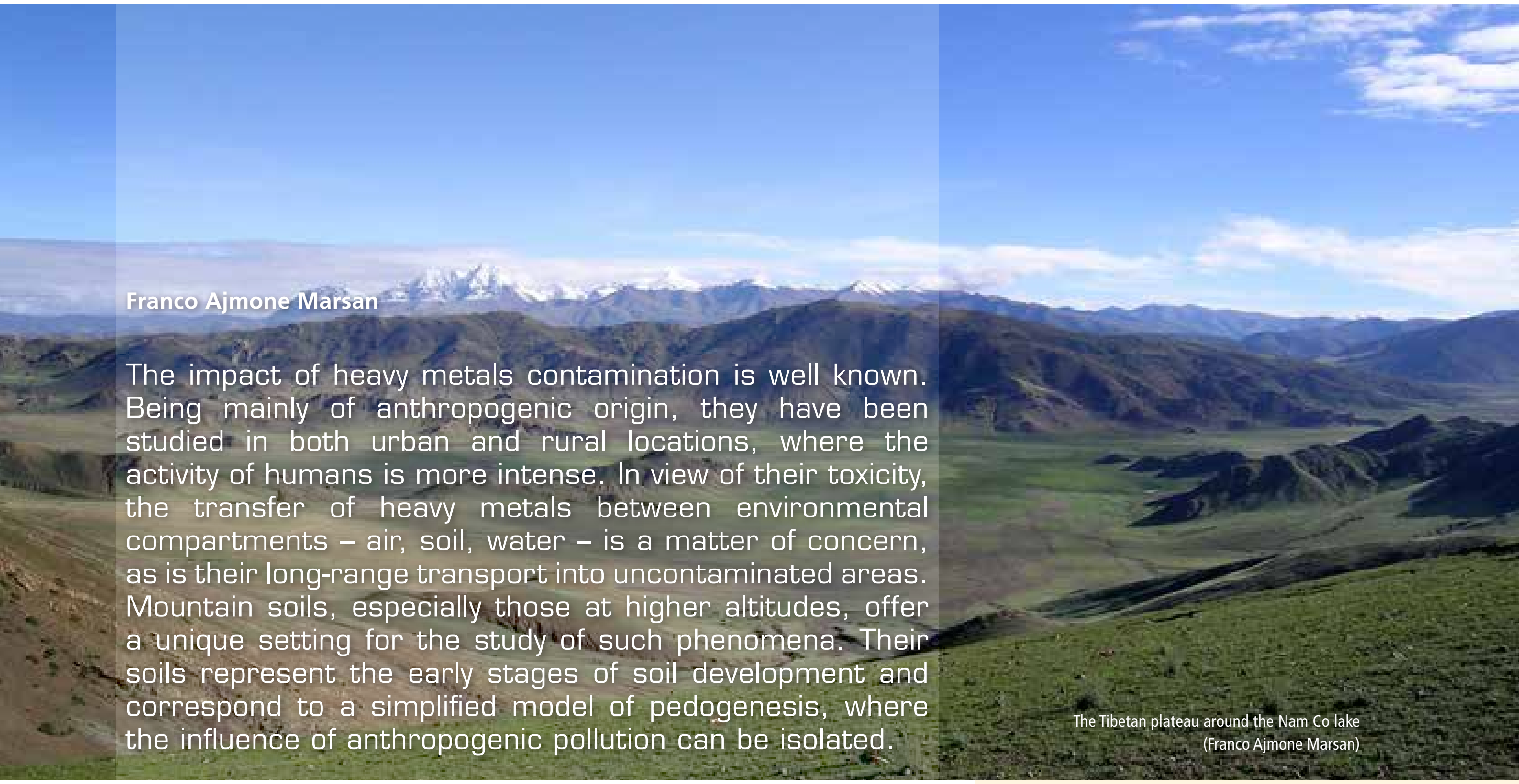
Using artificial snow means that extra water is discharged onto the pistes when the snow melts, plus there is also a difference in the quality of the water from artificial snow, compared with natural snow. The average amounts of nutrient salts and ions in the melting water is, on average, eight times higher on pistes with artificial snow. Although this melting water is still of drinking-water quality, there is still the possibility that the composition of the vegetation will be altered. The discharge of water and ions can encourage those species that need moist, moderately acidic conditions, but at the expense of species favouring dry, acid soils which are low in nutrients. However, the additional amount of snow can protect plants and soil against damage from snow-grooming vehicles and ski edges, and also from ground frosts.

All things considered, the most serious effects come from piste levelling during the period when there is no snow. Even at altitudes below the treeline, disturbance to the soil structure can be almost irreparable and cause erosion. This means that after levelling and other ground work, it is essential to apply the newest methods to restoration of soil and vegetation. The technology to do this has made great strides in recent years, creating near-natural soil conditions and using local plant species and seed suited to high altitudes. These methods may appear to be more expensive than traditional inexpensive solutions, but in the long run they pay off, and are more sustainable. Guidelines as to how to establish vegetation are already available in several languages, but they need to be applied more consistently.

Skiing and the use of artificial snow or other resources need not be demonized *per se* for environmental reasons, as their effects on numerous areas are actually very limited – for example, where the agricultural use of the land is relatively intense anyway. On the other hand, a more restrained approach is advised in ecologically valuable and sensitive areas, such as wetlands or nutrient-poor grassland with endangered plant species, or areas where the soil is particularly prone to erosion. Here, particular care should be taken in ski piste construction and management as there are plenty of other areas where the sport can take place without causing any problems.

Snow-making machines (C. Rixen)

Heavy metals pollution



Franco Ajmone Marsan

The impact of heavy metals contamination is well known. Being mainly of anthropogenic origin, they have been studied in both urban and rural locations, where the activity of humans is more intense. In view of their toxicity, the transfer of heavy metals between environmental compartments – air, soil, water – is a matter of concern, as is their long-range transport into uncontaminated areas. Mountain soils, especially those at higher altitudes, offer a unique setting for the study of such phenomena. Their soils represent the early stages of soil development and correspond to a simplified model of pedogenesis, where the influence of anthropogenic pollution can be isolated.

The Tibetan plateau around the Nam Co lake (Franco Ajmone Marsan)

Even though they are far from sources of contamination, studies of remote ecosystems such as the Himalayan mountain range and the Tibetan Plateau indicate that they are still subject to the deposition of long-range atmospheric contamination. Heavy metal deposition is especially influenced by precipitation, and there is evidence that mountains are regional convergence zones that trap atmospheric contaminants because of cold condensation and enhanced atmospheric deposition.

Investigations of atmospheric depositions in the Himalayas have produced contrasting results. For example, they found little indication of a possible influence of anthropogenic activities on heavy metal pollution from the Mount Everest atmospheric environment, but recent studies reveal a contribution of wet and dry depositions to the concentration of metals – especially of cadmium – in the soils of the area. Also, they found influence of anthropogenic sources of metals on the soils of the southern slope of the Himalayas with a marked seasonal variation between monsoon and non-monsoon seasons.

However, any investigation into the possible atmospheric transportation of contaminants must be preceded by an examination of the geochemical assemblage of the area to ascertain if there is a contribution from the rock substrate. A study of the Tibetan Plateau collected soil samples from the Nam Co basin, analysed them for heavy metals (cadmium – Cd, chromium – Cr, nickel – Ni, copper – Cu, zinc – Zn, lead – Pb and manganese – Mn) and rare earth elements (REEs), and measured their physicochemical properties – pH, organic matter, electrical conductivity and cation exchange capacity.

The results confirmed that the soils in the Nam Co basin are at an early alkaline weathering stage (pH = 7.94). Mean concentrations of heavy metals decreased in the order of Mn > Cr > Zn > Pb > Ni > Cu > Cd. The values of Cd, Cr, Pb and REEs were higher than the average background values for China. The chondrite-normalized diagrams of REEs suggested a high REE ($\sum$La to Eu) enrichment, a high REE ($\sum$Gd to Lu) depletion and europium (Eu) depletion. Vertical profiles indicate that heavy metals and REEs primarily exist in the surface soil. However, heavy metals and REEs vary in the surface soil between the southern and the northern banks of Nam Co. These differences are controlled mainly by parent materials. However, a contribution of heavy metals from wet deposition was observed in this area, demonstrating that human activities – industry, mining – can have an influence even on these remote areas.

Transport of suspended particulate in river waters after a monsoon (Franco Ajmone Marsan)

The Tibetan plateau around Manasarovar lake (Franco Ajmone Marsan)

6

Mountain soils and threats

The alluvions of 25 march 2015, with much water and mud, devastated almost the entire region of Atacama, Chile
(Jorge Carabantes Ahumada)

Silvia Stanchi, Michele Freppaz, Sven Walter and Luisa Vanderwegen

Mountain soils and threats

Devastation after earthquake. Kathmandu, Nepal (Flickr/ReSurge International)

Soil degradation in mountain environments is a worldwide problem. Mountain soils are intrinsically vulnerable and therefore very sensitive to degradation processes such as water erosion, loss of chemical and physical quality, and desertification. Degradation processes result from a combination of factors: low soil formation rates and slow pedogenesis; steep slopes favouring profile erosion and even topsoil truncation; limited organic matter inputs; extreme climate affecting the soil biological communities; and the organic matter turnover.

In addition, mountains are particularly sensitive to climate change. For example, the impact of climate change on the snowpack duration, rainfall regime and frequency of extreme meteorological events can heighten soil erosion and degradation, often leading to non-tolerable soil losses.

In particular, when marginal areas are abandoned, they become even more prone to natural hazards such as shallow slope failures and heightened erosion. Besides localized events, the impact of climate change on mountain soils may also have off-site effects. For example, glacial retreat in mountains is followed by a consistent reduction in glacial runoff water, which will affect the availability of most of the world's freshwater resources for domestic, agricultural and industrial consumption. Climate change will also affect vegetation, as it can induce altitudinal shifts of plant species, threatening biodiversity. The interactions of soils, biosphere and water cycle can be therefore seriously compromised.

In arid zones, populations are heavily dependent on ecosystem services provided by highland areas. One-third of the global population in lowlands survives thanks to water flowing from frequently far-off highland areas. In semi-arid and arid regions, mountains may be the only areas with sufficient precipitation to generate runoff and groundwater recharge, serving as water towers for millions of people living in surrounding lowland areas. Mountains play a key role in the hydrological cycle of dryland regions, and are the source of many of the world's greatest rivers including the Nile, Colorado, Yangtze and Mekong. Unfortunately, over-exploitation of natural resources and land conversion, as well as the spread of invasive alien species and climate change, are altering hydrological and fire regimes, leading to land degradation and desertification, and impacting mountains' abilities to deliver key ecosystem services such as water.

Soil degradation in Tres Molinos
(UNCCD/Jorge Valenzuela)

Mountain agricultural soils face several limitations related to severe slopes, limited accessibility and mechanization. Since ancient times, terracing has been widely used to guarantee agricultural quality and to prevent natural hazards. For example wide areas in Europe have been subject to recent land reclamation and reshaping operations, carried out in order to make agriculture more profitable and to allow mechanization.

Mountain soil degradation includes a variety of processes, strictly related to soil hydrology and watershed management. Recently, Alewell proposed to group all hazards that induce mountain soil loss in the wide category of "soil erosion", including for example shallow landslides and mudflows that involve the first decimeters of soil.

In particular in drylands, sustainably managed land resources – such as those that employ organic, ecological or conservation agriculture – can significantly increase soil water retention and filtration to help ensure improved availability. Sustainable land management (SLM) and ecosystem restoration represent "win-win" investments that benefit multiple sectors and stakeholders operating within the nexus of food and water security.

Soil vulnerability to erosion can be assessed through a wide set of lab methods such as direct field measurements with sediment collection (*e.g.* sediment traps); radionuclides measurements (both field and lab applications); estimate models such as the revised universal soil loss equation (RUSLE) applied at plot, catchment and regional scales.

Among the recently used methods for soil erosion estimation, RUSLE-derived models are widely applied in heterogeneous mountain environments. However, validations for non-agricultural systems are scarce, and the performance of the methods is still controversial. Recently, discrepancies have been noted between estimation models and radionuclide measurements (*e.g.* 137Cs) on mountain slopes – differences attributed to erosion processes that take place in winter such as snow-induced erosion from snow gliding and full-depth avalanches.

Land slips are common in Ecuador's eastern Andes.
Upper Mazar watershed, Cañar, Ecuador
(Fundación Cordillera Tropical)


Gallreide (Austrian Service for Torrent and Avalanche)

A correction factor for RUSLE estimates accounting for snow-driven erosion has been proposed in the last years for the Alps by Konz *et al.* and by Stanchi *et al.* Sets of indicators of physical vulnerability have been introduced and tested for mountain soils by several authors in a variety of environments, from the Mediterranean to the Alps for Europe, giving promising results. These indicators are related to soil aggregate stability (*e.g.* aggregate breakdown curves), and soil liquid and plastic limits, describing soil consistence and resistance. Applications are available for both natural ecosystems and agro-ecosystems, and can be adapted to different environmental contexts.

Considering the wide range of processes affecting mountain soils, and their potential on-site and off-site effects, hazard and risk assessment are essential. Linking soil properties with extreme event thresholds is fundamental for improving knowledge of soils and mountain ecosystems, and would be a relevant step in mountain hazard studies.

Moreover, civil protection and preparedness are becoming fundamental for mountain populations. Best practice and management suggestions that target local conditions are needed to mitigate soil vulnerability and to cope with the issues of anthropogenic impacts and climate change. In particular in drylands, the sustainable management of natural resources must be ensured in order to promote conservation and rehabilitation of land as well as of freshwater resources. This will lead to the enhancement of community drought resilience and increase understanding of other risks associated with water scarcity and land degradation in mountainous areas and related lowlands. Furthermore, sustainable landscape management over large territorial units is required to maintain the functionality and sustainability of highlands and lowlands in dryland systems.

The United Nations Convention to Combat Desertification (UNCCD) promotes a wide range of such measures with the aim of enhancing sustainable environmental and natural resource management. This work is based on the understanding that the conservation, protection and rehabilitation of land together with freshwater resources are essential components of any policy that targets the protection of natural resources and the environment. This also incorporates the enhancement of community resilience to drought and other risks associated with water scarcity and land degradation.

Rotational grazing in Tajikistan

Sven Walter and Luisa Vanderwegen

During the Soviet era the steep mountain slopes in the Faizabad district were intensely cultivated, which led to severe soil degradation. Rotational grazing is an option for sustainable land use in these areas. Farmers near the Karsang and Tshinoro mountains applied a rotational scheme of 10 to 14, dividing a grazing day into a grazing period of four hours in the early morning and a later period in the afternoon. The dung left by the animals enhances soil fertility. The dung favours palatable species and compensates for the fertilizers that used to be applied in the Soviet era. The applied rotational scheme also has the advantage of having fewer trampled paths than the overgrazed village pastures.

A farmer cultivating soil for fruit crops of grapes and pomegranates. Hosilot, Tajikistan (@FAO/Vasily Maximov)

Large-scale hydrological and agricultural water harvesting

Sven Walter and Luisa Vanderwegen

Many mountain peoples have developed large-scale hydrological and agricultural water-harvesting infrastructure to overcome water constraints. Water harvesting by early farmers was probably pivotal in the emergence and diversification of food production, the domestication of plants and animals, and the shaping of ecocultural landscapes. For example, the Inca civilization in the central Andes had a social organization based on water management and work sharing and cooperation. Irrigated terraces play an important role in protecting soil against erosion and in maintaining agricultural fertility, but they are also cultural and landscape elements that provide a strong identity for numerous mountain landscapes in the Mediterranean basin from North Africa to southern Europe and the Levant area of Southwest Asia.

