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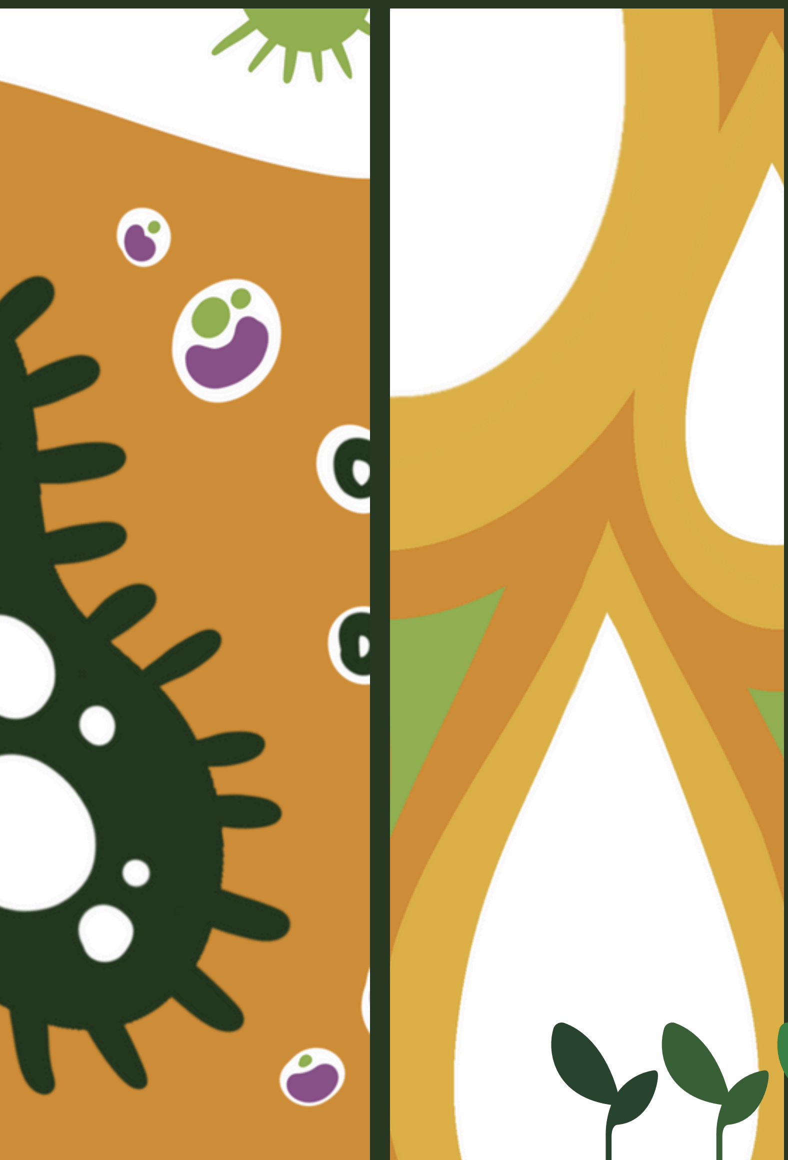


CITIZEN SCIENCE FACTSHEETS *for* SOIL HEALTH INDICATORS

ENGLISH

ECHO

WHAT IS SOIL?

Soil is a vital, limited resource, considered non-renewable and irreplaceable on a human timescale, and essential for supporting the economy, environment and society. The European Soil Observatory (EUSO) estimates that **60-70% of European soils are in an unhealthy state**. Therefore, it is critical to manage and protect soils to ensure their preservation for future generations. In response, the EU launched initiatives within the EU Soil Strategy for 2030, the EU Mission 'A Soil Deal for Europe' - Implementation Plan, and the new Soil Monitoring and Resilience Directive aiming to protect, restore, and ensure healthy soils by 2050. Raising awareness about the vital and societal importance of soil is crucial to achieving these objectives.

