



# SOIL:OurInvisibleAlly

COLLECTION OF EASY-TO-USE SUSTAINABLE SOIL  
MANAGEMENT METHODOLOGIES

CONCEPT NOTE – SUSTAINABLE SOIL MANAGEMENT  
IN THE ALPINE SPACE AREA



### D.1.1.1 – Concept for multiplication for transferability & scalability supporting long term action plan of AC

The deliverable combines the concept note and accompanying graphic, which serve as the conceptual basis mapping the interconnections between soil functions, sustainable soil management and soil resilience and the questionnaire created to inform our collection of easy-to-use SSM methodologies characteristic of the Alpine region.

**NOTE:** This deliverable is our internal compass that sets the framework for the partners' work. It is a fluid document intended to provide the basis for upcoming project activities and outputs, as well as definitions fundamental to them. As such, it remains open for adjustments and additions throughout the project's lifetime.

### General information

Project	SOIL:OurInvisibleAlly
Project ID	ASP0500310
Project duration	2024-2027 (36 months)
Priority	Climate resilient green Alpine region
Specific objective	SO1.2 – Enhancing protection and preservation of nature, biodiversity and green infrastructure, including in urban areas, and reducing all forms of pollution
Total eligible costs	2.849.646 EUR
ERDF grants	2.137.235 EUR

### Project partners

Slovenian Forestry Institute (SI) • Art and Nature Foundation (DE) • Agricultural Institute of Slovenia (SI) • Salzburg Institute for Regional Planning and Housing (AT) • Climate Alliance Tyrol (AT) • National Research Institute for Agriculture, Food and the Environment (FR) • University of Torino (IT) • County Administration Landsberg a. Lech (DE) • Autonomous Region of Aosta Valley (IT) • Consulting for Naturland (Association for Organic Agriculture, DE) • Slovenia Forest Service (SI) • Orobie Valtellinesi Parc (IT)

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## Summary

The conservation of soil resources is of particular importance in the Alps, given the scarcity of soil, its threatened state, the narrow climate zones, and the slow rate of soil formation. Despite the existence of a knowledge base and a set of best practices in the field of sustainable soil management (SSM), these are yet to be effectively disseminated and applied on the local governance level, which is a necessary step for the long-term preservation of soils.

Soil: Our Invisible Ally is a project that aims to enhance the uptake of SSM practices at municipal and regional level in Alpine countries to promote local yet synchronized implementation. The project's objective is to facilitate the integration of knowledge, policy, and practice by consolidating existing knowledge and implementing concrete actions at pilot sites to safeguard and enhance the resilience of Alpine soils. In contrast to previous top-down initiatives, the project employs a bottom-up approach, engaging municipalities as pivotal drivers and integrating SSM into spatial planning processes. It is often overlooked that a considerable number of steps are required to render knowledge applicable in practice. Consequently, the project is focused on transforming expert knowledge into formats that can be readily adopted by local authorities, landowners, and the public.

The concept note is part of Work Package 1 (WP1). The objective of WP1 is to collect and adapt existing knowledge in a way that makes it accessible, simple to use and transnationally transferable. By providing easy-to-use SSM methodologies, it will be possible to support soil ecosystem services and soil-climate resilience more efficiently across the Alpine region.

The purpose of this document is to provide a definition of SSM and related best practices.

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## Soil as “natural capital”

Soils can be defined as natural capital because they provide essential ecological, economic, and social services that support life and human well-being (Robinson et al., 2017). Natural capital refers to the world's stocks of natural assets, which include minerals, soil, air, water, and soil biome. These assets provide a flow of benefits to people.

When we consider soil as natural capital, we emphasize the importance of healthy soil ecosystems and the benefits they offer in sustaining life and enabling economic activities.

