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SOIL HEALTH: DEFINITIONS, CRITERIAAND ECONOMIC DIMENSIONS IN THE EUROPEAN CONTEXT

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Abstract
This report provides a comprehensive overview of the concept of “soil health,” examining its historical evolution, contemporary scientific definitions, key assessment criteria, and economic dimensions within the European Union. Through a structured literature review and analysis of major EU policy documents – including the EU Soil Strategy for 2030, the Farm to Fork Strategy, the Soil Monitoring Law, and the Soil Deal for Europe – the study traces how the understanding of soil health has shifted from a narrow focus on soil fertility toward a multidisciplinary concept that integrates biological, physical, chemical, ecological, and socio-economic perspectives.
Historically, soil health was assessed primarily through physical and chemical properties, with particular emphasis on soil fertility and humus content. By the 1930s, biological characteristics such as vegetation, organic matter, and microbial communities became central to the concept. Modern definitions by FAO and international researchers conceptualize soil as a “living system,” whose continued capacity to function determines its health. This includes the ability to sustain plant and animal productivity, maintain or improve water and air quality, regulate nutrient and hydrological cycles, and support biodiversity. European policy frameworks expand this understanding, highlighting soil as a key actor in climate regulation, carbon sequestration, food security, and the resilience of ecosystems and economies.
The report reviews the principal groups of soil health indicators – chemical, physical, and biological – and discusses the persistent challenges of establishing harmonized monitoring systems across the EU. European soils are highly diverse, spanning multiple climatic zones, soil types, and land-use practices, which complicates the definition of uniform threshold values. According to the European Environment Agency, coherent assessment requires integrated indicator sets, functional thresholds, and standardized sampling methods. The proposed Soil Monitoring Law aims to address these gaps by setting common criteria, harmonized methodologies, and mandatory monitoring across Member States.
From an economic perspective, the report emphasizes that soil health functions both as a private asset and a public good. Healthy soils generate direct economic benefits by improving crop yields, reducing input costs, increasing land value, and enhancing resilience to climate extremes. Indirectly, they provide essential ecosystem services – including carbon storage, water purification, flood mitigation, and biodiversity conservation – that are not reflected in traditional markets but carry substantial societal value. Conversely, soil degradation imposes significant economic losses, estimated at tens of billions of euros annually in the EU, through reduced productivity, environmental remediation costs, and increased vulnerability to climate risks.
The report concludes that maintaining soil health requires integrated scientific knowledge, effective policy implementation, and broad societal engagement. Expanding harmonized monitoring, strengthening advisory services and knowledge transfer, and increasing public awareness are

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essential steps toward achieving the EU's soil health goals for 2030 and ensuring long-term ecological and economic sustainability.

Key words: soil health, soil health indicators
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Introduction

The current era is characterized by massive global phenomena such as food insecurity and malnutrition, poverty, climate change, biodiversity loss, land degradation, pollution, the modification of water and nutrients cycles, and widespread disease outbreaks. (FAO, 2022). The key to solving these challenges lies in recognizing the importance of natural resources and using them responsibly. Taking care of them means not just protecting the environment, but protecting our own health, economic stability, and future. Land and soil continue to be subject to severe degradation processes such as erosion, compaction, organic matter decline, pollution, loss of biodiversity, salinisation and sealing. This damage is the result of unsustainable land use and management, overexploitation and emissions of pollutants. (EC, 2021). Against the backdrop of interconnected global challenges, soil health gains crucial importance as a key factor shaping both ecological resilience and socio-economic development.

While global frameworks such as the "2030 Agenda for sustainable development" emphasize the necessity of protecting natural resources, the European Union has also placed soil at the center of its sustainability agenda. The "EU Soil Strategy for 2030" explicitly identifies healthy soils as a fundamental for climate neutrality, reversing biodiversity loss, a resilient food system and a circular economy. Complementing this, the proposed "Soil Monitoring and Resilience Directive'' establishes a legal framework for assessing and restoring soil health across Member states. Moreover, initiatives such as the 'EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', and the EU Soil Mission "A soil deal for Europe" further highlight the European commitment to achieving land degradation neutrality, improving soil monitoring, and fostering innovation through living labs and lighthouses

Thus, in the European context, soil health is not only an ecological concept but also a socio-economic imperative, directly linked to agricultural productivity, climate action, and long-term sustainability.

Within this European context, the present study pursues three main objectives:

1. To examine the conceptual foundations of soil health, with a focus on existing definitions and their implications for research and policy.
2. To identify and analyze key criteria for assessing soil health, linking ecological indicators with socio-economic dimensions.

3. To evaluate the economic significance of soil health in the European Union, highlighting the interconnections between soil functions, agricultural productivity, ecosystem services, and long-term sustainability.