Soil is defined as "the top layer of the Earth's crust situated between the bedrock and the land surface, which is composed of mineral particles, organic matter, water, air and living organisms". Its ability to support plant growth, regulate water, and enhance climate resilience makes understanding soil properties essential for sustainable land management. Soil is also fundamental to food production and contributes to sustainability by supporting essential societal and ecosystem services.

WHAT IS SOIL HEALTH?

The concept of soil health highlights the critical link between the health of soils, humans, animals, and the environment. Soil health refers to the soil's ongoing ability to function as a living, dynamic system that sustains plants, animals, and humans, while also supporting broader ecosystem services such as water purification, biodiversity, and climate regulation. It is closely linked to concepts like:

a. **Soil Quality:** soil ability to perform specific functions, particularly in agriculture and environmental services, such as water filtration and plant growth.
b. **Soil Fertility:** soil ability to supply essential nutrients for plant growth, supporting agricultural productivity.

THREATS TO SOIL HEALTH

Soil health in the EU and Scotland is under pressure from various factors such as:

- pollution (e.g., pesticides, heavy metals),
- nutrient imbalance, aridity,
- soil erosion (caused by wind and water),
- soil compaction.

The main drivers of these processes often include agricultural intensification, overgrazing, and changes in land use, the effects of which are further catalysed by climate change. These factors disrupt crucial soil-based ecological processes (e.g., carbon storage, habitats for microorganisms), underscoring the importance of maintaining soil health.

SOIL HEALTH PROTECTION AND RESTORATION

Maintaining and restoring soil health is achievable through sustainable soil management, defined as “soil management practices that maintain or enhance the ecosystem services provided by the soil without impairing the functions enabling those services or causing harm to other environmental properties.” These practices are context-dependent, varying with land use (e.g., agricultural land, forests, urban and industrial areas, natural and semi-natural areas). For this reason, the ECHO project considers various land uses, including agricultural, forestry, urban areas and natural/seminatural areas, as well as mixed land uses such as agroforestry, reflecting the diversity of ecosystems and their specific soil health needs.

ASSESSING SOIL HEALTH

Soil health is assessed using simple and practical indicators such as pollutant levels, soil organic matter, pH, soil structure, and earthworm abundance. These help land users understand the natural limits of each system. Assessing soil health is important for several reasons, including crop fertility, identification of land degradation processes, assessment of soil biodiversity, educational purposes, and self-assessment of farms.

Agricultural soils cover over 33% of the EU’s land surface, providing food for people and livestock, raw materials for industry, and exports to third countries. However, their conservation is challenging due to threats, such as soil compaction, erosion, loss of organic carbon, excessive fertiliser use, and pollution. Natural areas, including forests and grasslands, account for nearly 40% of the EU's land surface and provide key ecosystem services, such as carbon storage, water retention and purification, and wildlife habitats. Urban soils, while only making up 3.4% of the EU’s land surface, are often found in green urban spaces like parks. Despite their limited size, assessing urban soil health is crucial for raising public awareness about soil conservation and promoting nature-based solutions, such as gardens, orchards, and trees. Evaluating soil health across different land uses and increasing citizen awareness of soil conservation are key objectives of the ECHO project.

ECHO SOIL HEALTH INDICATORS

Soil health assessment in ECHO is based upon the eight soil health indicators described in the Mission Soil Implementation Plan:

1. **Presence of pollutants (debris of metals and plastics),**
2. **Soil organic carbon stock,**
3. **Soil structure,**
4. **Soil nutrients and pH,**
5. **Soil biodiversity,**
6. **Vegetation cover,**
7. **Forest cover,**
8. **Landscape heterogeneity.**

1. PRESENCE OF POLLUTANTS

Soil pollutants encompass a wide range of contaminants, including both organic and inorganic compounds, primarily associated with human activities such as waste disposal, mining, agrochemical use, industrial processes, and atmospheric deposition. This pollution diminishes the soil's ability to support plant growth, water filtration and carbon storage, leading to reduced crop yields, decreased organic matter, limited buffering and filtering capacity, and increased greenhouse gas emissions that contribute to climate change. Soil pollution disrupts nutrient balance by altering soil biodiversity and nutrient availability, leading to diminished vegetation cover, increase the risk of flooding and make sometimes soil unsafe or farming, housing or recreational use. Some pollutants, such as heavy metals (e.g. arsenic, cadmium, and lead) are toxic to plants, animals, and people even in small amounts. Other emerging pollutants, such as microplastics or chemicals from medicines or personal care products pose significant challenges for monitoring and remediation efforts since their long-term effects on soil health and ecosystem functioning is unknown.