## Soil ecosystem services (SES)

**Soil ecosystem services (SES)** are a direct consequence of the existence of soil functions, which depend on soil properties and are based on ecological-functional processes occurring in soil (Wallace, 2007; Vallés-Planells, Galiana et al., 2014, Vrščaj, 2020). Soil's capacity to perform specific functions within the context of natural or human-altered ecosystems is closely linked to their quality, which is determined by their chemical, physical and biological properties, that are also directly related to soil health. There are several important **soil functions** such as: (1) water regulation (absorbing, storing and filtering water), (2) nutrient cycling (decomposition of organic matter and the cycling of nutrients), (3) support for plant growth (providing nutrients, water and root support), (4) habitat and gene pool (environment for all living organisms), (5) carbon sink and climate regulation (locking carbon in soil organic matter and minerals), (6) retention & decomposition of pollutants and heavy metals (through adsorption on soil particles, cation exchange capacity, physical filtration and decomposition by microbes, enzymatic breakdown, synergistic degradation) (FAO, 2025; Greiner et al., 2017). These soil functions determine the capacity of soils to provide SES, thus maintaining optimal soil functions is key for enabling the delivery of SES. Furthermore, the quantity and quality of SESs available may also be contingent upon human inputs (tillage, fertilization, irrigation, etc.) that affect the state of soil functions (La Notte et al., 2017).

EU Soil Strategy for 2030 lists key SESs, as soils are capable to:

- provide food and biomass production, including in agriculture and forestry,
- absorb, store and filter water and transform nutrients and substances, thus protecting groundwater bodies,
- provide the basis for life and biodiversity, including habitats, species and genes,
- act as a carbon reservoir & contribute to climate regulation,
- provide physical platform and cultural services for humans and their activities,
- act as source of raw materials,
- constitute an archive of geological, geomorphological and archeological heritage.

**Soil resilience** refers to the ability of soil to recover its functional and structural integrity after a disturbance. It acts as a key indicator of soil sustainability, reflecting both past and present management practices while predicting potential responses to future disturbances, where this integrity can be considered as soils capacity to perform soil functions (Karlen et al., 1997; Ludwig et al., 2018). It is largely influenced by response diversity, which is the range of reactions to environmental changes

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among species contributing to the same ecosystem function. Since soil operates on multiple spatial and temporal scales, an adaptive management approach is necessary.

In terms of human activities, soil resilience depends on sustainable soil management, as the latter ensures that soil retains its ability to perform multiple SES including nutrient cycling, water retention, and organic matter decomposition, carbon cycling and storage, etc. The sufficient operation of these functions and natural cycles and the soil's capacity to provide ES is considered an important marker of resilient soils.

The living component of soil or soil biota represents a little but essential fraction of many SES, such as carbon cycling, nutrient provision and the cycling and availability of water. A resilient soil can recover from or adapt to environmental and anthropogenic stress easier and faster, with the health of the living/ biotical component of the soil being crucial for soil resilience (Karlen et al. 1997, Lehman et al. 2015,). Moreover, soil biota is key within the interactions of soil properties and soil processes, which reflects the presence and dynamics of soil functions. This, in turn, provides capacity for the delivery of soil ecosystem services. For example, diversity of soil biota can affect water regulation and porosity (both soil properties), which in turn impacts soil fertility (soil function) (Ludwig et al., 2018).

For more information and classification of SES, we provide a link to CICES (Common International Classification of Ecosystem Services) ES categories (CICES, version 5.1) and to SES from the EU project Link4Soils (table below). A more detailed version of SES classification, with embedded CICES ES classes and practical examples (tangible goods and services) is given in Annex 1.

**Table 1: Classification of soil ecosystem services**

CICES ES category	Soil ecosystem services (CICES-based SES)	Link4Soils SES
Provisioning services	Biochemicals and active pharmaceutical ingredients	
	Food, wood and fiber	Agricultural biomass production Forest biomass production
	Water	Water retention
	Carrying capacity for infrastructure, buildings and animals	
	Raw materials	
	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	
Regulating services	Water purification and soil pollution reduction	Water filtration and purification

	Regulation of baseline flows and extreme events (also control of erosion rates)	Surface runoff regulation
	Biological control of pest and disease populations	
	Carbon sequestration	Global climate regulation ("the carbon cycle")
	Greenhouse gas balancing	
	Managing local climate/temperature	Local climate regulation ("the cooling effect")
	Noise attenuation	
	Air quality management	
	Regulation of soil quality	Nutrient cycle regulation
	Lifecycle maintenance, habitat and gene pool protection	Soil habitat and biodiversity
Cultural services	Recreation and tourism	Recreational and spiritual services
	Knowledge / scientific research, cultural heritage and education	Cultural and natural archives
	Spiritual and symbolic experiences	Recreational and spiritual services

The link between natural capital, soil functions and soil ecosystem services, in relation to soil resilience and sustainable soil management, can be illustrated by a conceptual framework that shows how different supporting factors are linked to soil properties that build up soil natural capital. At the same time, supporting processes are essential regulators of soil functions, which, in turn, allow the provision of SES to meet human needs.

