SOB4ES
Integrating SOil Biodiversity to Ecosystem Services

Reliable soil biota monitoring across EU soils

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Key messages

- Between 60 and 70% of EU soils are already degraded but this figure could rise to 90% by 2050.
- Despite the EU Directive on Soil Monitoring and Resilience being a pivotal step to safeguard our soils, excessive flexibility given to authorities and land managers could undermine the implementation of a solid and coherent soil monitoring framework.
- Soil organisms are an integral part of the soil, and their presence is interrelated with soil health.
- Member States (MS) should report on a minimum of soil descriptors (the same across borders) to provide minimum soil protection, to enable comparisons across regions and soil types and to reduce inequalities.
- Goal-driven approaches, instead of target fixation, will facilitate the willingness to implement.

Meeting the goal of achieving healthy soils across Europe by 2050

Over 60% of European soils are in an unhealthy condition as they are continually being subjected to several degradation processes[1]. Despite the European Commission implementing several strategies to ensure sustainable food provision (Farm to Fork), climate neutrality (Climate Strategy), clean environment (Zero Pollution Strategy & Chemicals Strategy) and the protection of biodiversity (Forest Strategy & Biodiversity Strategy 2030), soils continue to be degraded. It has been estimated that more than 90% could become degraded by 2050[2]. This deterioration costs billions of euro (an estimated over €50 billion per year due to the loss of essential services they provide), which has prompted the EU to urge the need to achieve healthy soils by 2050 by laying the Directive on Soil Monitoring and Resilience (COM(2023) 416).

Could the Directive on Soil Monitoring and Resilience (DSMR) be more effective than other EU policies in protecting soils?

The DSMR provides a definition for healthy soils: “soils are healthy when they are in **good chemical, biological and physical condition,** and thus able to provide as many ecosystem services as possible”. This highlights that soils are not just mere substrates to supply food and raw materials (**provisioning services**), but also habitats to sustain plants and animals (**supporting services**) and key for ensuring the proper functioning of ecosystems through their **regulating services** (water filtration and flood mitigation, climate regulation and nutrient cycling) alongside wider societal benefits (**cultural services**). Having a clear, common definition of healthy soils avoids misinterpretations *on what to achieve* but raises questions on *how to achieve* this ambitious goal. The DSMR provides a more explicit framework to instruct Member States (MS) on how to “monitor and assess soil health” (Pillar I) using the indicators defined in Annex 1 (article 7(1)), to “promote sustainable soil management (Pillar II), and to “manage contaminated sites” (Pillar III). However, uncertainties in standards and targets and practical challenges related to geographical heterogeneities (in terms of economic means and country-level governance) could prevent compliance.

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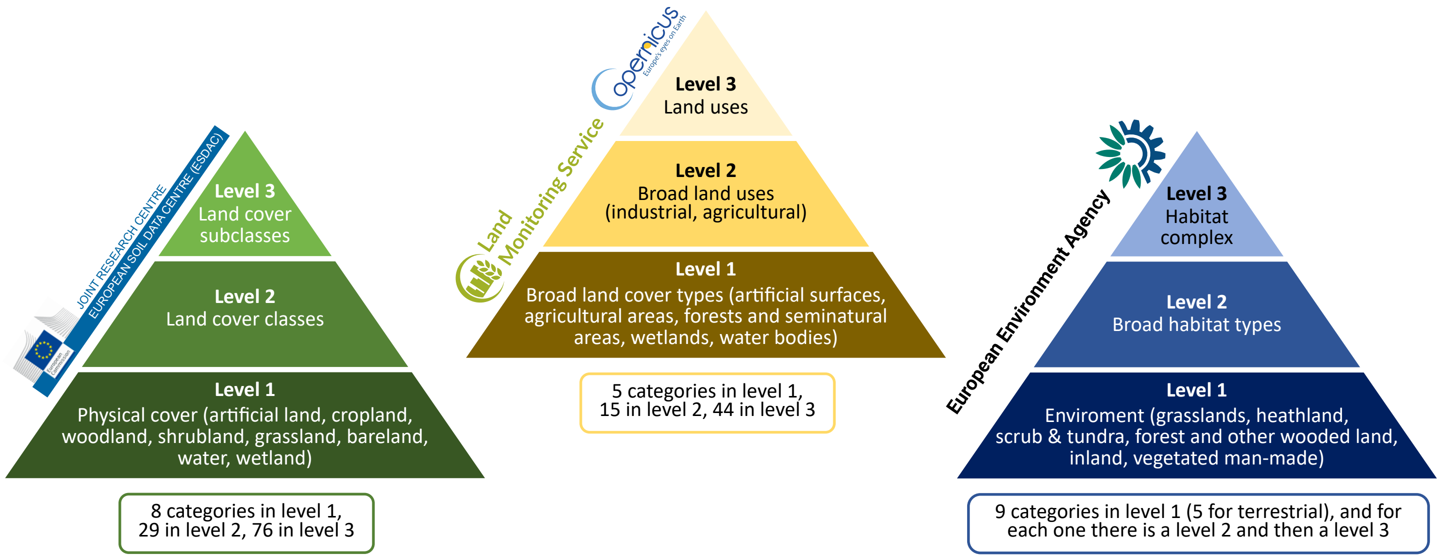
Policy insights into soil monitoring