In the EU, approximately **30%** of soils are already polluted, showing excess concentrations of high levels of heavy metals such as arsenic, cadmium, chromium, copper, mercury, lead, zinc, antimony, cobalt, and nickel in the topsoil. While some heavy metals, like copper, zinc and nickel are essential in trace amounts for plant growth, when present in excessive amounts, heavy metals can disrupt plant growth, harm biological functions, and accumulate in the environment, leading to long-term ecological and health issues.

The ECHO project assesses soil pollutants in two ways:

- **On-site** through visual inspection of plastic and metal debris
- **Off-site** by measuring heavy metals concentration using X-ray fluorescence, a fast non-destructive analysis.

Citizen active participation plays a key role in pollutant assessment. Through visual observation techniques, and training people can learn to recognize visible signs of soil pollution, such as unusual textures, the presence of debris.

2. SOIL ORGANIC CARBON STOCK

WHAT IS SOIL ORGANIC MATTER?

Soil organic matter (SOM) originates from decomposed plant and animal residues broken down by microbes in response to temperature, moisture, and, specific soil conditions. The major component of SOM is carbon, and therefore it is often called soil organic carbon (SOC).

IMPORTANCE OF SOM

SOM plays a crucial role in ecosystem services, particularly in climate regulation as it has a major rolein carbon storage, helping in climate regulation. SOM represents the largest carbon stock in most terrestrial ecosystems and the second-largest carbon reservoir after oceans.

- SOM provides essential nutrients for plants, serves as a food source for soil organisms.
- SOM maintains or enhances soil structure and the capacity of a soil to hold water.

FACTORS INFLUENCING SOM CONTENT

- **Natural factors** (e.g. climate, soil type, or vegetation).
- **Human-induced factors** (e.g. land use, management practices and degradation).

ESTIMATING SOM

Soil colour is a useful indicator for assessing SOM content: darker soil indicates higher SOM content.Although SOM can be measured through laboratory analysis (chemical, combustion as well as physical methods), on the field, soil colour can also provide valuable insights into key factors, including mineral composition, organic matter levels, iron content, and moisture content.

SOM LOSS AND SOIL HEALTH

SOM loss can lead to soil degradation, resulting in reduced crop yields and vegetation cover, as well as negative impacts on nutrient cycling, carbon storage, buffering and filtering capacity, and biodiversity loss.Protecting and enhancing SOM is crucial. Policy frameworks that influence land use and changes in land use can significantly impact on SOM levels and thus soil health.

3. SOIL STRUCTURE AND TEXTURE

WHAT IS SOIL STRUCTURE?

Soil structure refers to the three-dimensional arrangement of soil particles and aggregates. These aggregates consist of mineral particles (sand, silt and clay) and SOM, create pores that can support roots, fungi, bacteria, and other organisms. The type of soil structure influences water movement, air circulation and overall soil health. Soil structure is usually assessed by visually identifying the types of aggregates present. The most common soil structure types include **massive (A), prismatic(B), blocky (C) and granular (D)**.