Dry lands. Purulia, West Bengal, India (@UNCCD/Aniruddha Pal)

Rehabilitating red soils in the Nepalese Himalayas

Hans Schreier, Sandra Brown and Pravakar Shah

Ultisols or red soils, the oldest soils in the middle mountains of the Nepalese Himalayas, have a long history of intensive human use and as a result the productive capacity of the soils has gradually declined. No longer able to support crops, these soils were used for livestock grazing and, today, they have become mainly degraded and eroded, producing sediments that enter the rivers, clogging irrigation channels and increasing flooding events downstream. This study tested several local trees and grasses to determine the best way to restore these soils. The combination of fast-growing native broadleaf trees that fix nitrogen and local grasses were effective in establishing organic matter, improving the nutrient status and protecting the soils from erosion during the monsoon. At the same time the trees provided fodder for the livestock, and the litter accumulation improved the soil water and nutrient holding capacity. This option was found to be much more effective than the traditional planting of chir pine forests.

Red soils before rehabilitation (Hans Schreier)

In the middle mountains of the Nepalese Himalayas, the Ultisols, commonly known as red soils, occur at elevations up to 1 200 masl. Known to be the oldest soils in the region, they are highly weathered, have fine textures, and high aluminium and iron content which is responsible for their characteristic colour. They are acidic, highly leached and deficient in organic matter, phosphorus and base cations. These soils are very fragile, have a long history of human use and, because they have received insufficient inputs over time, many red soil areas are highly degraded and are no longer able to support adequate biomass production.

These soils, classified as Haplustults and Rhodustults, have a high clay content, and without sufficient organic matter and plant cover they have limited soil water holding capacity (important during the dry season), and tend to form crusts that reduce the infiltration rate of water (critical during the monsoon). As the chemical and physical properties declined, the use of these soils changed from crop production to grazing, and ultimately to degraded lands. Large areas have been abandoned, resulting in gullying and widespread soil erosion.

To improve and rehabilitate these soils requires a good understanding of the physical, chemical and biological soil processes. Nitrogen, phosphorus and potassium are the three macronutrients that are required in large quantities to support plant growth, and as these red soils contain little organic matter, the nitrogen release from decomposing organic matter is small. They are also highly acidic (pH 3.8–5.5) and, at low pH, aluminium (Al) and iron (Fe), which are abundant in these soils, become soluble and readily interact with plant-available phosphorus to form insoluble aluminium phosphate. As phosphorus is a macronutrient, these soils then become highly deficient in plant-available phosphorus. Potassium is the only macronutrient in adequate supply, as the geological formations contain abundant mica minerals.

The lack of vegetation cover and organic matter has reduced the soils' nutrient and water holding capacity, which has increased surface runoff and made them prone to erosion during the monsoon season. Their biological activity is also impaired due to the lack of organic matter. A study sponsored by Canada's International Development Research Centre (IDRC) in the Jhikhu Khola watershed estimated that degraded red-soil sites are responsible for 40 percent of the sediment load in the river, which is responsible for clogging irrigation and local stream channels, and increasing flood events.

The high demand for food and animal feed by the rapidly increasing rural population highlights the need to minimize degradation and provide new biomass from previously degraded sites. Reforesting these degraded soils is an obvious solution as it will provide vegetation cover that reduces the rain impact, and the tree roots will assist in holding the soils in place. Nepal's native chir pine, the primary species used to stabilize these degraded sites, can prosper on nutrient-deficient soils, and will be left to grow because they do not provide much useful material for the rural population in terms of firewood, fodder and litter. However, they do provide timber after 15-20 years.

However, it is now evident that this type of reforestation may be causing significant long-term problems. A recent study by Ghimire *et al.* found that chir pine has significantly higher water demands during the dry season than natural broadleaf forests and grasslands. Additionally, because fuelwood and organic matter is in high demand, the rural farmers harvest the understorey vegetation in the pine forest and collect the pine litter on an annual basis, which reduces organic matter availability and soil water recharge which, as found by Ghirmire *et al.*, is probably contributing to the decreased streamflow during the dry season.

Pine litter decomposes very slowly, and the organic acids released during the decomposition of the litter acidifies the soils, which are already at a very low pH. This was demonstrated in an experiment that incorporated 10 kg of pine litter into the red soils every six months for three-and-a-half years. As shown in Figure 1, the addition of pine litter increased the soil organic matter content over time but depressed the pH by another 0.3 units, further increasing the solubility of Al and impairing the already low plant availability of phosphorus. In contrast, an annual incorporation of broadleaf litter did not increase acidity significantly, but did improve the organic matter content of the soil.

A demonstration site was established to show how the degraded red-soil site could be improved by planting nitrogen-fixing fodder trees. Nepal has more than 20 fodder tree and shrub species which can fix nitrogen from the air and are native to the Himalayas. Six of them were planted in hedgerows on the site and additional experiments were conducted to determine which of the N-fixing fodder trees could support *mycorrhizal fungi*. These fungi live in a symbiotic relationship with selective tree roots and are able to convert insoluble phosphorus into a plant-available form. Two of the selected fodder tree species were found to be conducive to this process.

Grasses were planted between the rows for additional surface cover, while their root systems also increased below-surface organic matter production. The combination of fodder trees and grasses has proven to be a good management approach because they draw nutrients and water from different depths in the soil. After three years, the fodder trees and shrubs were established to the point that partially harvesting of leaves was possible twice each year – once to provide fodder and once to incorporate green biomass into the soils to enhance the soil organic matter content. This helps in recycling of nutrients and improves water infiltration, water storage and nutrient-holding capacity and enhances the overall soil health. It also provides extensive year-round vegetation cover that limits soil erosion.

The sustainable vegetation cover was established after six years and now is sufficient to protect the site from erosion, to improve the soil nutrients and to produce useful biomass for livestock on a continuous basis. The lessons learned are manifold. It was possible to restore the soil productive capacity and create a permanent vegetation cover that has improved biodiversity, increased resilience to extreme climatic events, and protects the soil from erosion. The knowledge generated has been transferred to nearby community forest groups in the watershed, to show the potential to restore these degraded red-soil sites using native tree species, to improve biomass productivity in addition to limiting soil erosion and downstream sedimentation.

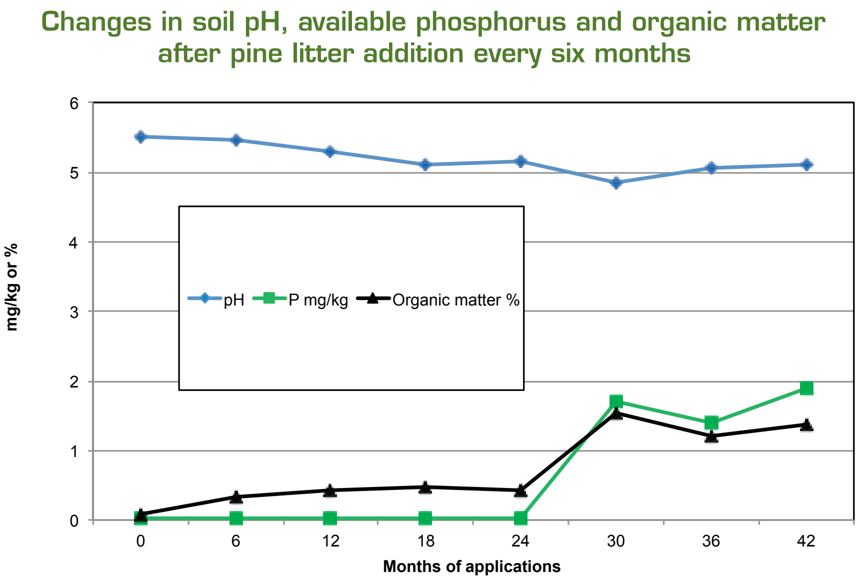
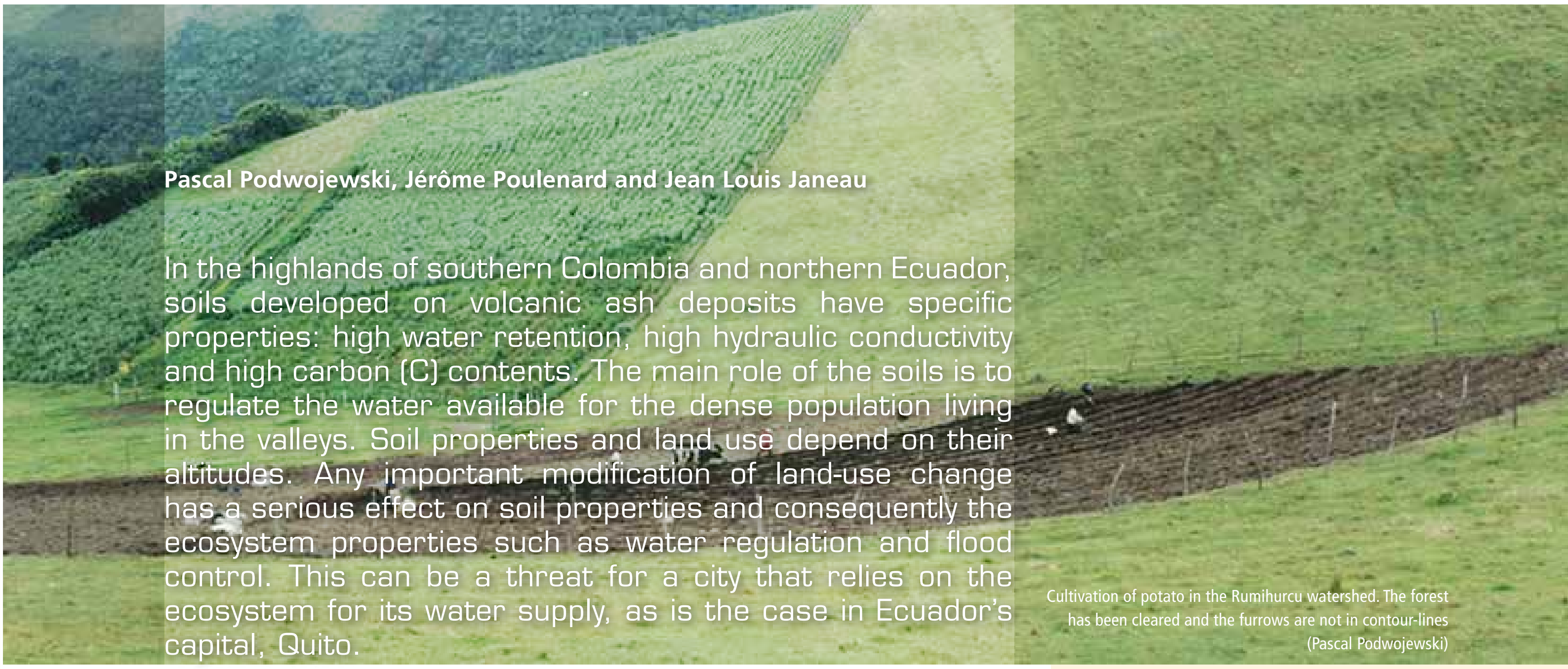


Figure 1: Changes in soil chemistry of red soils as a result of addition of chir pine litter at a rate of 10 Kg/m^2 every six months over a 3½ year period

Effects of land-use changes on soil properties: volcano watershed in Quito, Ecuador



Pascal Podwojewski, Jérôme Poulenard and Jean Louis Janeau

In the highlands of southern Colombia and northern Ecuador, soils developed on volcanic ash deposits have specific properties: high water retention, high hydraulic conductivity and high carbon (C) contents. The main role of the soils is to regulate the water available for the dense population living in the valleys. Soil properties and land use depend on their altitudes. Any important modification of land-use change has a serious effect on soil properties and consequently the ecosystem properties such as water regulation and flood control. This can be a threat for a city that relies on the ecosystem for its water supply, as is the case in Ecuador's capital, Quito.

Cultivation of potato in the Rumihurcu watershed. The forest has been cleared and the furrows are not in contour-lines (Pascal Podwojewski)

The Pichincha volcano dominates the city of Quito, Ecuador. A study conducted by Poulenard *et al.* of the soil types and hydrostructural properties in the watershed of Rumihurcu on the steep slopes of the Pichincha between 4 200 and 2 800 masl. found degradation of their physical properties due to changes in soil chemical properties and land use.

Between 2 800 and 4 400 masl, air temperature on the Pichincha decreases by 0.6 °C per 100 m of elevation, which provides a gradient of land-use constraints (Table 1). All year, the mean daily temperature remains constant, but with very high day/night amplitude. For the same range of altitude, the mean annual rainfall increases starting with 1 000 mm and reaching 1 500 mm on the crest while the rain intensities decrease. At this altitude, frequent fogs, drizzle and hailstorms contribute to the total precipitation amount, and the hydric balance is largely

Upper altitudinal limit (masl)	Land-use	Infiltration rate	Mismanagement	Consequences
4 400	*Páramo* Bunch grasses Grazing	Strong	Overgrazing Burning Pine plantation Pathways	Compaction Irreversible soil drying Local water repellence Linear erosion
3 850	Range land Matorral-shrubs Grazing, Cultivation	Good	Local invasion Local forest clearing Unadapted crops	Irreversible soil drying Local water-repellence Linear erosion
3 750	Cultivation Potatoes, broad-beans	Medium	No contours No soil cover after the harvest	Irreversible drying Slacking of aggregate Sheet erosion
3 500	Buffer forest (eucalyptus)	Weak with burned plots	Clear cut Burning	Severe water repellence
3 200	Semi-urban Small cultivated plots (maize)	Very weak	Uncontrolled building Littering in stream flow Construction of pathways and electric lines	Mudflows channelized in pathways

Table 1: Altitudinal levels, landuse with drainage, mismanagements and their consequences

positive. The ecological function of that ecosystem described by Janeau *et al.* is to collect rainwater, store it in the soils and release it progressively. At lower altitude, soils are much less permeable and more prone to generate runoff, especially with the more intense rainfalls.

Strong volcanic activity occurred from north to central-south Ecuador during the Pleistocene, leaving acidic ash falls that are mainly rhyodacitic to andesitic in composition. On the slopes of the Pichincha volcano, the topsoil developed on young -300 years BCE andesitic ashes over a non-weathered lapilli layer. Soils are very dark, soft with loose aggregates and very porous. The dominant Pichincha soil is classified as a vitric Andisol characterized by low amounts of amorphous constituents (aluminium – Al and iron – Fe), estimated by oxalate extraction (0.7 percent < Al^o percent + ½ Fe^o < 2 percent), a sandy texture with high amount of glass and a relatively high bulk density for an Andosol (0.8 g cm^{-3}). The carbon content is >7percent; the water content at -1 500 kPa matric potential is generally close to 500 g kg^{-1}. All soils have a high hydraulic conductivity (>100 mm h^{-1}).

From 2 500 masl, the soil becomes an andic Cambisol and the carbon (C) content decreases (50-65 g kg^{-1}), as does the water-holding capacity (<300 g kg^{-1}). The water infiltration rate is still high but very variable.

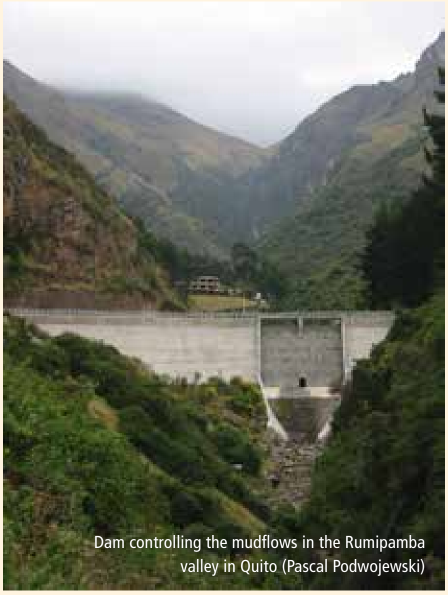
At lower altitudes, the vitric ash layer is often eroded, and the old volcanic ash layer outcrops in a very hard duripan (*cangahua*). The soil is a Leptosol or Durisol with a very low amount of carbon, high bulk density water content and very poor hydrodynamics, which lead to rapid surface water flows.

The slopes of the Pichincha have been increasingly encroached by agricultural land at higher levels and urbanization at lower levels since the 1960s, due to increased population pressure in Quito.