The geographical basis for soil monitoring

According to article 4 of the DSMR, the monitoring should be done in **"soil districts"**, which will be established by each MS and "shall as a minimum correspond to the number of NUTS 1 territorial units established under Regulation (EC) No 1059/2003". The NUTS classification, based on administrative divisions, creates significant variation in the size and nature of NUTS areas, even at the same level, both within and between countries. For example, the first level (NUTS 1) refers to major socio-economic regions (92 in total for EU, ranging from 1 in countries such as Croatia, Czechia, Denmark or Estonia to 16 for Germany) and whereas Spain, with a covering area of 506,030 km^2, has 7 NUTS 1, metropolitan France extending over 551,500 km^2 has 14 NUTS 1.

Article 4 also indicates that MS shall **"seek homogeneity within each soil district"** regarding soil type (WRB), climatic conditions, environmental zone[3], and land use or land cover (as used in the Land Use/Cover Area frame statistical Survey (LUCAS) programme). This is in line with the proposed solution by the EU Council with the introduction of the concept of **"soil unit"** within the soil district, with fairly homogenous soil characteristics, based on minimum EU-defined parameters (soil type and land use), but leaving MS with sufficient flexibility to use more detailed equivalent data, if available, and take into account additional parameters such as climate, environmental zones or river basins. This selection of parameters makes it very difficult to achieve "homogeneity" and "harmonisation" across and within MS. LUCAS establishes land cover distribution based on ortho-photo interpretation, but this information can also be derived from interpreting satellite images (CORINE Land Cover and Land use). Another alternative would be to use the more detailed EUNIS habitat classification that covers all types of habitat from natural to artificial, from terrestrial to freshwater and marine.

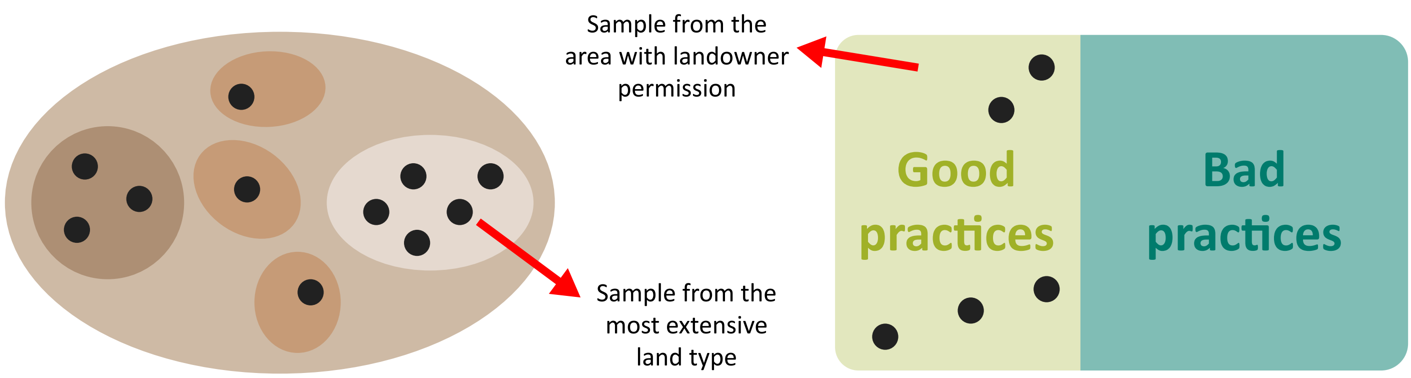


POLICY RECOMMENDATIONS:

- Homogeneity within each soil district and between soil districts and across borders requires a common strategy to define territorial units and land cover/land use classifications. Since these divisions are based on above-ground vegetation, priority should be given to ensure full coverage of all soil types in each MS to secure soils as functional living systems.
- A common interactive map of EU-27 that includes advance research tools (e.g., by coordinates) to identify land cover/land uses for a given "geographical unit" will reduce ambiguities and ensure comparability across borders.