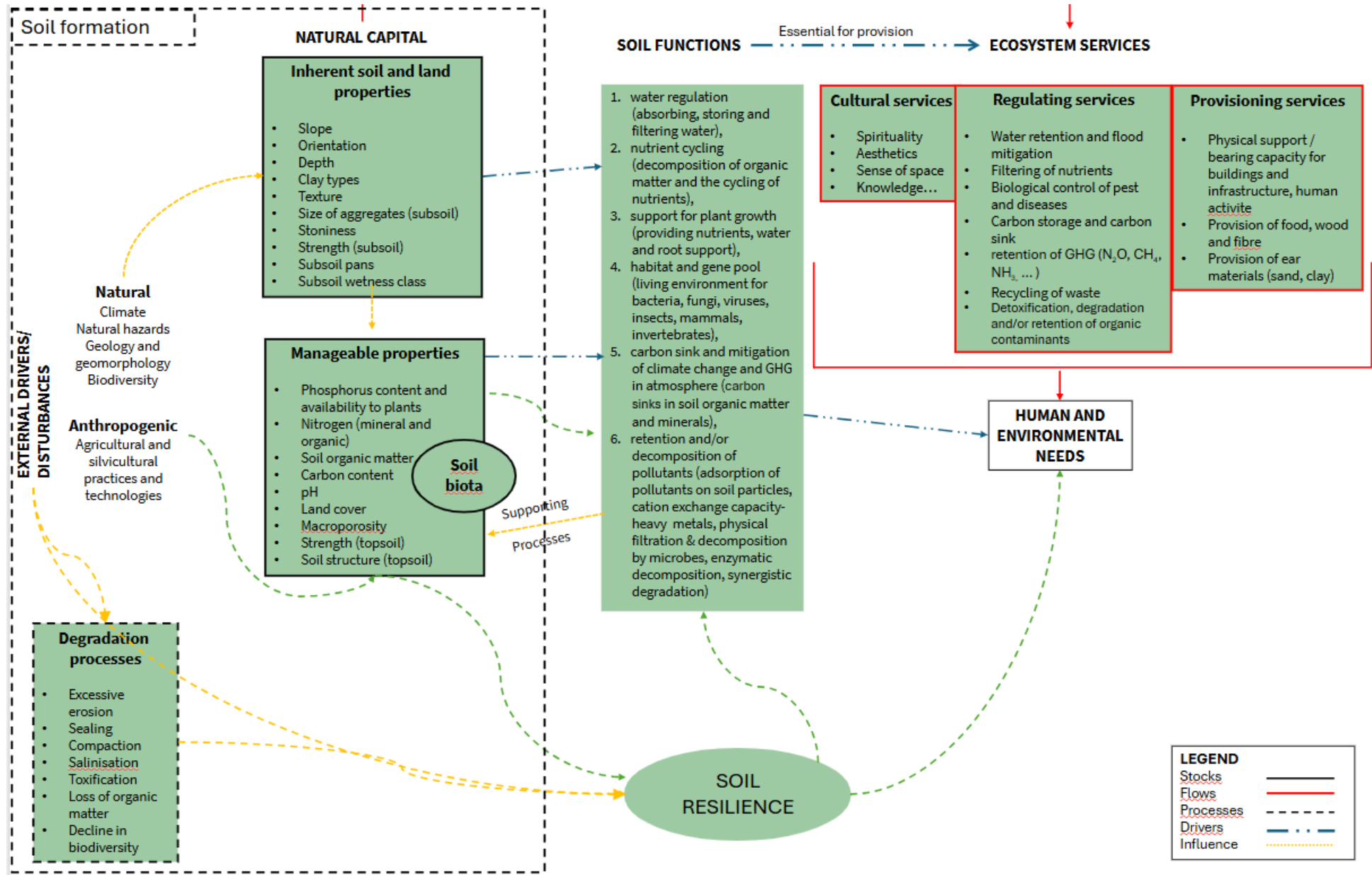
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## Graphics explanation

The conceptual framework illustrates the interconnections among soil properties (natural capital), soil functions and soil ecosystem services (SES), while pointing out the crucial role these building blocks play in guiding sustainable soil management (SSM) and creating resilient soils. The framework highlights the importance of continuous assessment and adaptive management to maintain soil as a natural capital and a key resource for a sustainable future. By adopting SSM practices tailored to specific areas, stakeholders can positively impact soil properties, ensuring the long-term stability of soil functions and ecosystem services.