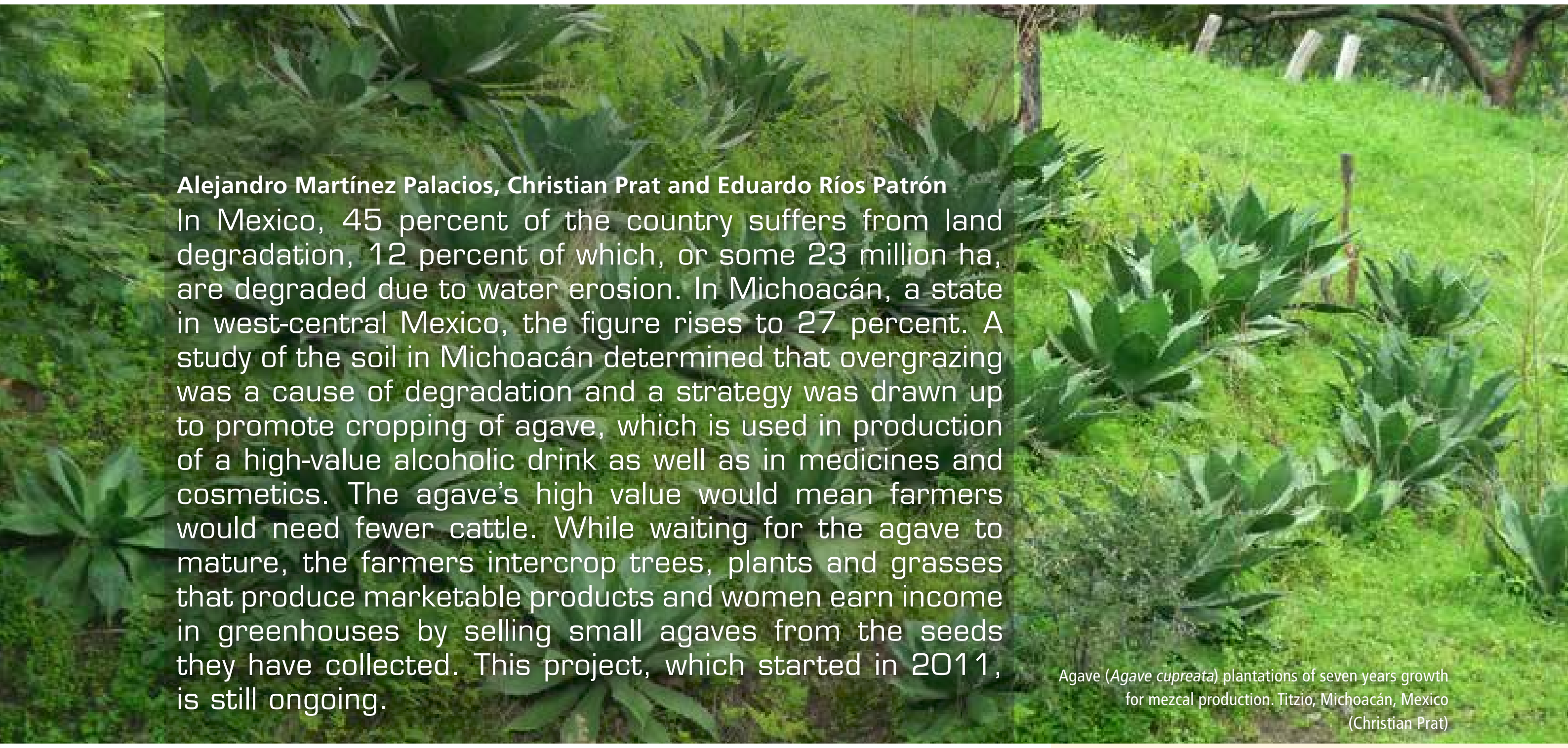
In the *páramo* highlands, repeated fires that generate scattered hydrophobic soil properties are associated with the overgrazing that compacts soil in localized patches and decreases infiltration. The accompanying reduction in vegetation exposes the bare young Andisols' surface to raindrop impact and aggregate slacking which generates surface crusting and runoff, and causes superficial but irreversible drying of bare surfaces. Intense solar radiation and the Andisols' black colour increase soil evaporation. When the soil cover is altered, the surface hydraulic conductivity is reduced by a factor of three, which generates concentrated flows leading to gullies.

At lower altitudes, the planted forest should be protected, never burned to avoid the formation of severe water-repellent soil patches. After tillage, the soils are exposed to rain, hailstorms and rapid irreversible changes in the soil structure by irreversible drying. Dry aggregates develop strong water-repellence, leading to diffuse surface flows and interrill erosion by floating water repellent aggregates. Cultivation should be conducted in contour lines with minimal tillage and maintain a soil cover as long as possible, especially after the harvest. If the topsoil is eroded, the sterile duripan outcrops at low altitude, which is a severe constraint for cultivation and water infiltration, and can lead to mudflows on steep slopes that are catastrophic with risk of loss of life and economic problems.

Due to the modification in land-use change and global climate change, the water-regulation of this ecosystem and its soil fertility could be adversely affected for the future. It is clear that such changes will have a detrimental effect on the city's water supply.


Dam controlling the mudflows in the Rumipamba valley in Quito (Pascal Podwojewski)

Land reclamation by agave forestry with native species in the mountains of Michoacán state



Alejandro Martínez Palacios, Christian Prat and Eduardo Ríos Patrón

In Mexico, 45 percent of the country suffers from land degradation, 12 percent of which, or some 23 million ha, are degraded due to water erosion. In Michoacán, a state in west-central Mexico, the figure rises to 27 percent. A study of the soil in Michoacán determined that overgrazing was a cause of degradation and a strategy was drawn up to promote cropping of agave, which is used in production of a high-value alcoholic drink as well as in medicines and cosmetics. The agave's high value would mean farmers would need fewer cattle. While waiting for the agave to mature, the farmers intercrop trees, plants and grasses that produce marketable products and women earn income in greenhouses by selling small agaves from the seeds they have collected. This project, which started in 2011, is still ongoing.

Agave (*Agave cupreata*) plantations of seven years growth for mezcal production. Titzio, Michoacán, Mexico (Christian Prat)

The Cointzio catchment located in the transverse volcanic belt of central Mexico covers 630 km^2 (Figure 1). The catchment bedrock consists of igneous rocks generated by Quaternary volcanic activities and, according to the World Reference Base (WRB) for soil resources, its soils are mainly Andosols in the headwater areas and on the hillsides up to 3 000 masl, Acrisols on the foothills, and Luvisols on the plains at 2 000 masl. An area river network is dominated by the Rio Grande de Morelia with a dam located at the outlet of the catchment, 13 km upstream of Morelia, the state capital, which has more than 1 million inhabitants. This dam was built in 1940 to create a reservoir to supply water for domestic consumption as well as for agricultural irrigation. However, the reservoir (4 km^2 – 65 × 106 m^3) has undergone significant sedimentation, which has led to severe deterioration of environmental conditions in the lake and to a 20 percent loss of its water hoding capacity.

Fingerprinting methods to study soil erosion in this watershed provided very similar results regarding the origin of sediment in the subcatchment, which is dominated by Acrisols and the bulk of sediment is supplied by gullies. In contrast, in the subcatchment dominated by Andosols, the bulk of sediment was supplied by cropland.

The combination of the fingerprinting and the sediment export data measurements yielded information on the erosion dynamic as well the origin of the eroded soil particles. The studies showed that soil erosion in the Cointzio catchment is due to overgrazing, mainly on the upper part and the mountainsides – information used to prioritize the implementation of erosion control measures to mitigate sediment supply to the Cointzio reservoir.

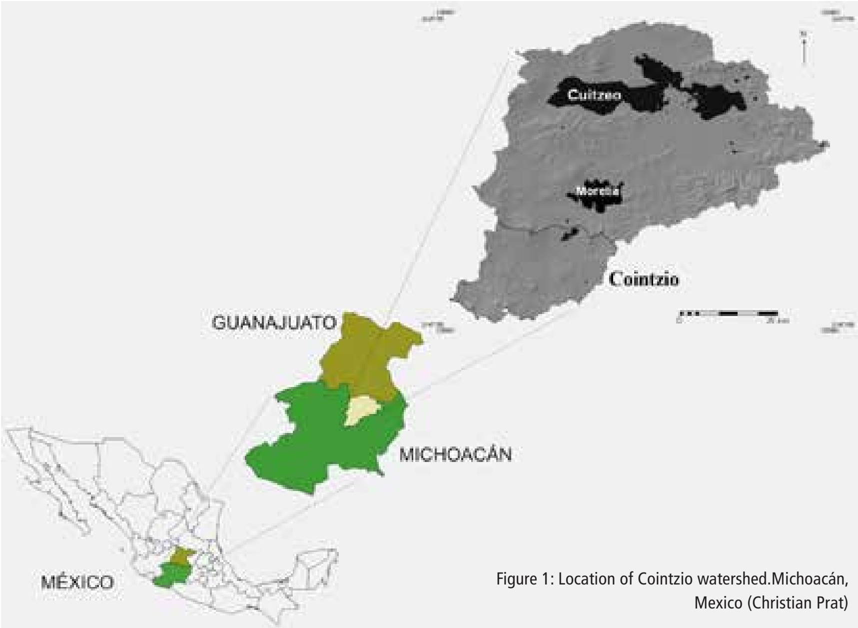


Figure 1: Location of Cointzio watershed.Michoacán, Mexico (Christian Prat)

The main suggestions called for improving the agronomical system by improving cattle production, reducing free grazing and the number of animals. However, due to the fact that this proposal would call for more work, more funds and more time, and as the level of poverty in the area is medium to high, and the income from agriculture accounts for only 10 to 20 percent of the total family budget, few farmers were able to follow this recommendation. Thus, building from this information and from workshops in some farming communities with national institutions and local authorities, another strategy was developed based on plantation of native agave (*Agave inaequidens*), trees or fruit trees, shrubs and grasses plants to create at mid-term (7–12 years) a sustainable production of a traditional Mexican alcoholic liquor (*mezcal*) or cosmetic and medicinal products, fibres or fodder for cattle or wood.

One part of the agave is planted in continuous lines to create a green wall to control soil and water runoff and the other part is planted in staggered. In addition, other native plants are planted between the lines of agave, to be used as food, fodder and/or medicinal products.

Unlike most agave, *Agave inaequidens* reproduces from seed, which requires harvesting seeds from native plants found growing wild in the fields. One plant generates 80 000 seeds with a 90 percent success rate of germination, which is enough to cover 25 ha of agave forestry plantations to control soil erosion. The harvested agave, tree and shrub seeds are maintained in a greenhouse managed by the owners or tenants of the land. At the beginning of the rainy season, plants are transferred to the plots, where cattle are not allowed for at least the first two years of planting.

While the trees, shrubs and grasses are harvested annually, agaves are only harvested after 7 to 12 years depending on the soil degradation level. Harvesting requires removing the heart of the agave (*piña*) which weighs around 50 kg. The actual *mezcal* production requires an average of three weeks with at least two men to process 25 agave plants (1.5 tons) and produce 300 litres of *mezcal*. The proximity of the site to the Michoacán state capital and recognition by the

Handmade mezcal 100% Agave (*Agave cupreata*) – La Perla de Tzitzio. Las Nueces, Tzitzio, Michoacán, Mexico (Christian Prat) authorities of the designation of origin for this *mezcal* creates high value for their future production.

The main purpose is to reach sustainable land rehabilitation while generating high incomes for the farmers. This allows them to reduce the amount of livestock and overgrazing, which is the main cause of soil erosion in this region. The production of *mezcal* will give local farmershigh incomes. While waiting the 7-12 years for the agaves to produce, farmers are growing small agaves from seeds that they collected. This activity gives jobs to a dozen women in each community who receive income from selling part of this plant production. Trees, shrubs and grasses for medicinal uses, food and fodder are complements of agave production and are processed mainly by women, while agave harvesting is a male activity.

As it is very financially convenient, farmers will remain in the communities instead of migrating to cities or abroad. Biodiversity is preserved with the increased use of native agaves, trees, shrubs and grasses. Turning eroded soil into productive soil also sequesters carbon and increases water availability as a result of the new soil cover.

The agave project was initially implemented for five years (2007-2012) through Mexican (Secretaría de Medio Ambiente y Recursos Naturales – SEMARNAT, Secretaría de Educación Superior Ciencia, Tecnología e Innovación – SENESCYT, Michoacán State, Ministerio de Agricultura, Ganadería, Acuacultura y Pesca – MAGAP, Universidad Nacional Autónoma de México – UNAM, Universidad Michoacana de San Nicolás de Hidalgo – a UMSNH), French (Institute de recherche pour le développement – IRD) and the European Desertification mitigation and remediation of land (DESIRE) project funds. Since 2013, SEMARNAT, municipality of Morelia and UMSNH have continued to follow the project and share the results with other communities. They also have supported the local population with introduction of efficient woodstoves and a drinking-water network.


3 months old agaves (*Agave inaequidens*) San Andrés Coapa, Michoacán, Mexico (Christian Prat)

Turning rocks into soils from the Ecuadorian Andes to the Mexican transvolcanic sierra

Christian Prat, Julio Moreno, Jaime Hidrobo, Germán Trujillo, Carlos Ortega, Jorge D. Etchevers, Claudia Hidalgo, Aurelio Baéz and Juan Fernando Gallardo Lancho

A volcanic rock known as tuff is found throughout the Andes. Problems have arisen as the layers of light but fragile soil that once covered the tuff have been lost for both natural (environmental) reasons and because of over-cultivation. When the soil is gone, the tuff is impermeable. Now, a project in Ecuador has determined that the tuff itself can be reclaimed and is supporting a programme that sends bulldozers to the tuff regions to break up the rock and become the base for a more fertile soil.

Bulldozer, Province of Ibarra, Ecuador (Christian Prat)

Along the Andes – from Chile to the Mexican Sierras Madres – layers of hard volcanic materials cover large areas of the foothills. These materials have been given local names where they are found: *tepetates* or stone beds in Nahuatl in Mexico, *talpetate* in Central America, *cangahuas* or hard ground in Quichua in Colombia and Ecuador (Figure 1), *sillar* or *ashlar* in Spanish in Peru, and *toba* or *tuff* in Spanish in Chile (for simplicity, this report refers to the material as tuff).

The tuff layers cover a very large area: 30 700 km^2 in Mexico, 2 500 km^2 in Nicaragua, 15 000 km^2 in Colombia, 3 000 km^2 in Ecuador, areas inhabited by millions. Originally emitted

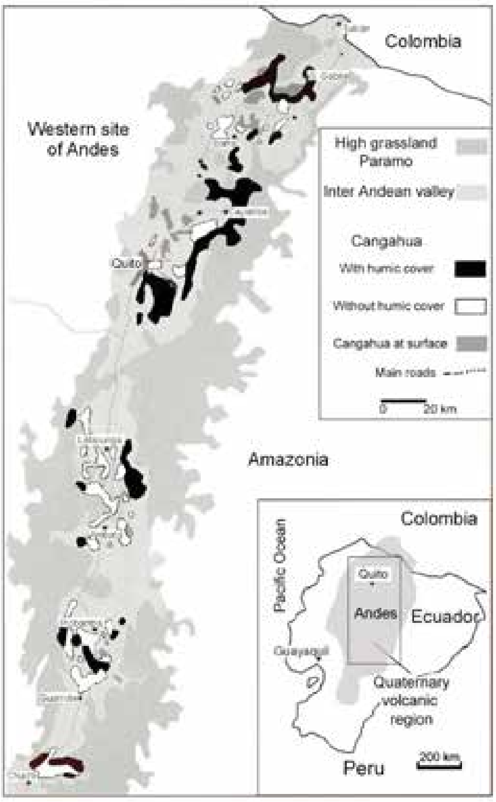


Figure 1: Location of the different types of *cangahuas* in the inter-Andean valley of Ecuador (Zebrowski et al.)