The monitoring framework must ensure regular and accurate monitoring of soil health

This implies a long-term network of sites within each MS that can be continuously visited to track trends in the effects of climate and land management strategies. Since landowners/managers need to be informed of the activities occurring in their property, judgmental (targeted or biased) sampling design (e.g., field margin) could lead to clustered and autocorrelated results. The LUCAS stratified random sampling approach, with land cover as the main stratifier, could exacerbate the representativeness of the sampling design by having more samples from those land covers that extend over a larger area[4].



POLICY RECOMMENDATIONS:

- Sampling bias can be mitigated by weighing the survey data to correct for under- or over-representations.
- Since “competent authorities” responsible for carrying out the duties are to be designated by each MS (Article 5), an independent board at EU-level should evaluate/approve the monitoring framework before the sampling starts.

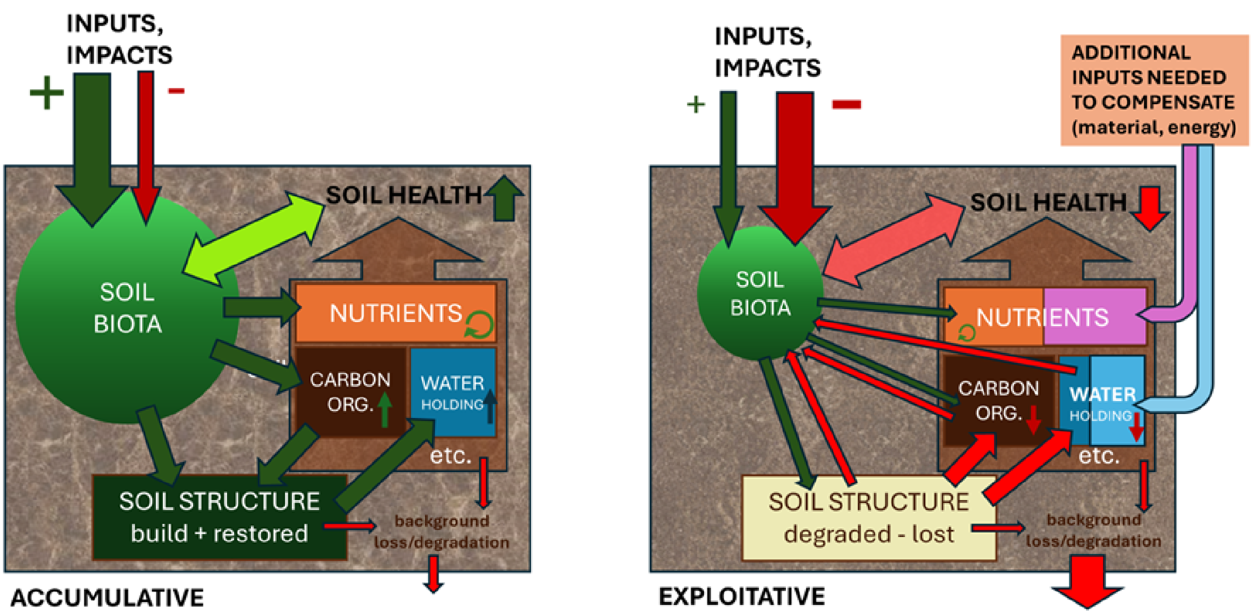
The challenge of adequately protecting the soil “biological” health

Since the foundation of agriculture, the focus has been placed on “soil fertility” (adequate levels of nutrients) to produce food, which is why we know more about the physical and chemical properties of a **“good soil”** than about its biological condition. There is convincing evidence that soil organisms (“soil biota“) are both soil inhabitants and integral part of the soil, and their presence is interrelated with soil health. Soil itself cannot be created without their action, and in all soils they provide many vital functions: they secure nutrient cycling via decomposition and mineralisation processes, support carbon sequestration, build and maintain soil structure, which is essential for water-holding capacity and creates highly variable microhabitats back for soil organisms. Obviously, soil functionalities are dependent on inputs and losses – in healthy soils, positive inputs (some, such as soil texture, are fixed, while others, like organic matter input, aboveground vegetation, and hydrological regime, are more variable) override negative impacts, and soil works in **“accumulative regime”**, improving and/or holding good soil health status. If positive inputs diminish (e.g., significant lowering of organic matter input, dramatic change of aboveground ecosystem) and negative impacts – such as mechanical or chemical disturbance, pollution, dramatic pH change, dramatic increase of farming intensity, etc. – increase, soil biota is affected, positive impacts on soil health are lost, and consequently, soil structure and soil health are degraded, losses increase, and this is reflected by negative changes in abundance and structure of soil biota. In the case of productive soils, this **”exploitative regime”** requires increasing additional inputs (nutrients – fertilisers, irrigation, chemical treatment, etc.).