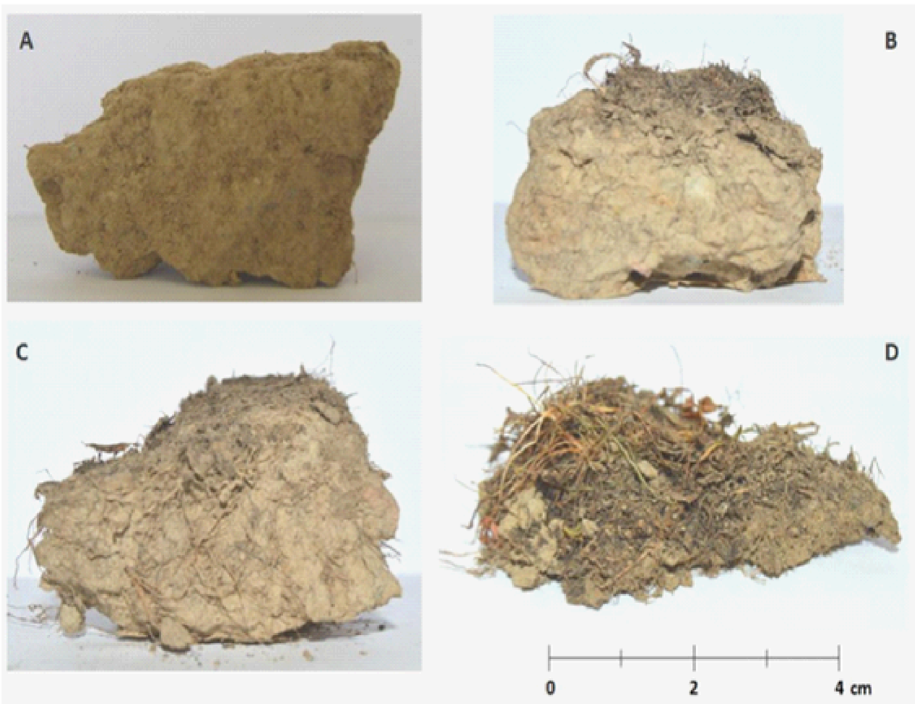
IMPORTANCE OF SOIL STRUCTURE

A well-structured soil enhances:

- Water retention and drainage.
- Air circulation for plant roots and soil organisms.
- Increases resistance and resilience against land degradation processes (e.g. compaction and erosion).

THREAT ON SOIL STRUCTURE

Soil structure is a fragile property that can be quickly altered by factors such as erosion, compaction, decline of SOM, anthropogenic activities.



Examples of different soil structure types. A: massive, B: prismatic, C: blocky, D: granular

HOW TO IMPROVE AND PROTECT SOIL STRUCTURE

(some examples among others):

- Afforestation (planting trees where there were no forests) and Reforestation (restoring forests by planting trees) can improve soil structure through root systems that improve aggregate stability, enhance organic matter through leaf litter, and reduce erosion.
- Cover crops and green manure can add organic matter to the soil, enhancing soil structure.
- Erosion Control measures, such as planting vegetation along slopes or using silt fences can help maintain soil integrity and structure.
- Mulching using wood chips or straw to maintain soil moisture and reduce soil erosion, and gradually add organic matter as it decomposes, improving soil structure.
- Reduce activities that disturb the soil, such as heavy foot traffic or construction, can help maintainsoil structure and prevent compaction.
- Soil aeration (mechanical or manual methods) can help improve air and water movement.
- Use of permeable surfaces such as permeable paving materials can improve water infiltration and reduce runoff, promoting better soil structure beneath.

WHAT IS SOIL TEXTURE?

Soil texture refers to the size of mineral particles and is categorised into three main types: sand (0.05 mm – 2 mm), silt (0.002 mm – 0.05 mm), and clay (<0.002 mm). Most soils contain a mix of these particles, forming different textural classes such as sandy, sandy clay, silty, silty loam, clayey and clay loam.

IMPORTANCE OF SOIL TEXTURE

Soil texture influences many soil properties:

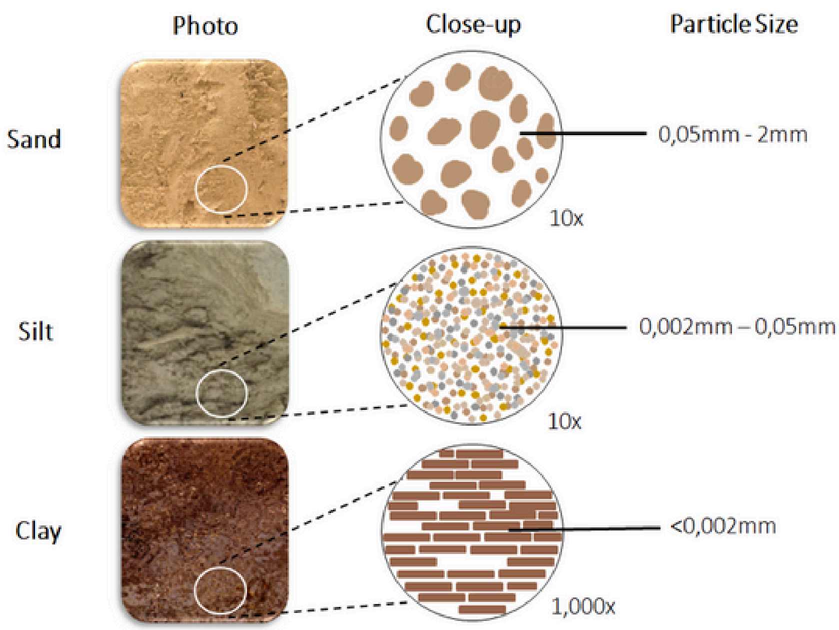
- **Water infiltration and retention:** sand in soil will enhance draining while clay will retain water. An excess in clay can lead to waterlogging.
- **Nutrient adsorption:** clayey soils can hold more nutrients, while excessive clay can lead to compaction.
- **Soil aeration:** sand can aid it.

Understanding soil texture is essential for effective management across different land uses.

THREATS ON SOIL TEXTURE

- Compaction from heavy machinery can reduce soil porosity
- Erosion from tillage, ploughing or subsoiling can alter texture over time.

While soil structure can often recover relatively quickly, changes in texture are longer to reverse. Significant textural changes are less common, typically occurring due to erosion and depositional processes. The effects of these changes on soil health are often more challenging to address in short term.

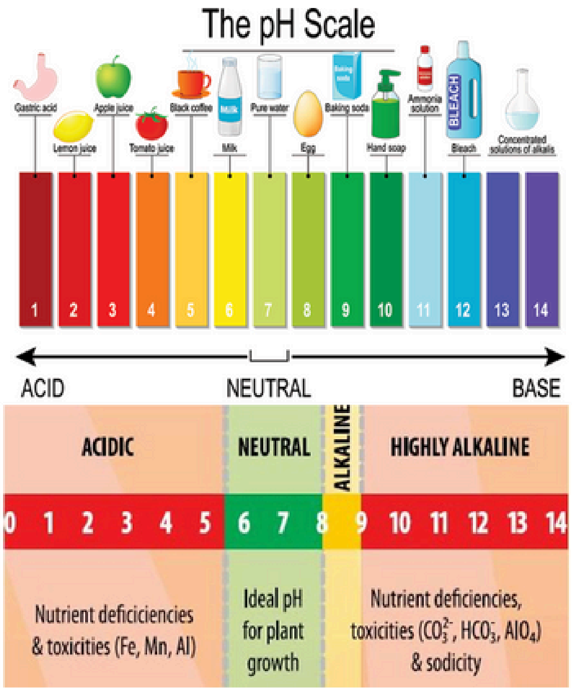


Mineral fractions of the soil's fine earth (Ø <2 mm)

4. SOIL pH

WHAT IS SOIL pH?

Soil pH is an indication of the acidity or alkalinity of soil, ranging from very acidic (3-4) to very alkaline (8-9) and is a key indicator of soil health.



Indicative values of pH within a logical context aimed at their proper interpretation

IMPORTANCE OF SOIL pH:

Soil pH influences:

- **Nutrients availability:** some nutrients such as nitrogen and phosphorus are more accessible within specific pH ranges.
- **Biological activity:** most organisms, including plants and microorganisms, thrive best within a certain pH range, so extreme acidic or alkalinity can negatively impact their populations.