Cangahuas. Canton of Cangahua, Pichincha province, Ecuador (German Trujillo)

by phreatic magmatic-volcanic explosions, they have a thickness ranging from a few centimetres to several metres. They were buried beneath loose ashes, which turned to a fertile but fragile soil during the process of weathering.

Environmental (*e.g.* slopes, rains) or anthropogenic (*e.g.* overgrazing, agricultural mismanagement) erosion has made the topsoils disappear completely in many areas, revealing the hard tuff layers. These exposed tuffs are impermeable due to their high compactness and very low porosity.

Environmental. When aggressive tropical rains fall, the water runs off of the hard layers, concentrating and generating huge volumes of water downstream, destroying crops and causing flash floods which strongly erode soils. As the tuff materials are rocks, they lack soil organic matter or nutrients, except in isolated cracks. Sulfur and phosphorus are especially scarce in available form, while potassium can achieve high content. Obviously, the microbiological activity is residual, because micro-organism diversity is low. So, when the tuffs are exposed, the landscape looks like a sterile desert.

Anthropic. The anthropogenic pressure on the land can be very problematic. Instead of dealing with the sterile landscape, farmers have moved higher on the slopes of the mountains to reach new land with deep, fertile black soils, which forms the high-altitude ecosystems called *páramos*. *Páramos* play a key role in water resources, retaining huge volumes of water that are redistributed gradually, ensuring a permanent water supply for farmers and urban populations. But after they are used for cultivation, the soils become dry and, as a consequence, lose their capacity to retain water and resist erosion, repeating the processes observed downhill.

National and local policies have focused on reclaiming exposed tuff, *e.g.* in Mexico beginning in the 1970s and in Ecuador beginning in the 1980s. National and European funds supported research programmes for some 20 years yet, despite some success, governments gradually stopped funding them.

However, in recent years, Ecuador has recommitted. Its 2008 Constitution of the Republic State points out the obligation to protect soil and to recover eroded areas for sustainable agricultural productions, which contribute to food sovereignty of the country. In 2012 the government funded nine bulldozers, managed by the Secretary of Agriculture, for all provinces with exposed tuffs, and launched a new project focused on transforming tuffs into soils. The project was supported by the Global Environment Facility (GEF), with the Food and Agriculture Organization of the United Nations (FAO), Ecuador's Ministry of Agriculture, Livestock and Fisheries (MAGAP) and Ministry of Environment (MAE), as well as local programmes.

While Ecuadorian small farmers can break 1 m^2 of tuff per day using a pickaxe, the quickest and effective way to form soils there is with bulldozers. These machines can fragment the tuff on 0.5 to 1.0 ha per day, even on slopes, if they are less than 50 percent steep. This work also integrates an erosion-control system by breaking the highly porous tuff and creating a physical support for plants.

The strategy is to establish an agro-ecological sustainable system by incorporating, as much as possible, organic residues, preferably composted, including fertilization and microbial activity. The first crop includes legumes and grasses that will later be buried as green manure. The next crop is fertilized with small amounts of mineral fertilizers, administered three times during the year, as well as with composted manure. This plus the incorporation of the crop residues (green manure) makes it possible to achieve regional yields of, *e.g.* oat, wheat or beans in one to three years and of corn in five years.

Through this method, after three to five years, from 40 to 90 Mg C ha^{-1} of carbon can be captured as soil organic matter, ten times more than found in European soils. In the context of global warming, this high potential of carbon capture provides an additional environmental service. At the same time, it also makes additional land available for agriculture, which prevents farmers from expanding to higher-level *páramos* seeking land for cultivation. Finally, it also avoids liberation of carbon dioxide (CO_2) thus reducing greenhouse gas emissions.

Different land uses (agave, crops, forests) of *cangahuas* turned to soil. Cayambe, Pichincha province, Ecuador (Christian Prat)

Research continues to identify and select the optimal micro-organisms, for example to improve crops, crop association and rotation, and allopathic interactions between crops, as well as the quality of manure, in order to find agro-ecological systems that are correctly adapted to the typical Andean crops (such as quinoa, lupine, chia, amaranth, vegetables and pastures). Where irrigation is not possible and a traditional use of the agaves exists, agave forestry is promoted, inspired by previous Mexican experiences (see p. 107). For example, the mezcal liquor obtained from agaves could be an additional income source for families. As this species (*Agavae americana*) reproduces through seeds, the authorities used the plant picking and seeding activities to reintroduce the traditional collective work, the *mingas*, and to put emphasis on pre-hispanic traditions to protect the environment.

All these strategies focus on participative works to offer opportunities to small farmers to produce highly profitable crops, helping them to emerge from poverty. This will allow peasants (including their children) to remain farmers, instead of migrating to the cities, where they will join the legions of unemployed. Creating new spaces of productive and living soils from volcanic hardpans located in the foothills of the Andes has changed the look from deserted landscapes into fertile fields, avoiding further environmental destruction, and giving small farmers and their children new opportunities to live quite well from their production.

Field work after bulldozer and tractor préparation, Ibarra Ecuador (Christian Prat)

7

Mountain soils and climate change

Laguna Santa Rosa, Nevado de Tres Cruces National Park. Atacama region, Chile (Corporación Nacional Forestal Region de Atacama)

Michele Freppaz and Mark W. Williams

Mountain soils and climate change

A view of Mt Kilimanjaro, Tanzania (Al'Sarwat)

Mountains are among the regions most affected by climate change, and one of the most visible effects is glacier retreat. In the Alps, glacier retreat has continued with few interruptions since the end of the Little Ice Age (LIA), between 1300 and 1821/1861 (Figure 1). Today, glaciers are shrinking globally with losses reported in different areas of the world, from the equatorial glaciers in South America and Africa to the North America and Asian mountains. In the tropical Andes, for example, glaciers may totally disappear in the next few decades, leaving potentially severe water supply problems for countries such as Peru, where 10 million residents of Lima depend on fresh water from the Andes. In Africa, Mount Kilimanjaro – one of the nation's main tourism attractions – is suffering severe glacial melt and its glacier, along with the others of East Africa, is expected to disappear altogether in the coming decades.

Thus, the newly deglaciated (proglacial) areas generally are exposing barren surfaces to physical and biological weathering processes while at the same time producing new hydrologic features. Surprisingly high elevation areas with little or no developed soils have shown large amounts of microbial activity, sometimes within a few years of deglaciation. Microbes are able to function under these extreme conditions because their response time and turnover rates are much faster than those of large eukaryotic organisms. Atmospheric aerosols may be an important vector of inorganic and organic nutrients to these barren soils, and may play an unknown role in soil formation. The Niwot Ridge in Colorado, United States, part of the United States Long-term Ecological Research (LTER) Network, provided one of the first carbon budgets for alpine soils (Figure 2). Excluding the more highly productive tundra and meadow areas and considering the most barren and carbon-limited parts of an alpine watershed, the C budget illustrates that atmospheric C inputs can be more than 30 percent of the C inputs from autotrophic primary production.

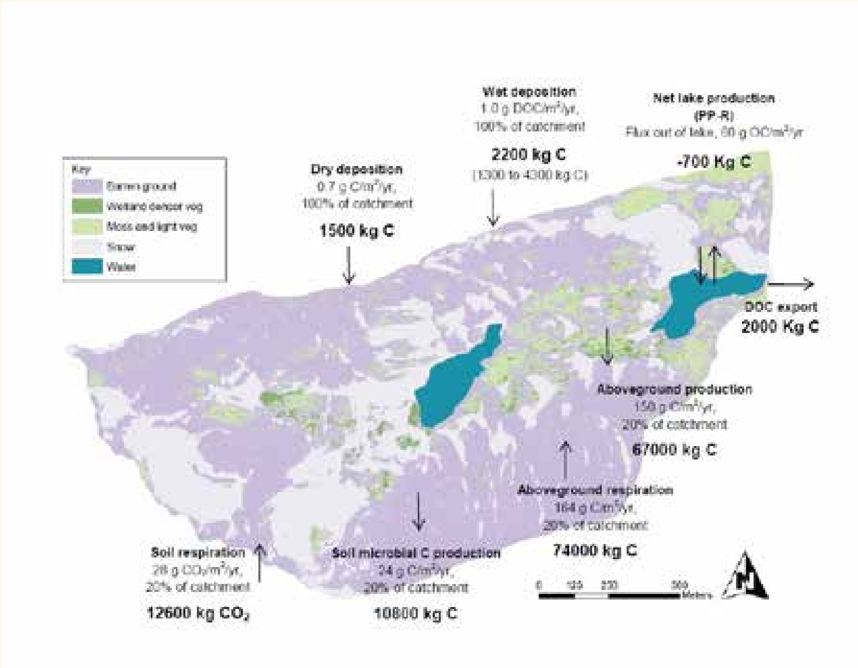


Figure 1: Estimated annual C budget for the GL4 watershed overlaid on land classification map of June 2008. Only major pools are included. Wet and dry deposition mean values and ranges are derived from long-term (2002-2010) weekly monitoring of wet deposition and snow at maximum accumulation. DOC export was taken as the mean annual yield from Green Lake 4. Art and GIS (E. Parrish)

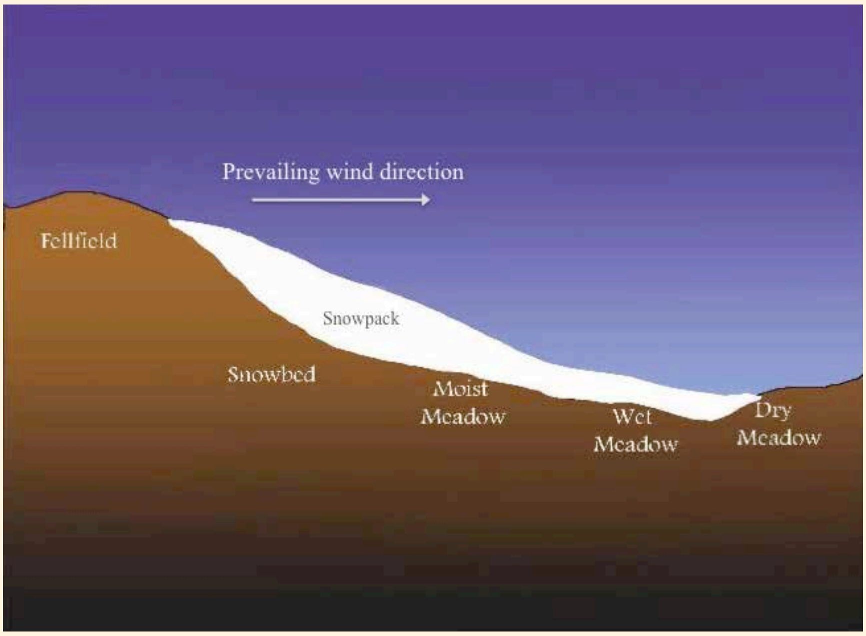


Figure 2: Alpine mesotopographic gradient at Niwot Ridge LTER site (3 528 masl). Colorado, United States (Freppaz *et al.*)

Most small and micro-scale variations in the alpine soil environs have resulted from the combined effect of cryoturbation, biological activity, parent-material and eolian deposition. In contrast to this small-scale variation, the large-scale variations originated as a result of the topographic/snow gradient. Snow cover (snowpack distribution and duration) is considered critical to the development of mountain soils because of its direct effect on soil temperature, soil moisture and duration of the growing season, which in turn controls nutrient availability in the alpine environment. The depth and duration of snow cover, for example, regulates soil temperature with stable values close to 0 °C when the snow depth is enough to ensure thermal insulation. Differences in the duration, amount and depth of snow at the mesotopographic scale result in large changes in soil properties and plant communities over short distances, as revealed by snow manipulation studies. In temperate mountain regions of the Northern Hemisphere, climate change is expected to result in a more unstable snow cover with earlier spring snowmelt. For the full range of the 1996 Commonwealth Scientific and Industrial Research Organisation (CSIRO) scenarios in Australia, Whetton estimated an 18-66 percent reduction in the total area of snow cover by 2030. Less snow cover may consequently lead to lower soil temperatures and an increase in frequency and intensity of freeze/thaw cycles. This not only effects C and nitrogen (N) dynamics, it also effects soil structure, which is a key factor for soil stability and erodibility.


View of the Eastern Nilgiri mountains of south India the day after a night's rain (Nilgiri Documentation Centre)

In the eastern Himalayas, changes in snow-cover dynamics will directly affect biodiversity at high elevations. Potential evapotranspiration is also likely to increase, due to enhanced soil water availability and higher temperatures in the future. The greater percentage increase in potential evapotranspiration compared with precipitation means relatively drier years, with implications for water resources and drought-related problems. Strong winds combined with a semi-arid to arid climate increase the risk of wind erosion when dry soil is exposed.

In areas where snowfall is the current norm, warming is also expected to lead to an increase in precipitation in the form of rain, with more frequent rain-on-snow (ROS) events and potential impact on snow characteristics (*e.g.* snow density) and soil properties (*e.g.* soil temperature) when the snow melts. For every degree Celsius the temperature increases, the snow line will rise an average of 150 m. Significant flooding can occur during mid-winter ROS events, particularly if the soil is frozen, which limits the infiltration processes and increases the amount of surface runoff. Mountain watersheds are particularly vulnerable to extreme rainfall events, which may trigger shallow soil movements, involving limited soil depths and diffuse erosion.

In mountain areas, soil erosion due to rainfall is generally considerable, but of special note, is the impact of other factors on soil erosion, such as snow movements. In particular, wet snow avalanches are well known for their high sediment yields, and their frequency may change in response to future climate conditions. Flowing avalanches can produce considerable soil removal and sediment transport along the avalanche path, altering the soil morphology on the local scale and transporting a significant amount of soil across the runout zone. If full-depth avalanches predominate, and the avalanche flows interact directly with the soil surface, the soils can be stripped off in the track zone and can be fragmented or highly degraded. Complex soil profile morphologies may occur along an avalanche path with both buried and truncated soil horizons.

Long-term data are fundamental for detecting and evaluating the impact of climate change on mountain soils. The LTER Network links a multidisciplinary group of scientists all over the world, with the recognition that long-term and broad-scale research is necessary for truly understanding environmental phenomena under a changing climate.

Information gaps on climate change in mountain regions

Tim Stott and Gerd Dercon

The rapidly changing climate in mountain regions has alarmed communities, environmentalists, scientists and policy-makers. Many fear that soils will become unstable and that water in soil will be less available for mountain communities. There is also concern that greenhouse gases locked away in the soils of these regions will find their way into the atmosphere, causing further changes to the Earth's climate. While knowledge about climate-change impacts, adaptation and vulnerability has increased substantially during the past ten years, acute knowledge gaps still exist on the effects of climate change on land-water-ecosystem quality. Because the highly vulnerable and very sensitive mountain regions across the world are likely to be most immediately impacted by climate change, these provide the ideal setting for filling these knowledge gaps.

Supported by the Joint Food and Agriculture Organization of the United Nations (FAO)/International Atomic Energy Agency (IAEA) Division of Nuclear Techniques in FAO through an IAEA Technical Cooperation project on *Assessing the Impact of Climate Change on Soil and Water Resources in Polar and Mountainous Regions*, an information gap analysis was carried out on the impact of climate change on land-water-ecosystem quality in polar and mountainous regions across the world where climate change is known to progress significantly faster than the global average. Information from these regions should assist in predicting future climate change-related processes in other mountain and lowland regions. A database of 769 peer-reviewed scientific papers (published since 2000) that focused on thirteen representative benchmark sites with mountainous characteristics located on all continents was developed to identify and quantify these knowledge gaps. All entries in the database were assigned up to three keywords so that a total of 1 015 unique keywords were used to describe the papers. These were then grouped into five broad categories. The number of keywords in each category and the percentage of all keywords in that category (in brackets) were:

- Snow and Ice (366; 36.1 percent);
- Terrestrial Ecosystems (260; 25.6 percent);
- Water (173; 17 percent);
- Livelihoods (146; 14.4 percent) and
- Land Degradation (70; 6.9 percent).