Soil biota integrates all impacts and reflects the real state of the soil, therefore, robust soil biological indicators are needed for an effective common monitoring framework of soil health across EU soils.

Accumulative and exploitative regimes of soil explained

In an **accumulative regime**, negative impacts are time-limited, occasional, or absent, and positive impacts (such as organic matter input and natural physico-chemical conditions to which the system is adapted) prevail. Relatively rich, condition- and site-specific soil biota reflects good soil health under a given geo-physical-chemical condition, and is vital for support and maintenance of nutrient cycling, carbon sequestration, soil structure, water holding capacity and many other ecosystem services provided by soil. In an **exploitative regime**, the natural conditions to which soils were adapted are dramatically changed and negative impacts override positive ones for long periods or permanently (e.g., highly intensive farming). Soil biota is negatively affected and fails to support sufficiently some or all important ecosystem services – nutrients and organic carbon may be lost, soil structure degrades, water-holding capacity decreases. Degraded soil provides fewer habitat opportunities for soil biota, which further support degradation process (positive feedback). Until new, poorer "steady state" is reached, losses from soil ecosystem are increased, and (e.g., in productive soils) they need to be increasingly supplied by additional external inputs. Returning to the natural accumulative regime of soil means restoring soil health through natural processes. However, reaching a healthy state may be time-dependent.



The DSMR indicator criteria for soil health assessments

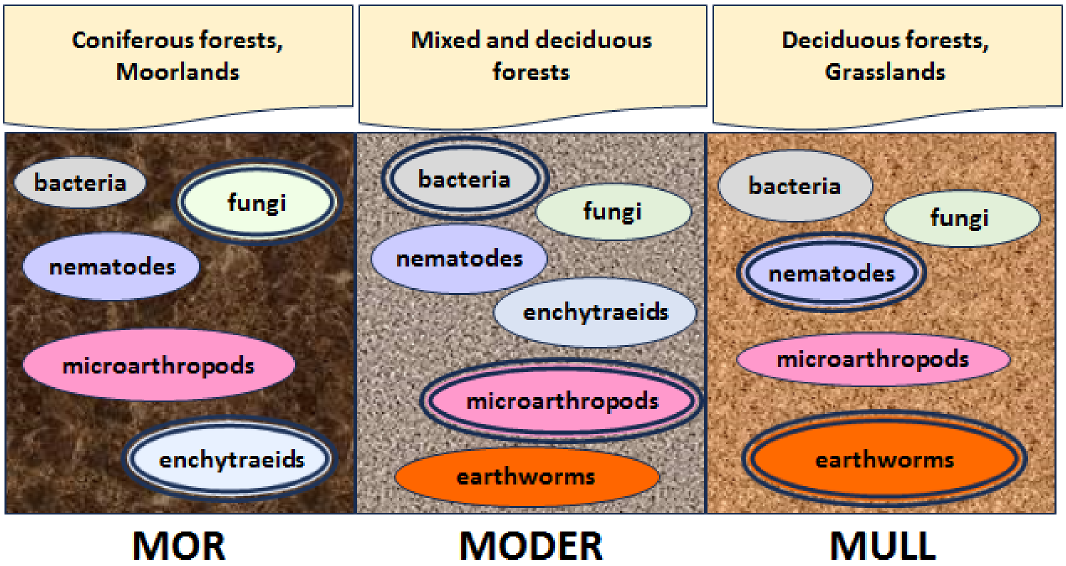
In the EU Parliament, the Committee on the Environment, Public Health and Food Safety (ENVI) adopted the **Tiers approach,** which is based on a progression of soil monitoring intensity, i.e. in terms of the number soil descriptors measured. This provides the much-needed flexibility for MS to implement their monitoring programmes (they can choose among three tiers, with different soil descriptors and soil health criteria), but also gives them more allowances to define the health status of their soils. Tier 1 represents the minimum requirements to comply with the Directive: "A Member State qualifies for a Tier 1 soil monitoring design in accordance with the conditions of Annex I, and shall ensure that they include at least all soil descriptors in Part A of Annex I". The soil biological descriptors included here are: (i) taxonomic diversity (diversity of soil organisms (presence, counts per taxonomic group) based on metabarcoding targeting the 16S and 18S rRNA gene regions) and (ii) population abundance (bacteria and archaea – using 16S rRNA; fungi – using 18S rRNA; total number and proportion of pathogenic fungi; total nematode abundance per functional group based on morphology (bacterial feeders, fungal feeders, root feeders, omnivores, predators)). This means that soil health status merely focuses on microorganisms and nematodes (microfauna) potentially harmful for crops.