SSM influences manageable soil properties—such as pH, organic matter, bulk density, and soil structure and biodiversity. These properties together with inherent soil properties, support soil functions (e.g., water regulation, nutrient cycling), which in turn contribute to soil resilience over time. Resilient soils can better withstand disturbances while maintaining their functions and their capacity to provide essential ecosystem services.

At the same time, soil resilience acts as a bioindicator of the effects of soil management practices. If a given soil has been managed well, it will be reflected in its ability to maintain its properties and its key functions despite external pressures. Soil biota plays a key role in this process by driving main supporting processes (soil biological activity), which influence soils' overall capacity to maintain key functions.



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# Sustainable soil management (SSM)

According to FAO (2017), the definition of SSM is: “ *Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern.* ”

Adopting SSM is an essential step towards climate change mitigation and adaptation and a way to safeguard key soil ecosystem services and maintain or enhance soil biodiversity. In this context, it should provide one or more of the following outcomes:

1. Minimal rates of soil erosion by water and wind;
2. The soil structure is not hampered (e.g. soil compaction) and provides at least a stable medium for movement of air, water, and heat, as well as root growth;
3. Sufficient surface cover (e.g. from growing plants, plant residues, to ensure continuous forest vegetation cover, etc.) is present to protect the soil;
4. The soil organic matter content is stable or increasing and is ideally close to the optimal level for the local environment;
5. Availability flows and *in-situ* cycling of nutrients are appropriate to maintain or improve soil fertility and productivity, and to reduce nutrient losses to the environment, especially to surface waterbodies and groundwater;
6. Water regulation services need to provide (e.g. from precipitation, snow and ice melting and supplementary water sources such as irrigation) efficient water infiltration, and optimize plant-water availability;
7. Human induced contaminants are below toxic levels, i.e. those which would cause harm to plants, animals, humans and the environment;
8. Rich soil biodiversity provides a full range of biological functions; e.g. decomposition of plant residues; carbon sink and carbon and nutrient cycling;
9. The soil management systems for producing food, feed, fuel, timber, and fiber rely on the optimized and safe use of inputs; for example, crop rotation, cover cropping, conservation tillage, agroforestry, and sustainable grazing practices all contribute to maintaining soil fertility and reducing erosion;
10. Soil sealing is minimized through responsible land use planning. Practical approaches to prevent soil sealing include maintaining permanent grasslands and meadows, restricting construction on highly fertile soils, preserving traditional pasture systems that prevent abandonment and subsequent sealing. In mountainous regions, maintaining terraced landscapes, forested buffer zones, and extensive grazing systems also helps to reduce sealing pressure and land degradation.

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Sustainable soil management (SSM) is a term used to describe a range of practices that vary depending on the specific land use, environmental conditions, and socio-economic factors of a given area (FAO, 2017). The concept of SSM can also differ significantly across sectors, for example in agriculture, forestry, or urban land use. This highlights the need for sector-specific recommendations that align with the challenges and opportunities specific to each area (<https://www.alpine-space.eu/wp-content/uploads/2022/06/46-3-links4soils-Sustainable%20Soil%20Management%20Guidelines-output.pdf>).

## How to assess the effectiveness of SSM?

A measurable bioindicator of sustainable soil management is soil resilience (Ludwig et al. 2018). It reflects how well soil can withstand disturbances and continue providing essential ecosystem services, ensuring agricultural productivity and environmental health in the long run (Ludwig et al., 2018).

Soil resilience can be demonstrated via functional and response diversity against disturbances, which can be man-made (disrupting soil structure by logs skidding) or of natural origin (landslide, flooding etc.). Soil biota is the main source of response diversity in soil, as it contributes to soil processes and consequently supports the dynamics of soil functions (Gunderson and Pritchard, 2002).

For (soil) resilience to be an operational concept for assessing the sustainability of soil management, two further elements are needed; potential of recovery (ability to cope with disturbances) and connectedness (the possibility of functionally shifting species, i.e. specialization and networking of species of forest and other ecosystems biota). Different combinations of these two elements indicate whether (or by how much) the ability of soils to withstand disturbances is hampered and whether it will be able to retain its functional activity, or the tipping point was breached, and a new self-organizing structure of soil is established (shift in regime) (Allen et al., 2014). The fundamental element for measuring soil resilience is therefore response diversity, which means that this is only possible in the context of continuous monitoring of soil functions and soil biota and the effects of disturbances on both.