After normalisation of the data, the priorities for future research on climate change impact in mountainous regions should be considered in the following order of priority:

- impact on land degradation: soil erosion, sediment redistribution and slope stability;
- impact on livelihoods: food and feed production, agricultural sustainability, soil and water quality, land and water availability for cropping, irrigation, livestock and forestry systems, energy production and hydropower;
- impact on water: runoff, river discharge dynamics;
- impact on carbon and nutrient cycling: soil organic carbon dynamics, greenhouse gas emission and feedback mechanisms;
- impact on the cryosphere: snow cover, glacier dynamics, permafrost and land-water-ecosystem quality interactions.

Improved knowledge on the impact of climate change in mountainous regions will not only assist marginal farming communities in mountain regions, it will also assist national and regional policy-makers in better forecasting the impacts of such change on less sensitive and lowland regions and communities.

Initial soils (Michele D'Amico)

Carbon stocks in oceanic alpine landscapes

Andrea J. Britton, Rachel C. Helliwell, Allan Lilly and Lorna A. Dawson

This study looks at the oceanic alpine landscape of a catchment in Scotland's eastern Highlands. Oceanic climates are typical of the western margins of continents at mid-latitudes. Scottish mountain landscapes experience an oceanic climate characterized by high rainfall, high wind speeds and cool temperatures year round, with limited differentiation between winter and summer, and a highly variable winter snowpack. These conditions give rise to specialized oceanic alpine habitats, with vegetation often dominated by mosses and lichens. Oceanic alpine habitats also occur at much lower altitude than their continental counterparts, descending almost to sea level in parts of northern and western Scotland.

Soil sampling in the Cairngorm mountains, Scotland, United Kingdom (Andrea J. Britton)

Cold and wet northern biomes contain large stocks of carbon (C) in their soils and may hold up to one-third of the global pool of soil C. High-latitude and altitude areas, where rapid warming is already occurring, are also predicted to experience the greatest effects of climate change. While C stocks in lowland environments are relatively well characterized, those in alpine systems are less well known. Interactions between complex topography and snow cover lead to steep local gradients in soil temperature and moisture which, in turn, influence the potential for C fixation by primary plant production and for losses through biological, chemical and physical decomposition processes. This points to the likelihood of high spatial variability in the C stocks held within mountain soils. In this case study we explore the variability in soil C stocks, C fixation in plant primary production and decomposition rates across an oceanic alpine landscape in Scotland.

Oceanic alpine landscapes in Scotland include ecosystems typical of many mountain areas on the northwestern fringe of Europe. With a high prevalence of bryophytes and dwarf shrubs, these systems also have similarities with arctic and subarctic tundra. Winter snow cover in Scotland is highly variable, and likely to become more so in the face of climate change. Loss of snow cover could have a major impact on the distribution of plant communities within the landscape and also on the processes controlling inputs to, and losses from, the soil C store (for example by changing the quality and quantity of plant litter, or through changes in the composition or activity of the soil microbial community). There is therefore an urgent need to improve understanding of the status of C stocks in mountain soils in order to predict the likely impacts of climate change. We investigated C stocks in the oceanic alpine landscape using a study catchment.

A typical oceanic alpine landscape in spring – complex topography leads to high soil variability (Andrea J. Britton)

In the eastern Highlands of Scotland, the Allt a'Mharcaidh catchment, on the western edge of the Cairngorm mountains, covers an area of around 10 km^2, spans an altitudinal range of 320 to 1 111 masl, and is underlain by granite parent material. The climate is cool oceanic with mean monthly temperatures (at 575 masl) ranging from 1.2 °C in February to 10.3 °C in July, and a mean annual rainfall of around 1 100 mm, about 30 percent of which falls as snow in winter. This catchment represents a typical Scottish upland/alpine ecosystem, with blanket mire vegetation on deep peat soils in the valley bottom, lichen and bryophyte-rich heather (*Calluna vulgaris*) moor and podzolic soils on the valley sides, and a high plateau with alpine soils and vegetation above 700 masl.

The investigation included plant and soil C stocks, net primary production (NPP) and decomposition rates at the Allt a'Mharcaidh, across a typical toposequence of oceanic alpine habitats. This included blanket mire and boreal *Calluna* heath on the lower slopes and within the alpine mosaic on the upper slopes; early-melting snowbeds dominated by *Nardus*, alpine *Calluna* heath on exposed ridges and moss-dominated *Racomitrium* heath typical of summit areas. These habitats represent the most prevalent alpine habitats in the United Kingdom. In each habitat we measured the C stocks in both vegetation and soils, estimated C inputs from net primary production of plants, and measured decomposition rates of plant litter.

It was found that total ecosystem C stocks were large: 11-26 kg C m^{-2} in the alpine habitats and 50 kg C m^{-2} in the blanket mire. Spatial variability of C stocks was high, as expected. Within the alpine zone, C storage was greatest in the snowbed (S3) (26 kg C m^{-2}) and least in the *Racomitrium* moss-dominated summit heath (S1). In all habitats, the C stocks were dominated by C held in the soil, with only a small fraction of the total C stock in the vegetation. Total C stocks did not vary consistently with altitude, but reflected topographic gradients of temperature and moisture within the alpine zone. Variability in total C stock also matched the between-habitat variability in net primary productivity of the vegetation.

Early- and late-melting snowbed communities in the Cairngorm mountains, Scotland (Andrea J. Britton)

In almost all habitats, the soil C stock represented approximately 280 years of current net primary production. Decomposition of plant litter was extremely slow. The cool, wet climate, combined with the recalcitrant nature of litter from the bryophytes, lichens and dwarf shrubs, which dominate oceanic alpine vegetation, produce favourable conditions for C accumulation in the soil. As with C stocks, the plant litter decomposition rate did not follow a simple altitudinal pattern; it varied between habitats and was controlled by the chemical quality of the litter and the amount of moisture in the soil. Surprisingly, decomposition was fastest in the snowbed – faster than in the blanket mire and boreal heath on the lower slopes.

The results demonstrate that oceanic alpine habitats contain significant stores of C, and indeed are among the most C-dense ecosystems on a global scale. The results from this single study catchment highlight the high spatial variability in alpine soils and their C stocks, arising from complex topography and resulting gradients in temperature, moisture conditions and plant community composition. The snowbeds studied here appear to represent hotspots for carbon accumulation within the alpine landscape, but may also be under threat from future climate change. Climate warming and changes in the amount and distribution of winter snow cover could greatly impact the distribution of plant communities across the alpine landscape. A better understanding of the mechanisms underlying the spatial variability in C stocks and fluxes that we observed is now urgently needed if we are to predict the fate of alpine soil C stocks.

Location of the Allt a'Mharcaidh catchment and toposequence study sites. S1 – *Racomitrium* moss-heath, S2 – Snowbed, S3 – Alpine *Calluna* heath, S4 – Boreal *Calluna* heath, S5 – Blanket mire (Andrea J. Britton)

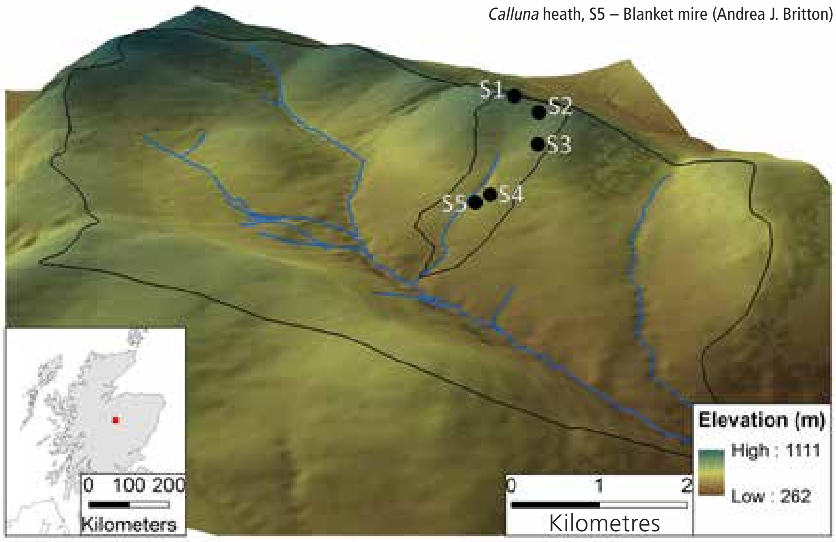


Figure 1

Lesotho mountain wetlands potential for carbon storage

Botle E. Mapeshoane

About 40 to 60 percent of soil carbon pool is held in the top 0.2 m of the Lesotho mountain wetlands soil, the layer that is most prone to changes in soil use and management. Minimum carbon distribution occurs in the subsoil due to restricted root growth. Declining vegetal cover due to grazing of wetlands reduces the potential of the wetlands to store carbon. The main threat is the release of carbon from soils due to increased rate of soil organic matter decomposition as a result of drainage of the wetlands.

No buffer zones, animals graze within a wetland (Botle Mapeshoane)

The mountain wetlands of Lesotho play a major role in sustaining the perennial water flow and regulating the water quality of the major Orange-Senqu River Commission (ORASECOM). They also serve an economic purpose, as there is trade in quality water between South Africa and Lesotho through the Treaty on the Lesotho Highlands Water Project (LHWP). The main use of the mountains wetlands catchment is grazing of domestic animals, although relatively small protected portions have been made nature reserves because of their endemic alpine flora and fauna.

The stock of organic carbon present in natural soils represents a dynamic balance between the input of dead plant material and loss from decomposition. The prolonged soil water saturation (high water table) and anaerobic conditions in wetlands lower the rate of organic matter decomposition and lead to organic matter accumulation. When wetlands are drained by gullies, the water table declines, the organic carbon that is normally under water becomes exposed to the air, where it decomposes and releases carbon, which is one of the major greenhouse gases. With the ongoing degradation of Lesotho wetlands, there is a possibility that their stored carbon will be released into the atmosphere (Figure 1).

Land-use change can alter the water table of the wetlands through compaction, which will cause runoff and soil erosion. Land use and management also control organic carbon distribution in the soil. The vertical pattern of soil organic carbon (SOC) can be used to predict consequences of loss of vegetal cover on soil carbon storage in wetlands.

The wetlands, described as peatlands, comprise bogs and fens, even though some researchers disputed the existence of bogs in these wetlands because of their varying organic carbon content. Most soil classification systems describe peat as an organic material that contains organic carbon content greater than 12 to


Unsustainable use of land damages the delicate vegetal layer of the wetlands (Botle Mapeshoane)

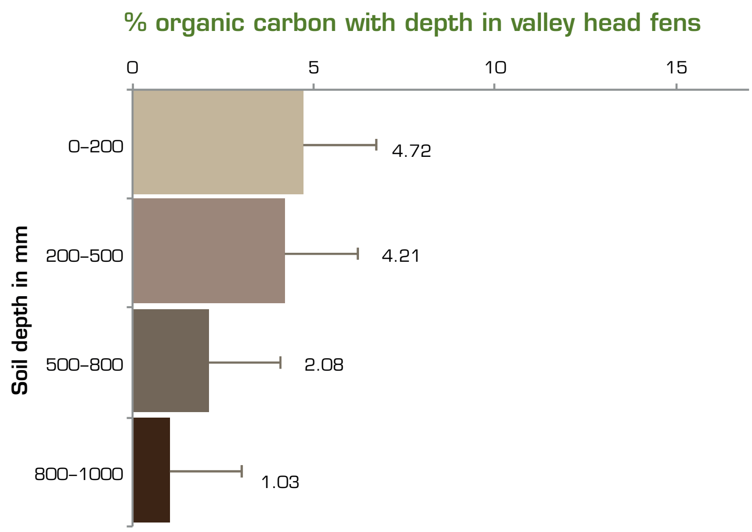
18 percent depending on clay content of the mineral fraction. In this project, vertical distribution and carbon pools were evaluated to a depth of 1 000 mm. Representative soil samples were collected from the three wetland types (bogs, valley head fens and hillslope seeps) at various depths in soil (Figure 1). SOC was determined from total carbon. Bulk density was determined by core samples from each depth. The soil profile carbon mass was calculated as the sum of the product of SOC and bulk density for each depth.

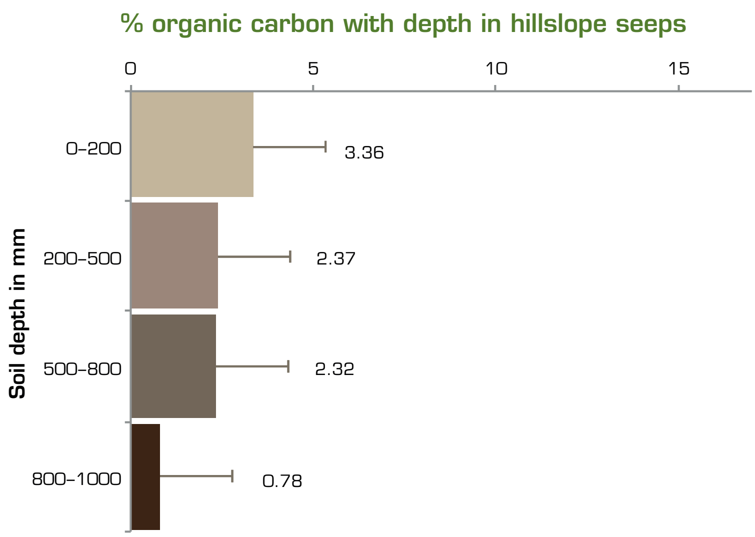
About 40 percent of SOC was stored in the top surface soil layer which are 200 mm thick in fens and hillslope seeps, while bogs hold about 60 percent SOC in the surface layer. The SOC content showed a drastic decrease from surface layers into the subsoil. This suggested the accumulation of organic matter from above ground litter and roots, and little distribution into the subsoil. This is a consequence of limited root distribution in the subsoil – the result of shoot/root allocations combining with vertical root distributions which affects the depth of the distribution of SOC. In the subsoils, SOC is added from aboveground and root litter through large pores draining water mixed with SOC and mixing by soil animals such as earthworms. The SOC input into the subsoil is of relative importance because it is characterized by high mean residence times of up to several thousand years.

The mean SOC density was 304, 210 and 205 t C ha^{-1} from bogs, fens and hillslope seeps respectively within the 1 000 mm soil depth. This is very low compared with 600 t C ha^{-1} estimated from global peats in temperate regions. Lal recalculated the soil organic carbon density of 1 170 t C ha^{-1} from wet organic soils, while the estimates of soil organic carbon densities from temperate grassland are between 141 and 236 t C ha^{-1}. Decline in above-ground biomass affects annual soil organic matter/carbon turnover and reduces potential for these wetlands to store atmospheric carbon. Additionally, an increase in soil temperature due to removal of vegetation cover will enhance the rate of carbon dioxide (CO_2) emissions from peat.


Soil inspection to 1m depth (Botle Mapeshoane)

The carbon storage in the mountain wetlands of Lesotho is significantly lower than the relative similar environments of the world. The degradation of wetlands impacted by grazing is putting the top 200 mm surface layer at risk of carbon loss. Grazing in the wetlands catchments requires the introduction of a buffer zone to control trampling by animals and encourage luxurious regrowth.





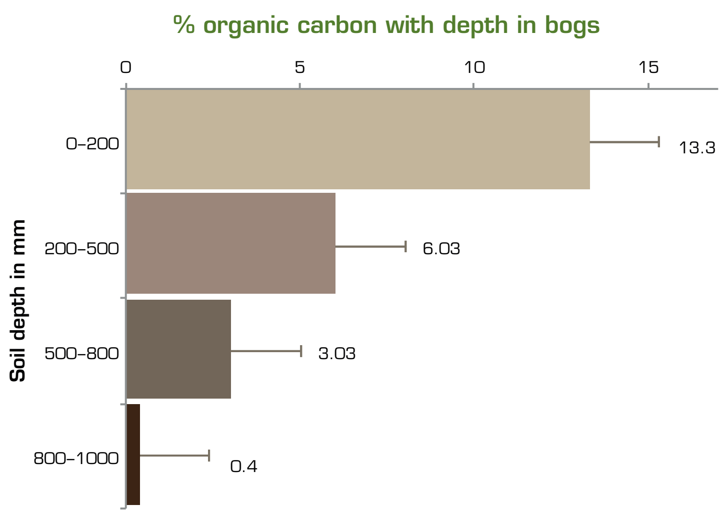


Figure 1: Soil organic carbon pools at four depths in different wetland types of Lesotho.