Soil biodiversity is shaped by climate and ecosystem type

There are 26 major soil types[5] and 133 pedoclimate regions[6] in Europe. Therefore, it can be anticipated a similar or higher diversity of European soil communities, which makes a fixed indicator selection very unlikely to reflect the true health status of EU soils.

Soil organisms include acidophilous/acid-intolerant, hydrophilic/xeric, etc. and can exhibit a wide range of feeding preferences (microbivores, herbivores, fungivores, saprotrophs, predators) and it is this functional dissimilarity that makes the dynamics of soil processes flow (multifunctionality). For example, it has long been well-known that plant litter decomposes more quickly by the native soil communities that have co-evolved in a specific environment than from elsewhere. This is called "home-field advantage hypothesis"[7] and highlights the strong influence of local adaptations in litter mass loss and nutrient release/retention. Because each soil type poses different abiotic conditions and challenges, the living actors are not the same everywhere and if one or two are not present that does not mean the soil is unhealthy.

Are ubiquitous organisms the best indicators?
Should the same groups be monitored across all ecosystems?



POLICY RECOMMENDATIONS:

- A good indicator has to be sensitive enough to detect real changes but not too sensitive that it reacts to stochastic events.
- Soil descriptors must be ecosystem/land use specific.
- Instead of the Tiers approach, MS should be offered the possibility of choosing a minimum number of criteria among a list of potential descriptors (limited number), which will be ranked and weighed according to their contribution to ecosystem services.
- All MS should report on the same descriptors (the minimum required) to enable comparisons across regions and soil types and to reduce inequalities.
- Optimal ranges instead of targets will facilitate willingness to implement and achieve the soil health goal.
- Monitoring trends (accumulative versus exploitative) may serve as a policy tool to assess the efficiency of measures taken towards effective soil restoration.
- Incentives need to be developed to enhance soil health (e.g. ecological awards similar to the World Smart City Awards).

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Project objectives

MISSION

Making soil biodiversity and its contribution to ecosystem services visible to society alongside integration into EU policies

Key objectives

- ✔ To assess soil biodiversity community composition, its spatial and temporal dynamics, linkages with aboveground biodiversity and ecological network structure in response to land use types and intensity
- ✔ To understand the interrelationships between soil biodiversity and ecosystem services for representative land uses and pedoclimatic regions
- ✔ To improve current evaluations of ecosystem condition by incorporating soil biodiversity structural and functional indicators into large-scale monitoring surveys and land management planning
- ✔ To integrate ecological knowledge of soil biodiversity into the daily lives of Europeans (stakeholders, policy-makers and citizens) by interactively exchanging knowledge, raising public awareness and fostering societal appreciation of the vital functions of soil biodiversity and its contribution to ecosystem services

Project partners

Coordinator: University of Vigo, Spain

- Airfield Estate, Republic of Ireland
- Aristotle University of Thessaloniki, Greece
- Charles University, Czech Republic
- Cologne University, Germany
- EURICE - European Research and Project Office GmbH, Germany
- Gent University, Belgium
- Harper Adams University, United Kingdom
- INRAE - Institut National de Recherche pour l'Agriculture, l'Alimentation et l'environnement, France
- Institute of Biology Bucharest, Romania
- KNAW - Royal Netherlands Academy of Arts and Sciences, The Netherlands
- KU Leuven, Belgium
- Mel Finca Organica S. Coop. Galega, Spain
- Swedish Agricultural University, Sweden
- The Agricultural Research Organisation of Israel – The Volcani Centre, Israel
- University College Dublin/National University of Ireland Dublin, Republic of Ireland
- University of Catania, Italy
- University of Ljubljana, Slovenia
- WSL - Swiss Federal Institute for Forest, Snow and Landscape Research, Switzerland

Funding scheme

CALL	DURATION	BUDGET
Soil biodiversity and its contribution to ecosystem services (HORIZON-MISS-2022-SOIL-01-03)	**1 June 2023 – 31 May 2028** (60 months)	**EU contribution:** € 7,213,228.75 **Other funding sources:** € 1.2 Million from Swiss and UK national funding

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