FACTORS INFLUENCING SOIL pH

- Natural factors such as climate, rainfall, SOM decomposition, root respiration and litter composition.
- Human factors such as irrigation in arid/semi-aridregions, land-use changes and management practices,inadequate waste management in urban areas.

ASSESSING SOIL pH

Testing soil pH is a quick and effective way to assess soil health from a chemical perspective. However, pH values must be interpreted considering local factors such as climate, vegetation and dominant rock types. Rapid fluctuations in pH can disrupt microbial activity, which can disturb nutrient and carbon cycling, reduce nutrient availability to plants, and overall harm soil health. These changes are often associated with land use mismanagement (e.g. overfertilisation, deforestation, waste disposal and pollution). Addressing these challenges requires sustainable land management practices that consider the implications of soil pH on different land uses.

5. SOIL BIODIVERSITY

WHAT IS SOIL BIODIVERSITY?

Soil biodiversity is the “variation in soil life, from gene to communities, and the ecological complexes of which they are part, that is from soil micro-habitats to landscapes” (Convention on Biological Diversity, CBD). Soil biodiversity is used to express the number of species and their abundance including bacteria, fungi, protists, nematodes, arthropods, earthworms and mammals. These organisms are categorised by size into micro-, meso-, macro-, and megafauna.

IMPORTANCE OF SOIL BIODIVERSITY

Soil biodiversity plays a crucial role in:

- Nutrient cycling by breaking down organic matter and making nutrients available to plants.
- Water regulation by enhancing soil structure, helping water infiltration and reducing soil erosion.
- Pests and disease management with natural predators regulating harmful organisms.
- Soil structure maintenance with organisms such as earthworms, which improve soil aeration and root penetration.
- Detoxifying pollutant with some microbes which can break down contaminants.

These services are critical for agriculture, water quality, climate regulation, and overall ecosystem health.

ASSESSING SOIL BIODIVERSITY

Soil biodiversity can be assessed using different methods, based on the organism group and the data type needed, such as species abundance (number of individuals of one species) or their role in soil functions. For example, invertebrates like earthworms can be directly observed, while identifying microorganisms like bacteria and fungi requires laboratory analysis to extract and analyse genetic material to identify them.

In ECHO, soil biodiversity will be assessed:

- On-site by counting earthworms, as their presence can reveal much about the soil structure and quality. However, being scientifically correct, numbers of earthworms are only relevant when you identify the species present.
- Off-site by using DNA-based sequencing techniques to examine the composition of the microbial community.

LOSS OF SOIL BIODIVERSITY AND SOIL HEALTH

The loss of soil biodiversity, often driven by human activities, negatively impacts soil health by:

- Reducing the number of organisms.
- Eliminating key species.
- Disrupting their interactions and disturbing the natural balance of the soil food web.

This loss of biodiversity can cause irreversible damage, diminishing the soil's ability to resist pests, store water, absorb nutrients, and sustain nutrient cycling and fertility.

HOW TO IMPROVE AND PROTECT SOIL BIODIVERSITY

Soil biodiversity and land use and management practices are closely intertwined. Sustainable management across all land uses is crucial to maintaining soil biodiversity and its associated ecosystem services. Some examples of sustainable management practices that will maintain soil biodiversity:

- Reducing soil disturbance by minimizing tillage and heavy machinery use.
- Increasing organic matter inputs by using compost, manure, and cover crops.
- Promoting crop diversity by encouraging a variety of plants to support different soil organisms. This can promote soil biodiversity by enhancing habitat variety.
- Protecting natural habitats by conserving wetlands, forests, and grasslands to sustain biodiversity. This will support diverse soil microbial and faunal communities.

6. VEGETATION COVER
7. FOREST COVER
8. LANDSCAPE HETEROGENEITY

ECHO will evaluate the impact of vegetation on soil health using three key indicators: vegetation cover, forest cover and landscape heterogeneity.