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.

Forest expansion on abandoned grassland. Trentino, Italy (Claudia Guidi)

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).

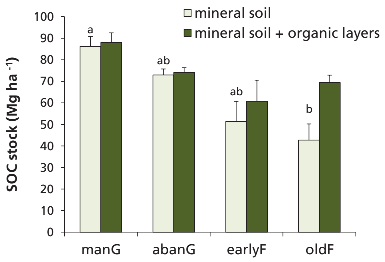


Figure 1: SOC stocks at the four successional stages (manG: managed grassland; abanG: abandoned grassland; earlyF: early-stage forest; oldF: old forest) in mineral soil (0–30 cm) and organic layers. Error bars represent the standard error of the mean (n = 3). Different letters indicate significant differences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

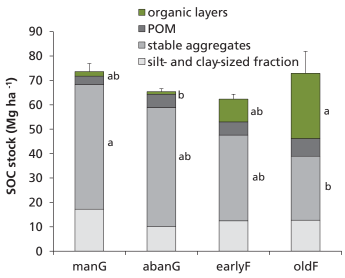


Figure 2: SOC stocks at the four successional stages (manG: managed grassland; abanG: abandoned grassland; earlyF: early-stage forest; oldF: old forest) in fractions within the mineral soil (0–20 cm) and in organic layers. Error bars represent the standard error of the mean of total SOC stocks (n = 3). 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.

Promoting soil health and productivity in Eastern Arc mountain ecosystems through collaboration and networks

Crispus Njeru, Paul-André Calatayud, Bruno Le Ru, Samira Mohamed, Sarah Ndonye and Tino Johansson

Smallholder farmers in the Taita hills and Mount Kilimanjaro recognize the need to conserve soil nutrients of fields and farms located in the upper, middle and lower zones of mountainous areas. These mountain communities depend on rain-fed subsistence agriculture which means that for sustainable subsistence crop production, they also depend on nutrient availability and use efficiency in farming households. A study under way in the area has looked at loss of land cover and infestations of plant pests and diseases and is using this information to raise farmers' awareness of soil fertility and to introduce best cropping practices.

Intercropping mosaic systems. Mount Kilimanjaro, United Republic of Tanzania (Crispus Njeru).

The Taita Hills are located in southeast Kenya. Mount Kilimanjaro, the highest free standing mountain in the world, is located in northeastern Tanzania, approximately 110 km west of Taita Hills, in southeast Kenya. Both Mount Kilimanjaro and the Taita hills are part of the Eastern Afromontane Biodiversity hot spot, and are important hubs for agricultural and economic livelihoods of their mountain communities. Rain-fed small-scale subsistence food production at household level remains the principle source of livelihood for these communities.

In these mosaic crop production systems, farmers plant their crops with few, if any, soil fertility inputs, because many believe that their soils are currently fertile enough to sustain crop production into the future. Crop yield reports by the local agricultural officials however show this belief to be far from the reality of the situation.

Climate change signals in the Taita and Kilimanjaro ecosystems have been experienced through decreased seasonal rainfall amounts, and increased duration of hot months and occurrences of droughts. This has had a negative effect on the ecosystem' natural soil nutrient replenishment process via the carbon (C) cycle. Deforestation has substantially reduced surface biomass accumulations thus accelerated the pace for soil organic carbon and nutrient loss. In the Wundanyi area of the Taita hills, for example, home to tropical indigenous forests more than 100 years ago but converted to agricultural crop production several decades ago, there has been a systematic and drastic reduction in cereal grain yields in the last ten years. Smallholder harvests are so low in the March to April rainy season, regarded traditionally as the "food seasons", that some fields are unable to produce enough seed to compensate for what was planted. Insect pests and disease pressure further devastate whatever little crop material that has emerged in the fields, resulting in total harvest loss.


Sloping land without adequate soil cover. Taita hills, Kenya (Crispus Njeru)

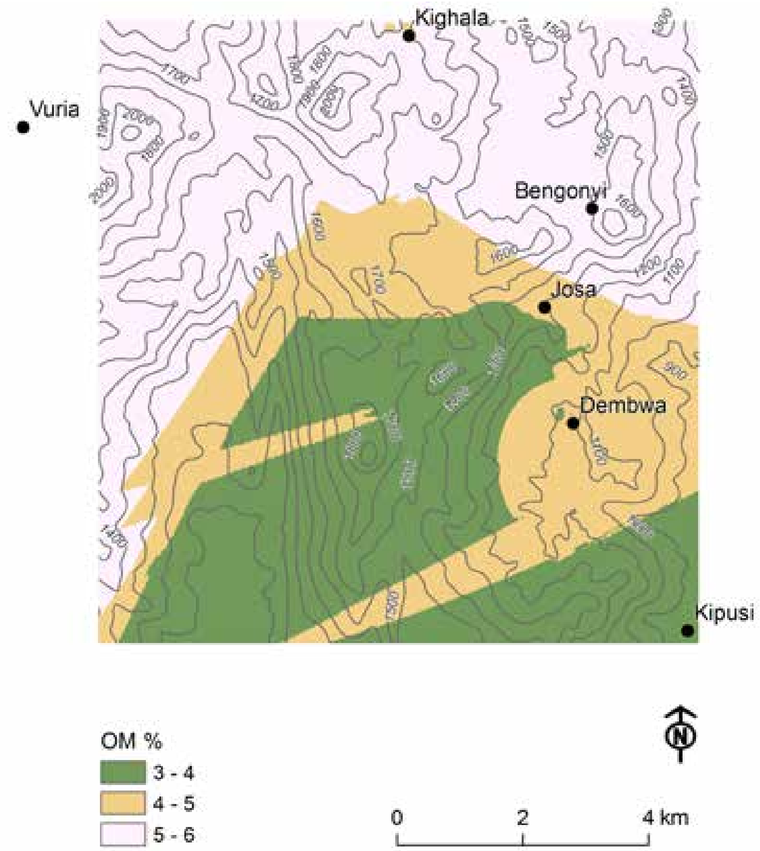
The initiative to increase awareness of restoring the fertility of degraded soils in the Taita hills and Mount Kilimanjaro did not start on without outside help. In early 2012, the Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa (CHIESA) project was launched in Nairobi, Kenya, to study the effects of change in land use/land cover, biophysical and socio-economic status on crop production and food security. Funded by the Ministry for Foreign Affairs of Finland, the project is coordinated by the International Centre of Insect Physiology and Ecology (ICIPE) with several collaborating institutions such as the University of Helsinki (Finland), University of York (United Kingdom), Universities of Dar-es-Salaam and Sokoine (United Republic of Tanzania), Institut de Recherche pour le Développement (IRD – France), among others. In these montane environments, smallholders are disadvantaged in several ways. Low household income and little investment in small- scale farming have reduced the quantity and quality of farm harvests. Additionally, new invasive pest and weed species continue to devastate the popularly grown maize crop, and other traditional value crops.

Thus, researchers and students from partnering institutions have embarked on an intensive campaign to assess the consequences of land cover loss, and accompanying soil physical and chemical deterioration on insect pest dynamic; occurrence, damage and infestation patterns, among other research questions. Results from the study show soils in these mountain ecosystems to be severely lacking in important macro and micro elements such as silicon, phosphorus and nitrogen. Soil organic carbon levels are also critically low in lower- to mid-elevation zones where farming has taken place for the last 50 to 100 years. It is against this backdrop that CHIESA embarked on a campaign to raise awareness of soil fertility and best cropping practices among smallholders.

Designed as informal training sessions involving agricultural, civic and development actors, pertinent issues such as the importance of soil testing and the logistics involved, have been discussed with more than 200 farmers from both ecosystems. Soil nutrient improving inputs, types, usage, timings and mode of application for maximum agronomic efficiency are some of the issues discussed with participants. From CHIESA research activities within the farming communities, simplified maps showing soil nutrients were produced, translated into the local *kiswahili* language, and published as brochures to facilitate farmer-to-farmer sharing. Diversification of farming enterprises to ventures such as honey production and establishment of native fruit and agroforestry tree species have huge potential to curb soil erosion and restore the fertility of degraded fields.


Maize tissue damage by pests. Mount Kilimanjaro, Tanzania (CHIESA)

Gender also plays an important role in mountain farming communities, where most important household decisions are made by the man of the house. In Mount Kilimanjaro and the Taita hills, men typically leave their household for work in the nearby Moshi and Arusha towns in Tanzania and the coastal town of Mombasa in Kenya. This rural urban movement often leaves only women, youth and the elderly in the homesteads, usually with women left in charge of the agricultural production. This has an important implication in future awareness campaigns, and cognizance of the need to sensitize mountain community women and youth on the outcomes and impacts of initiatives such as CHIESA.



Simplified map showing organic matter status for the Taita hills, Kenya (P. Catalayud)

Lessons learned

- For some forest lands converted to agricultural lands, it only takes ten years for harvested grain yields to fall to half those obtained immediately after conversion.
- Smallholder farmers in mountain regions need to be aware of strategies available to curb soil nutrient loss from their farms through fertilizer use and economy, soil management and agroforestry practices.
- In mountain environments, women and youth play an important role in agriculture and represent a critical entry point for initiatives seeking to restore and improve ecosystem fertility and productivity.

8 Mountain soils and cultural heritage

Aohan Dryland Farming System, China (GIAHS Conservation and Management Office of Aohan (China))

Moujahed Achouri, Rosalaura Romeo and Sara Manuelli

Mountain soils and cultural heritage

Hill tribe woman, Thailand (FAO/Piya Su-Utai)

The concept of traditional heritage and techniques is embedded in the inherent characteristics of traditional and indigenous food systems. This represents an evolving system of practices that has been perfected over time through trial and error, and by adjusting to the changing environment to cope with socio-economic needs while managing finite natural resources, such as soil, water and forests, in a sustainable way.

"The land has an owner? How's that? How is it to be sold? How is it to be bought? If it does not belong to us, well, what? We are of it. We are its children. So it is always, always. The land is alive. As it nurtures the worms, so it nurtures us. It has bones and blood. It has milk and feeds us. It has hair, grass, straw, trees. It knows how to give birth to potatoes. It brings to birth houses. It brings to birth people. It looks after us and we look after it."

Eduardo Galeano, "Memory of Fire", Volume 1, 1982

There are several traditional knowledge and food systems located in mountain areas. These systems have resulted in outstanding landscapes, but also in the maintenance and adaptation of biodiversity, indigenous knowledge and resilient ecosystems. Among the particularities of mountainous areas are that the weather is often more extreme than in plains and that altitude affects vegetation. These two factors have a direct effect on soils and on the traditional food systems that are viable in mountainous areas. These food systems, to survive over time and produce enough for their communities, have to be deeply rooted in tradition and heritage while being adapted to the harsh weather conditions and environment.

Many of these mountain areas and the livelihoods they host constitute Globally Important Agricultural Heritage Systems (GIAHS), defined as remarkable land-use systems and landscapes which are rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development.

The ancient Ifugao mountain rice terraces in the Philippines, the *waru-waru* systems in Peru, the *suka collos* in and around Lake Titicaca in the Inca region of the Peruvian and Bolivian Andes, and the *khettara*, a sophisticated water management system in Morocco, are just some of the living examples and proof of sustainable natural resources management, where the history of protecting and respecting soils has been passed from generation to generation.

Soils are at the very foundation of these systems. In fact, in mountainous areas where indigenous peoples live, soil is viewed as much more than a medium for growing food. It is considered a "sacred resource", an integral part of life which is linked to their cultural, social and spiritual identity. Indigenous peoples respect and protect soils as a key element within an integrated system that is part of Mother Earth. With their sophisticated understanding of nature and the properties of soils, indigenous peoples know that a healthy living soil is the foundation of productivity, cultivation and diversification of crops for food and medicine, as well as for raising livestock.

Landscape of the dryland terraces. Aohan, China. (GIAHS Conservation and Management Office of Aohan (China))

The relationship between soil and humans is an important part of almost all religious rites and beliefs. The earth, as the basis for human life, is present in cosmogonies as Mother Earth and as an "element", a basic constituent of natural bodies and humans alike. Ancient Greek and Roman, Chinese, Buddhist, Hindu, Inca and most non-monotheistic religious systems all emphasize the spiritual aspects of human interventions into soils.

Prescriptions to protect the soil and ensure its regeneration are even mentioned in the Bible. For example, the book of Exodus prescribes a year of fallow, Sabbath, to allow the land to rest after six years of agricultural activity.

In traditional Chinese rituals, soil altars were integrated into the greater belief system of Daoism and were a combination of an elemental approach and a fertility cult. The Altar of the Earth and Heavens in Sun-Yat-Sen Park dates back to the fourteenth century and contains hard-packed soil in five colours representing the basic soil distribution in China. Chinese religion influenced Japanese Shinto religion, which has ten deities connected to various aspects of the soil. In India, soil worship is celebrated in parts of the country on Dhulivandan day.

In the Andes, the fertility goddess Pachamama, revered by the indigenous peoples, presides over planting and harvesting. Rituals to honor Pachamama take place all year, but especially in August, right before the sowing season. During this cold month, the Andean people believe that they must be on good terms with nature in order to keep themselves and their crops and livestock healthy and protected. Pachamama reinforces the relations between human communities and their natural environments, bringing together people from different clans and villages at various points of the agricultural cycle.

One of the fundamental principles of agricultural heritage is conserving and safeguarding the "sustainability functions" of traditional food systems, because these functions guarantee a wide variety of ecosystem goods and services which we all depend on. For example, traditional agricultural and forestry systems strengthen soils by enriching and protecting their biological diversity.

Many mountain peoples have developed large-scale hydrological and agricultural water-harvesting infrastructure to overcome water constraints. Water harvesting by early farmers played a pivotal role in the emergence and diversification of food production, the domestication of plants and animals, and the shaping of eco-cultural landscapes.

The Inca civilization in the central Andes had a social organization based on water management and work sharing and cooperation. Irrigated terraces play an important role in protecting soil against erosion and in maintaining agricultural fertility, but they are also cultural and landscape elements that provide a strong identity for numerous mountain landscapes in the Mediterranean basin from North Africa to southern Europe and the Levant.

In Nepal’s Kabhrepalanchok district, now an area heavily affected by the 2015 earthquakes, where the slope of the land is not too steep, farmers use controlled gullying based on traditional techniques to protect fertile agricultural land, to minimize erosion and help to prevent landslides near villages. The practice is maintained by the traditional community approach and uses only locally available materials.

Women play a crucial role in managing and improving soil fertility as they are often the primary custodians of mountain resources, guardians of biodiversity and the main actors in terms of agriculture, animal husbandry, feed management and other small-scale economic activities. In mountain communities, women are keepers of traditional knowledge, guardians of seeds, custodians of local culture and experts in traditional medicine. Moreover, as men migrate to lowland areas or abroad in search of a higher income, women are left to manage the farms and households. They also participate in trade and income-earning activities by, for example, selling mountain products such as berries, mushrooms, honey, medicinal plants and handicrafts, which has proven to be the key to resilience.

Indigenous peoples and knowledgeable mountain farmers who practice traditional and indigenous food systems know how to protect their soils because they live on the land and have intimate knowledge of their soils. Their knowledge and practices are important not only in terms of soil conservation but for the production of high quality nutritious food for their family’s consumption and for local and global economies alike. Their livelihoods and the survival of their tradition, culture and spirituality are intrinsically linked to their relationship with the environment and in particular with the management of the soils.