Sustainable soil management align sectoral soil management practices (agriculture, forestry, planning, tourism, etc.) or soil protection with soil resilience measurements to maintain long-term productivity.

The effectiveness of sustainable soil management (SSM) could be assessed by the following steps:

1. Definition of key sectors
2. Definition of key soil ecosystem services that can be and should be monitored within individual sector / land use.
3. Monitoring Soil Condition & Crops:
  - a. Regularly assess soil properties, such as organic matter content, nutrients levels, biodiversity, acidity and structure, to track changes over time.
  - b. Use soil and plant tissue testing to diagnose limiting factors and evaluate the impacts of management practices.
4. Evaluating the provision of Soil Ecosystem Services:
  - a. Assess improvements in ecosystem services, such as water filtration, carbon sequestration, crop yields, and biodiversity conservation.

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5. Definition of best and bad soil management practices per sector in Alps
    - a. Agriculture
    - b. Forestry
    - c. Tourism and sports
    - d. Urban planning
    - e. any others?
  6. Tracking Adoption of Best and Bad Practices:
    - a. Document the implementation of specific SSM practices, such as crop rotation, organic amendments, minimal tillage, and erosion control measures.
  7. Impact on Food Security and Ecosystems:
    - a. Analyze how SSM practices contribute to food security, sustainable agricultural productivity, and the mitigation of environmental challenges like climate change and desertification.
  8. Stakeholder Engagement and Feedback:
    - a. Involve farmers, policymakers, and other stakeholders when assessing the practical outcomes of SSM initiatives.
  9. Use of Indicators and Reporting:
    - a. Establish and use indicators aligned with the Sustainable Development Goals (e.g., soil quality improvements, reduced erosion rates) and report findings at local, national, and global levels.
  10. Capacity Development and Knowledge Sharing:
    - a. Strengthen the education and extension services to enhance the capacity of stakeholders in monitoring and improving soil management effectiveness.

By combining these actions with evidence-based scientific and local knowledge, the effectiveness of SSM can be systematically evaluated.

## Best soil management practices (BSMP)

Best practices for sustainable soil management encompass methods that maintain, enhance, or restore the chemical, physical, or biological characteristics of soils. These characteristics are closely linked and essential for soils' capacity to perform specific functions (i.e. water regulation, nutrient cycling), for the provision of SES and for the overall health and resilience of soil and ecosystems. These practices should be both economically and temporally feasible. Furthermore, they should be flexible, innovative and interdisciplinary to address both the complexity of the concept of BSMP and long-term objectives of sustainability. For the successful implementation of BSMP practices, effective tools are needed.

## Best SSM practice tool

In the context of the project and this document, the term "SSM best practice tool" will be used to describe a method, technique, strategy or resource that has been designed to promote the sustainable use of soil. The objective of these tools is to achieve a balance between ecological, social, and economic needs while maintaining or enhancing soil ecosystem services such as water filtration,

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nutrient cycling, and carbon storage. Such tools include those for assessing and monitoring soil quality (e.g. soil testing kits, digital soil mapping tools), decision support systems for selecting sustainable practices (e.g. GIS-based tools and models like DSSAT or InVEST), and management practices like crop rotation, reduced tillage, cover cropping, and the use of organic fertilizers, close-to-nature forest management practices, etc. In addition, they encompass restoration and rehabilitation methods for degraded soils, such as reforestation and erosion control, as well as capacity-building resources like educational guides and training programs for target users like farmers, land managers, policymakers, and researchers. Used separately or together, these tools are intended to support and sustain soil ecosystem services and advance sustainable soil use at different sectors and levels.