IMPORTANCE OF VEGETATION COVER

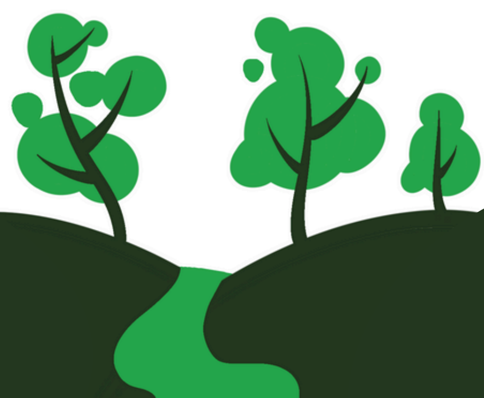
Vegetation cover plays a crucial role in maintaining soil health and stability by:

- Preventing soil compaction with plant roots enhancing soil structure, allowing air and water movement.
- Reducing erosion risk by protecting soil from water and wind erosion.
- Limiting CO_2 emissions, which can result from the rapid oxidation of SOM when soils are exposed.
- Promoting soil biodiversity, with plant roots contributing to improved soil structure, air and water movement and organic matter content.

IMPORTANCE OF FOREST COVER

Forest cover (tree density in a given area) provides essential ecosystem services such as:

- Carbon sequestration with trees absorbing and storing carbon, mitigating climate change.
- Water purification by water filtration, that will improve water quality.
- Erosion control with tree roots stabilising soil, that will reduce land degradation.
- Flood and drought mitigation by retaining water in the soil, reducing flood risks and maintaining moisture in dryer periods.
- Disease reduction with forest helping reduce pest populations and spread of diseases.



IMPORTANCE OF LANDSCAPE HETEROGENEITY

Landscape heterogeneity is the variety of habitats within a landscape, and influences biodiversity and the delivery of ecosystem services. Landscape heterogeneity supports:

- Diverse species by providing different habitats for various organisms.
- Enhancement of soil functions by improving nutrient cycling and soil stability.
- Promotion of ecological resilience by providing habitat diversity that helps ecosystems to recover from disturbances such as climate extremes.
- Improvement of wildlife connectivity with corridors between patches to ensure species movement.

INTERPRETATION OF VEGETATION COVER, FOREST COVER, LANDSCAPE HETEROGENEITY ON SOIL HEALTH

The influence of vegetation cover, forest cover and landscape heterogeneity interpretation varies depending on the type of land use:

1. **Urban areas:**
    - Heavily influenced by human activities, but may be more protected in areas like urban parks.
    - Degradation of urban soils can reduce their ability to sequester carbon, regulate temperatures (reducing urban heat islands), filter pollutants, manage floodwaters, support wildlife, and provide recreational space.
2. **Agricultural areas:**
    - Vegetation cover is often removed, typically through herbicide use, which exposes the soil to erosion and accelerates the loss of organic matter through oxidation.
    - Sustainable practices like cover cropping help maintain soil health and reduce nutrient loss.
3. **Forest areas:**
    - Forests support soil biodiversity and soil health.
    - Threats include reduction in tree numbers due to wildfires, windstorms, timber harvesting, pest induced mortality, and land reclamation activities such as road construction and the use of heavy machinery.

LAND DEGRADATION AND MANAGEMENT CHALLENGES

The key land degradation issues facing the EU include:

- Loss of vegetation cover that increases soil loss during rainfall, reduce soil's capacity for flood regulation, and release large amounts of carbon into the atmosphere.
- Landscape simplification, driven by both intensive agriculture and land abandonment, reduces biodiversity and weakens nature's ability to prevent wildfires and control pest spread.
- Land-use mismanagement, including overgrazing, deforestation, excessive fertilizer use, inappropriate irrigation, and urban sprawl, can cause irreversible damage to soil biodiversity and integrity, jeopardizing soil health for future generations.

HOW TO PROTECT AND MAINTAIN SOIL HEALTH

Sustainable land management practices including:

- Increase in vegetation cover by using cover crops, plant native vegetation, and reduce soil exposure.
- Protection and restoration of forests by encouraging reforestation and sustainable forestry.
- Promotion of landscape diversity by maintaining mixed land-use areas to enhance ecosystem resilience.