Farmers in Nepal (Alma Karsymbek)

The man from the glacier: Similaun Man

Carmelo Dazzi and Edoardo A.C. Costantini

The specific environmental conditions of mountains, generally characterized by steep slopes, poor and shallow soils and extreme climate conditions, coupled with traditional knowledge, cultural and spiritual values have resulted in several adapted land-use practices that shape the landscape of mountain soils. Although the geomorphological characteristics of mountains usually prevent the development of big cites, there is a great diversity of environments, including patches of fertile soils, that allows for plenty of opportunities for the subsistence of small settlements. This is testified by the millennia relationship between mountain soils and humankind.

The so-called "Man of Similaun" (nicknamed Ötzi) is the Europe's oldest known natural human mummy, displayed in the South Tyrol Museum of Archaeology in Bolzano (Italy) (Figure 1). Ötzi was a man who lived around 3,300 BCE in the Alps, who roamed mountains to hunt dears and ibexes, forestlands to hunt birds and collect fruits, roots, medicinal plants, and grew einkorn and barley in the valleys. He was also a shepherd and a skilled copper miner. The harshness of the environment in which he lived, similar to the current one in terms of climate and vegetation (Figure 2), did not prevent the development of rather sophisticated forms of civilization, allowing him to modify the morphology of the terrain through terracing and favour crop cultivation.

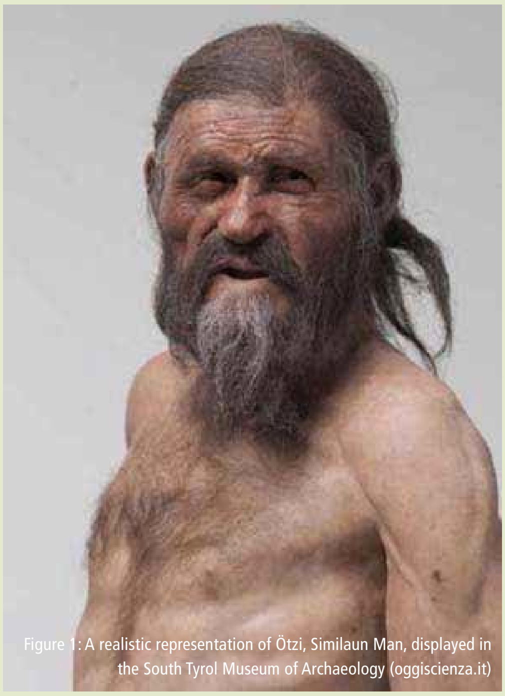


Figure 1: A realistic representation of Ötzi, Similaun Man, displayed in the South Tyrol Museum of Archaeology (oggiscienza.it)

Figure 2: The environment where Similaun Man used to live, about 5000 BP, is very similar to today's, scientists say (dolomitiedintorni.it)

Status and potential use of medicinal plants in the Pamir region of Tajik and Afghan Badakhshan

Aziz Ali and Anzurat Akobirshoeva

Badakhshan is a historic region located at the junctions of the Himalayan, Karakoram, Hindu Kush and Tine Shan mountains, comprising parts of what is now northeastern Afghanistan and south eastern Tajikistan, an area where indigenous medicinal plants have been traditionally used as affordable, effective methods of treating a multitude of ailments. The study, conducted over the course of four years by the Aga Khan Foundation (AKF) Afghanistan, looked on both sides of the border, gathered information from 248 residents in order to compare the plant use patterns in the two areas. As the first systematic look at traditional medicinal practices, the study found both common and distinct uses for the plants in the two areas, but also that they are being depleted at an alarming rate, which has environmental and economic implications for the area, as well as an impact on the health of residents who rely on the plants.

Anethum graveolens L. – dill plants, Ishkashim, Afghan Badakhshan (Aziz Ali)

For generations, the medicinal plants of Tajik and Afghan Badakhshan have been an abundant natural resource. The study found that local people in Tajik Badakhshan use 92 species and those in Afghan Badakhshan use 31 species for medical purposes, some on both sides of the border but for different problems. In total, 37 percent are used for treatment of the cardiovascular system, 22.8 percent for musculoskeletal problems, 16 percent for female-related diseases, 15 percent for skin diseases, and 14 percent for treating the urogenital system.

The study revealed a common understanding of herbal remedies in both Tajik and Afghan-Badakhshan as witnessed by how plants are collected, dried and stored, and how medicines are prepared and administered. At the same time, though, 32 percent of the plants used in both Afghan and Tajik Badakhshan have different uses and different vernacular names.

For example, the *Daucus carota* L. is used by Afghans to aid with dysentery and by Tajiks for relief of hypertension and abdominal discomfort. Both use the *Ziziphora pamoiroalaica* plant for treating blood-pressure problems. However, the Afghans boil the plant's stem, leaves and flowers in water and milk, whereas the Tajiks only infuse it with boiled water.

Both the similarities and differences in the specific uses and vernacular names of the medicinal plants can be explained by the historical interconnectedness of the two populations juxtaposed with their more recent separation into nation-states, and the mountainous isolation of the regions which is exacerbated by the Panj-Amu River separating the nations. The main scientific and local names of the common medicinal plants are given in Table 1.

Rheum sp. on sale along Salang road. Afghanistan (Aziz Ali)

Table 1

Scientific name of plants	Tajiki name of plants	Afghani name of plants
Equisetum arvense L.	*Bandakwokh*	*Bandakkah*
Juglans regia L.	*Gooz, bojak*	*Chormagz*
Urtica dioica L.	*Caginc, chaginc*	*Pich-pichonak*
Crataegus korolkowii L. Henry	*Inzekh, gegn*	*Dulona*
Rosa canina L.	*Akhar*	*Gulkhor, kikek*
R. fedtschenkoana Regel	*Akhar*	*Gulkhor, kikek*
Glycyrrhiza glabra L.	*Muthq*	*Shirinbuya, malakhch*
G. uralensis Fisch.	*Muthq*	*Shirinbuya, malakhch*
Melilotus officinalis (L.) Pall.	*Shorgarj, shorgarjak*	*Zardrishqa*
Peganum harmala L.	*Sipandar, sipand, sipandona*	*Sipandona, hazorispand, ispand*
Hippophae rhamnoides L.	*Chung, galagat, xinshuth*	*Gilgitak, siyohkhor*

Hippophae rhamnoides – sea buckthorn. Wakhan, Afghanistan (Aziz Ali)

Over the last 20 years, the availability of these valuable plants has greatly diminished due to various factors, most of which have human origins. Because of this, not only are the rich medical traditions of the region in jeopardy of being lost, removal of medicinal plants has been detrimental to the natural habitat as it has increased the frequency and severity of mudslides and lessened protection from wind, resulting in increased soil degradation.

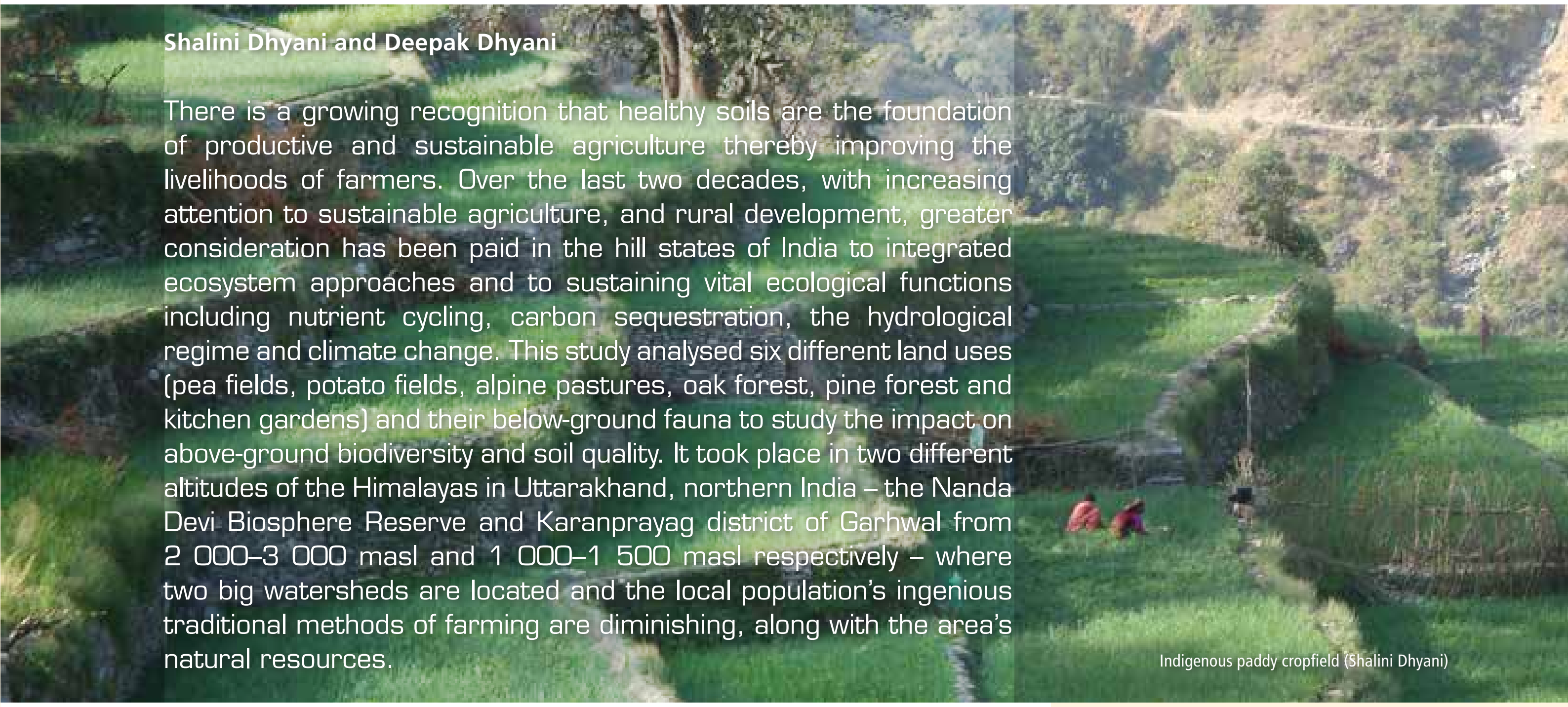
As the study found, there are several reasons for this depletion. Local people lack awareness of the importance of medicinal plants for their livelihoods and sustenance, often harvesting the plants for fuel and fodder rather than medicine. In addition, there is a lack of clear government policies for the conservation and management of medicinal plants and other non-timber forest products and there has been prolonged drought coupled with desiccating winds in high-altitude pastures and mountains. These factors have not only contributed to continuous decline in the medicinal plant population but also accelerated land degradation and soil erosion in the mountain environment. Landslides and flash floods have become common phenomena, jeopardizing the very survival of poor mountain communities.

A variety of interventions on behalf of development actors as well as government institutions have taken place to protect this natural resource, including soil and forestry preservation, increased training in harvesting and preparation to limit exploitation, additional on-farm planting of medicinal plants and further research on the medicinal benefits of plants in the Afghan Badakhshan region.

This is happening at a time when promotion and processing of plant-based products have been given a fresh impetus throughout the world, providing a niche market for medicinal and aromatic plants. Badakhshan has the indigenous species and unique climate to capitalize on these market trends if the region starts conserving, promoting and sustainably managing its unique resources.

The indigenous knowledge of medicinal plants passed down the generations in both parts of Badakhshan should be documented and preserved. This will help to revive the diminishing traditional knowledge about plants and recount it to the local communities, and to maintain a sense of pride in local cultural knowledge and practices, thus reinforcing the links between communities and the environment that are essential for conservation.

Sustainable indigenous hill agriculture practices to conserve mountain soils and improve crop yields in Garhwal



Shalini Dhyani and Deepak Dhyani

There is a growing recognition that healthy soils are the foundation of productive and sustainable agriculture thereby improving the livelihoods of farmers. Over the last two decades, with increasing attention to sustainable agriculture, and rural development, greater consideration has been paid in the hill states of India to integrated ecosystem approaches and to sustaining vital ecological functions including nutrient cycling, carbon sequestration, the hydrological regime and climate change. This study analysed six different land uses (pea fields, potato fields, alpine pastures, oak forest, pine forest and kitchen gardens) and their below-ground fauna to study the impact on above-ground biodiversity and soil quality. It took place in two different altitudes of the Himalayas in Uttarakhand, northern India – the Nanda Devi Biosphere Reserve and Karanprayag district of Garhwal from 2 000–3 000 masl and 1 000–1 500 masl respectively – where two big watersheds are located and the local population's ingenious traditional methods of farming are diminishing, along with the area's natural resources.

Indigenous paddy cropfield (Shalini Dhyani)

Soil is a rich resource that if not managed sustainably does not have the time to regenerate. Continuous use of chemical fertilizers and hybrid crop varieties has increased agricultural production in Karanprayag but, in doing so, has gradually decreased soil health, reducing the presence of beneficial soil fauna such as earthworms, ants and nitrogen-fixing bacteria.

About 80 percent of the population are actively engaged in traditional agricultural systems, which play a vital role in the subsistence economies and living standards of Garhwal hill locales. The agricultural land holdings in Garhwal are very small – average 0.02 ha per capita. Terraced slopes covering 85 percent of the total agricultural land are generally rain-fed, while 15 percent are irrigated. The soil under rain-fed agriculture is particularly vulnerable to soil losses through a combination of natural factors (sloping topography, heavy seasonal rainfall) and human factors (intensive cultivation and erosion-triggering agricultural practices). There are more than 40 crops cultivated along an altitudinal gradient of 300 to 3 000 masl. The inhabitants of Garhwal are fully dependent upon forests for water as well as sustainable low-cost traditional agriculture. Monocropping has replaced the traditionally valued indigenous crops.

In spite of living in uncertain, risky and fragile ecological conditions, the farming communities of Garhwal have developed and refined indigenous techniques over the centuries.

Diverse crops and crop rotation. Garhwal farmers generally cultivate 10-12 staple food crops a year including finger millet, pseudo millet, lesser-known legumes, oil seeds and spice varieties. The system is locally known as *barahnaja* (high crop diversity that provides food sufficiency and security). This practice is

Oil yielding crop in crop field (Shalini Dhyani)

beneficial because diverse canopies of a variety of crops (especially of millets and legumes) help to check the soil erosion during the rainy season, minimize the growth of weeds, and different crops do not compete for similar nutrients from the soil.

Farmyard manure (FYM). An indigenous practice in all the villages, FYM combines the fully decomposed organic matter of cow dung (and excreta of other livestock reared by the inhabitants) with animal bedding, leftover feed and tree leaves. The leaves of the oak (*Quercus leucotricophoa*), maple (*Acer caesium*), buckeye (*Aesculus*), black alder (*Alnus*) and walnut tree (*Juglans regia*) are excellent for FYM because of their fast decomposition. With the application of FYM, earthworms are also introduced to the cropland and increase the soil fertility.

Agroforestry practices. Local farmers plant fodder and fuelwood trees on the margins of their crop fields to bind the soil. These include *Carpus vimnea*, *Celtis australis*, *Grewia optiva*, *Sapindus mukorossi*, *Ficus neriifolia*, *Debrgeasia salicifolia* and *Boehmeria japonica*.

Fallow fields. Keeping agricultural land fallow for 4–6 months is a practice in rainfed agro-ecosystems. No crop is cultivated during *rabi* season on the land from which the mixed crop of finger millet and pulses is taken during *kharif* season. Fallowing of land gives the soil time to convalesce – otherwise it becomes exhausted from the intensive cropping.

Crop residues. Burning the tillage of the field crops, especially mustard, wheat, finger millet and amaranth, adds phosphorous to the soil. Spreading the ash is an indigenous practice for increasing fertility of different crops, especially onion, garlic, coriander and spinach.

***In-situ* manure.** Livestock are left in open fields for 2–3 days for their dung and urine, mainly before the sowing of winter crops by farmers who have large numbers of sheep and goats.