## SSM best practice toolbox

The SSM best practice toolbox is a structured collection of tools and guidelines. It is designed to support key stakeholders in understanding, selecting and implementing best practices for sustainable soil management. It offers a comprehensive overview and practical management guidance for various activities such as:

- Soil protection during harvesting and timber extraction
- Forest regeneration with climate-resilient tree species
- Maintaining the organic soil layer (e.g., through the use of organic fertilizer, compost, and farmyard manure)
- Water retention in forest landscapes
- Crop rotation and crop diversification to maintain soil fertility and break pest cycles
- Cover cropping and green manures for erosion control and soil organic matter build-up
- Conservation of tillage and reduced soil disturbance to enhance soil structure and carbon storage
- Sustainable grazing management to avoid compaction and protect permanent grasslands

The toolbox can serve multiple functions, including decision support, technical guidance, communication, and education. It provides freely available, tested, and efficient best practice tools for different contexts, ecosystems, and user needs. As a decision support system, the toolbox consolidates existing knowledge on SSM and turns it into accessible formats, guiding users with practical tips about the effective use of best practices. It enables users to navigate different choices, including a decision tree, and alternative solutions, offering easy-to-use information for planning, orientation, and the implementation of possible measures suited to local or regional conditions. The SSM toolbox facilitates informed decision-making, connects practitioners with existing policies and knowledge, and ensures accessibility and adaptability by taking various forms, such as technical guidance, manuals or interactive tools.

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## EU documents referring to soil protection, monitoring, criteria etc. since 2004 onwards

The main European Union (EU) documents regarding soil monitoring and their criteria include the following:

### 1. EU Soil Strategy for 2030

- Adopted in 2021, this strategy provides a framework to protect and restore soil health across the EU.
- It includes commitments to establishing a legally binding framework for soil health by 2023 and improving monitoring through the development of a harmonized soil information system.

### 2. EU Biodiversity Strategy for 2030

- Recognizes the critical role of healthy soils in biodiversity conservation.
- Includes targets to restore degraded ecosystems, with soil monitoring integrated into broader ecosystem assessments.

### 3. Thematic Strategy for Soil Protection (2006)

- Focuses on the sustainable use of soils and combating soil degradation.
- Promotes the development of national soil monitoring programs and EU-wide harmonized criteria for soil status evaluation.

### 4. Directive 2004/35/EC on Environmental Liability

- Establishes a framework for preventing and remediating environmental damage, including soil contamination.
- Requires monitoring and reporting to ensure compliance with remediation standards.

### 5. Industrial Emissions Directive (2010/75/EU)

- Addresses soil and groundwater protection as part of industrial operations.
- Requires operators to establish baseline reports and implement regular monitoring for soil contamination.

### 6. Zero Pollution Action Plan (2021)

- Aims to reduce pollution across air, water, and soil to achieve "zero pollution" for a toxic-free environment.
- Supports soil health by enhancing data collection and monitoring.

### 7. LULUCF Regulation (EU) 2018/841

- Focuses on land use, land-use change, and forestry, incorporating soil carbon monitoring into climate action reporting.

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8. **Directive on Soil Monitoring and Resilience (Soil Monitoring Law) (2023/0232 (COD)) – ongoing legislative process**

- Aims to establish a comprehensive framework for monitoring soil health across the EU
- Addresses issues such as soil erosion, contamination, and land take, promoting measures to preserve and enhance soil functions vital for ecosystems and human well-being.
- Outlines criteria for assessing soil health, emphasizes the importance of sustainable soil management practices and seeks to harmonize monitoring efforts among Member States.

9. **EU Mission: A Soil Deal for Europe**

- Horizon Europe mission that focuses on restoring and protecting soil health across Europe by 2030 through targeted research and innovation.
- Main goals include reducing soil degradation, enhancing soil biodiversity, promoting carbon sequestration, reducing soil pollution, boosting public awareness on soil health.

## Key soil indicators

Key soil quality indicators on soil conditions, soil health status, processes in / on the soil often specified by previously mentioned main EU documents regarding soil monitoring include:

- Soil organic carbon stocks
- Presence of pollutants, excess nutrients and salt
- Soil structure including soil bulk density (soil compaction, water filtration)
- Soil sealing
- Erosion rates (all types)
- Landslides
- Drought stress
- Soil biodiversity
- Soil nutrients and acidity (pH)
- Vegetation cover in percentage
- Landscape heterogeneity
- Forest cover (tree canopy cover, stocking density, and forest type)

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# Imprint

## About the SOIL:OurInvisibleAlly project

The project aims at ensuring the long-term vitality of Alpine soils, and thus the ongoing provision of soil ecosystem services, by fostering soil literacy and bridging the gap between pre-existing knowledge about sustainable soil management measures and their implementation. In this process, pilot sites showcasing best practice examples will also be highlighted. Additionally, the project places a strong focus on artistic expression and (scientific-) cultural events as powerful awareness raising tools that can help build curiosity and affinity towards the topic of soil.

## Project partners

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Project Website 

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