Woman weeding cropfields (Shalini Dhyani)

Due to a variety of sociocultural changes among rural communities and shrinkage in the natural resources, many of these indigenous practices are diminishing. At present a mosaic of landscape units with various degrees of disturbances, extension of agriculture and monoculture crop lands can be seen in each watershed area. The uniqueness of these practices is their suitability to the local conditions, their economic feasibility and easy implementation. One practice complements the other, so if applied in combination they tend to be even more effective in maintaining soil health.

Shifting cultivation: soil fertility and food security issues in Chittagong Hill Tracts, Bangladesh

Sudibya Kanti Khisa, Mohammad Mohiuddin and Justine Cherrier

Shifting cultivation, a traditional method of rotating crops and fallow lands, has provided livelihoods to millions for hundreds of years. Now, the cultivators, or *jumias* as they are called in the Chittagong Hills of Bangladesh, are facing a dilemma of decreasing availability of land due to environmental degradation and lack of policy support, because of the understanding that shifting cultivation amplifies soil degradation and erosion. However, some researchers find, and are promoting the fact, that shifting cultivation actually improves soil health. But in order to survive, many of the *jumias* have already converted what land they have to other farming methods which could have long-term negative effects on the land and on their traditional identity.

Jum field ready for harvest (Sudibya Kanti Khisa)

The Chittagong Hill Tracts (CHT), a predominately hilly area in southeastern Bangladesh, is home to 11 indigenous groups, totalling some 40 000 households, which have been practicing shifting cultivation, or *jum*, for generations. Known as *jumias*, most of them live in poor conditions, as their livelihoods and food security have been increasingly impacted by demographic, environmental and policy pressures. They do not have any private land for shifting cultivation, but they consider the land they cultivate – *jum* land – the *de facto* property of their communities.

Shifting cultivation is a sustainable form of land use, practised by indigenous peoples who cultivate multiple crops but then leave that land fallow so it can rebuild. It is an adaptive agroforestry practice that conserves biodiversity, maintains soil fertility and enhances water holding capacity with sound scientific principles and ecological forest and agricultural activities, especially in indigenous lands and territories. Many researches have shown that shifting cultivation improves soil by restoring soil nutrients and enhances water holding capacity. Indigenous peoples have been dependent on this practice for their food security, livelihoods and their sustenance for generations. In the CHT, many *jumias* are still in favour of continuing *jum*, as it is part of their culture and tradition.

The impacts of shifting cultivation have been the subject of debate for many years. Some researchers have reported that it causes deforestation and sedimentation of rivers and streams and that it amplifies soil degradation and erosion. However, other researchers have found that shifting cultivation has improved soil conditions and soil health suitable for cultivation of multiple crops with least disturbance. It is a resourceful multi-cropping system of agroforestry appropriate for hills and mountains.

Jum converted to agroforestry (Sudibya Kanti Khisa)

Unquestionably, the fallow period of the *jumias* in CHT has now shortened to two to five years, because of the scarcity of suitable lands for shifting cultivation. This scarcity has resulted from lack of recognition of land rights; unfavourable government policies and use of *jum* lands for construction of a hydro-electric dam 65 km upstream from Chittagong; expansion of forest reserve areas and leasing of unclassed state forestland for industrial rubber and tea plantations; and for infrastructure development related to the government-sponsored programme that provided settlement to the Bengali population from the plains districts.

Because of the short fallow period and intensive farming, the rate of soil deterioration has been quite alarming, with a long-term impact on soil fertility and productivity. In order to maintain soil fertility, the land rights and land titles should be given to *jumias* to motivate them to improve the *jum* plots and farming systems in those plots. They have sustainably maintained and enhanced soil fertility for generations by cultivating 50–60 different crop species of cereals, vegetables, medicinal herbs, spices and ornamental plants in the *jum* plots. The soil nutrients, bulk density and water-holding capacity of the soil found in the *jum* sites are the highest in CHT, but the soil colours and textures vary with the sites and land-use categories.

At present, some of the CHT *jumias* have changed their traditional cultivation practices in order to adapt to the ecological stresses and external pressures. They have switched to cash crops such as turmeric, ginger and chillis, fruits and vegetables, and they are planting trees in their *jum* plots – which require heavy use of chemical fertilizers and pesticides. That means the organic *jum* farming is gradually converting to inorganic and, in the long term, the soil fertility and productivity will be adversely affected, not to mention the drastic increase in the cost of production. Borggaard *et al.* estimated the cost of inputs (especially labour) at US$380 per ha per year for the output of US$360 per ha per year. It is also estimated that US$2 million are required annually to compensate the losses made by the use of commercial fertilizers.

An old *Jumia* women with her granddaughter in her back (Mohammad Mohiuddin)

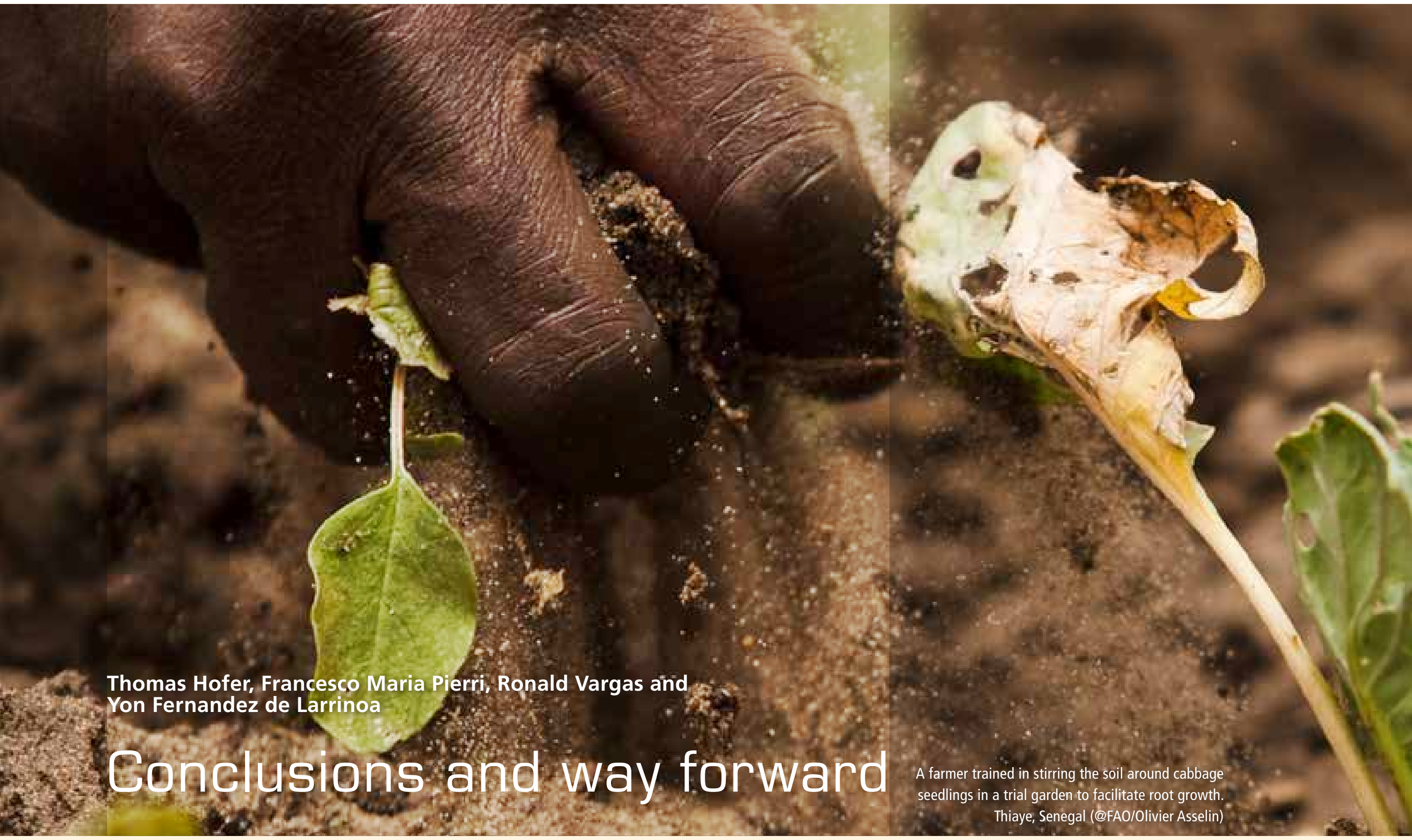
The *jumias* in the CHT are highly vulnerable to food insecurity due to their limited land and lack of access to food, especially in remote areas. As many cannot afford the high prices of commercial food grains, they depend on wild food and some collect and sell forest products as a source of income. However, many of them still believe that *jum* cultivation provides the organic food, rice and vegetables that are needed to provide high-flavoured, high-nutrient and tasty food for special occasions.

With the experience of the *jumias* in CHT and of other indigenous peoples across Asia, there is a need to review existing discriminatory policies on the practice of shifting cultivation. Likewise, land security and support from the state and other development actors should be provided to help provide indigenous peoples with other sources of livelihoods and income. An estimated 10 million hectares of land in South Asia are being used by indigenous peoples for shifting cultivation, which is directly linked to their cultures, identities, traditions and livelihoods. These values and the role of shifting cultivation in food security and enhancement of soil fertility should be fully accounted for by policy-makers, researchers and development actors who are in a position to ensure the *jumias* can maintain their traditions in a way that supports their livelihoods and the environment.

Plot near homestead slashed and ready for burning for *jum*
(Sudibya Kanti Khisa)

Conclusions and way forward

Ladakh, India, at the border with China (Jacopo La Forgia)



Thomas Hofer, Francesco Maria Pierri, Ronald Vargas and Yon Fernandez de Larrinoa

Conclusions and way forward

A farmer trained in stirring the soil around cabbage seedlings in a trial garden to facilitate root growth. Thiaye, Senegal (@FAO/Olivier Asselin)

The benefits of healthy mountain soils go beyond mountain regions and contribute to the well-being of the world at large. Yet mountain soils are prone to rapid degradation, due to their shallowness, the steepness of mountain slopes and unsustainable soil management practices. This process is accelerated by global – including climate – changes, which in turn affect mountain peoples, their livelihoods and food security.

Mountain peoples – the custodians of mountain soils – are among the most marginalized populations worldwide. Living in remote and often harsh environments, their voices are rarely heard, their knowledge and experience seldom acknowledged and their needs barely addressed in broader national development strategies. Indigenous mountain peoples are in particular affected by a combination of isolation, lack of recognition of their rights and ancestral livelihoods, and mounting pressures from extractive industries and private companies.

Mountains and upland watersheds need appropriate land-use planning and integrated management policies to safeguard their soils. There is an urgent need to promote the sustainable management of mountain soils by increasing investment, filling knowledge gaps, developing capacities and organizing the necessary governance, so that soil degradation is halted and degraded mountain soils restored or rehabilitated.

The case studies presented here demonstrate how mountain peoples have over the centuries developed valuable, adaptable and sustainable soil management technologies that contribute to soil conservation and limit degradation. At the same time, this timely publication aims to raise awareness during the International


World Mountain Forum (Alma Karsymbek)

Year of Soils 2015 about the potential threats that the degradation of mountain soils poses to the well-being of mountain and downstream populations. During and beyond the International Year of Soils 2015, global efforts should be made to raise awareness about the fundamental roles that soils play in mountain ecosystems by providing life-critical ecosystem services.

The recommendations are discussed in more detail below:

- **Empower mountain family farmers and small-scale farmers.** Develop capacity and increase support to mountain communities on sustainable soil management. Appropriate policy measures should be promoted for people living and working in marginal mountain areas. Traditional techniques and knowledge should be valued, preserved and shared as they have proven to be crucial for maintaining healthy mountain ecosystems.
- **Empower indigenous peoples living in mountainous areas.** Indigenous peoples are the holders of traditional knowledge on soils management known as ethno-pedology, many of them safeguarded under the Globally Important Agricultural Heritage Systems (GIAHS). When designing policies, the empowerment of indigenous peoples to determine their needs through the respect of Free Prior and Informed Consent in their territories, is fundamental to guarantee that their ancestral soil management techniques and ingenious food production practices survive in mountain areas.
- **Support rural women in mountainous areas.** Rural women living in mountainous areas face the double burden of producing food in a harsh environment as well as taking care of the household. In order to support rural women living in mountainous areas, it is necessary to design policies that empower them economically. Specific technologies, tailored training programmes and targeted social protection policies would enable mountain women to access credit, education and health services. At the same time their rights to land should be guaranteed and proper infrastructures developed. Soil management approaches should be targeted and designed taking into account the roles and the workload of rural women.
- **Promote a landscape approach for provision of ecosystem services.** A sound and integrated approach is crucial in the management of mountain soils, given the high variety of land-use systems and types of soils that can be found in mountain areas. Soil fertility maintenance and erosion control can be enhanced when the various influences and impacts of one system on

the other are fully understood, in particular regarding the vertical zonation of land use. After careful consideration of potential implications, mechanisms should be promoted to compensate the generation of ecosystem services mediated by soils and protected by mountain communities (*e.g.* carbon sequestration, biodiversity conservation and protection of water sources).

- **Incorporate information systems.** National soil information systems for mountain regions should be developed to share approaches, contribute to well-informed land-use planning and sustainable soil management, and support better decision-making, particularly in the context of climate change adaptation and mitigation.


Restoring Sukaqollos for potato planting in Caritamaya, Puno, Peru (@FAO/ Alipio Canahua)

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Agroforestry generates multiple ecosystem services on hillsides of Central America

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Sustainable mountain ecosystem results from participatory community planning: a story from the Syrian Arab Republic

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Alpine soils and forests: securing ecosystem services in the Pamir mountains of Tajikistan

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The history of terracing

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Tackling soil erosion with nuclear techniques in Viet Nam

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Oak and pine forests soils in the Western Himalayan region of India

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152

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Family coffee farmers improve mountain soils

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Beles – from an invasive plant to a blessing

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Crop-Nu – a phone app to calculate crop nutrient requirements

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Mountain pasture soils and plant species richness in the Austrian Alps

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154

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Effect of land-use changes on soil properties: volcano watershed in Quito, Ecuador

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Land reclamation by agave forestry with native species in the mountains of Michoacán state

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Turning rocks into soils from the Ecuadorian Andes to the Mexican transvolcanic sierra

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Lesotho mountain wetlands potential for carbon storage

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Forest expansion on grassland affects soil carbon protection

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Promoting soil health and productivity in Eastern Arc mountain ecosystems through collaboration and networks

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Status and potential use of medicinal plants in the Pamir region of Tajik and Afghan Badakhshan

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Sustainable indigenous hill agriculture practices to conserve mountain soils and improve crop yields in Garhwal

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Shifting cultivation: soil fertility and food security issues in Chittagong Hill Tracts, Bangladesh

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References and further reading

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Promoting soil health and productivity in Eastern Arc Mountain ecosystems through collaboration and networks

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Sustainable indigenous hill agriculture practices to conserve mountain soils and improve crop yields in Garhwal

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Shifting cultivation: soil fertility and food security related issues in Chittagong Hill Tracts, Bangladesh

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In every mountain region, soils constitute the foundation for agriculture, supporting essential ecosystem functions and food security. Mountain soils benefit not only the 900 million people living in the world's mountainous areas but also billions more living downstream.

Soil is a fragile resource that needs time to regenerate. 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. Mountain peoples often have a deep-rooted connection to the soils they live on; it is a part of their heritage. Over the centuries, they have developed solutions and techniques, indigenous practices, knowledge and sustainable soil management approaches which have proved to be a key to resilience.

This publication, produced by the Mountain Partnership as a contribution to the International Year of Soils 2015, presents the main features of mountain soil systems, their environmental, economic and social values, the threats they are facing and the cultural traditions concerning them. Case studies provided by Mountain Partnership members and partners around the world showcase challenges and opportunities as well as lessons learned in soil management. This publication presents a series of lessons learned and recommendations to inform mountain communities, policy-makers, development experts and academics who support sustainable mountain development.

ISBN 978-92-5-108804-3

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I4704E/1/05.15

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