This report is based on a structured literature review and policy document analysis as: EU Soil Strategy for 2030, Soil monitoring and resilience directive, A Soil Deal for Europe, Directive of the European Parliament and of the Council on soil monitoring and resilience (Soil Monitoring Law), Soil monitoring in Europe: Indicators and thresholds, etc. The scope was limited to the European context, with global references included where necessary to trace the historical evolution of the concept. The selection of sources was guided by relevance to the European policy framework and soil health research. The review covered publications and policy documents issued between 2000 and 2024, including peer-reviewed scientific articles, EU strategies, directives, and reports from the European Commission and the European Environment Agency. Databases such as Scopus, ResearchGate, and official EU repositories were consulted, while global references were included only when essential for tracing the historical evolution of the concept.

Soil health definitions and conceptual frames

The concept of soil health has evolved for more than a century. Early references emphasized soil fertility through physical and chemical properties, particularly humus. By the 1930s, biological aspects were introduced, highlighting the role of vegetation, organic matter, and soil microbes. The USDA's 1936 report "Soil Health and National Wealth" expanded the idea by recognizing the contributions of plants, animals, and microorganisms. In the same period, links between soil and human health also began to appear. Between the 1940s and 1970s, research increasingly connected soil health with human well-being, the rise of organic agriculture, and the importance of soil organisms, laying the foundation for the modern multidimensional view of soil health. And by the 1970s soil health was defined as "the inherent replenishment of nutrients in the soil through the process of weathering and soil formation." (Brevik. Eric. 2019)

The global perspective:

„Soil health has been defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health (Pankhurst. C. E. 1997). Thanks to this definition, in 2008, the FAO made the following statement: "Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production" (FAO, 2008). This definition explicitly introduces a temporal component by emphasizing the continued capacity of soil to function, which highlights that soil health must be sustained over time rather than assessed at a single moment. It recognizes soil as a dynamic ecosystem whose biological processes are central to supporting life and environmental quality and expands the concept of soil health by explicitly linking it to biodiversity and ecological interactions. It highlights the role of soil organisms in regulating pests and diseases, forming symbiotic relationships with plants, and recycling nutrients, thereby framing soil health as a driver of ecosystem services. Additionally, the definition introduces the idea that healthy soils actively improve soil structure and enhance water and nutrient retention, emphasizing not only ecological sustainability but also direct contributions to agricultural productivity. In the context of the EU Soil Strategy for 2030, soil health can be understood as the capacity of soils to sustain their ecological, economic, and social functions, including the provision of food and clean water, the regulation of climate through carbon storage, the preservation of biodiversity, and the support of a circular and resilient economy.

In European documents such as the EU Soil Strategy for 2030, Farm to Fork Strategy, The Implementation Plan of the mission "A Soil Deal for Europe", we find precisely this conceptual framework: ’Soil health is defined as 'the continued capacity of soils to support ecosystem services’.

Table 1. How does the EU Soil Strategy 2030 present healthy soils?

Provide food and biomass production, including 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	Provide a physical platform and cultural services for humans and their activities	Act as a source of raw materials; constitute an archive of geological, geomorphological and archaeological heritage

Criteria for assessing soil health

As I noted at the beginning of this report, we have data showing that in 1910 the emphasis was on assessing soil fertility through physical and chemical properties, especially humus. In the 1930s, biological aspects were introduced, emphasizing the role of vegetation, organic matter, and soil microbes.

Now soil health can be evaluated either through composite soil quality indices or by employing individual soil health indicators. On the one hand, indices integrate physical, chemical, and biological attributes into a single aggregated measure, thereby facilitating cross-soil comparisons. Nevertheless, they may generate inconsistent results and often provide limited guidance for practical management interventions (Stevens, 2015). On the other hand, indicators yield more detailed insights into specific soil properties; however, they are more difficult to quantify and compare across sites and regions.

Consequently, the development of robust and broadly applicable indicators and threshold values remains a significant challenge. In the European context this difficulty stems from the substantial heterogeneity of European soils, biota, and climatic conditions, as well as from the diverse political, economic, and social contexts that shape national priorities for target-setting and indicator selection. Within Europe, 23 major soil types have been distinguished, along with four dominant macroclimatic zones and eight officially recognized soil threats. Taken together, these factors create a complex matrix of vegetation growth conditions across the continent. (EEA, 2022).

Table 2. A simplified framework for soil health

Chemical Indicators	**Physical Indicators**	**Biological Indicators**
Soil pH	Soil texture	Microbial biomass
Soil electrical conductivity	Soil particle and bulk density	Population of soil micro and macro-organisms
Organic matter content	Penetration resistance of soil	Soil enzyme activities
Total carbon and nitrogen	Aggregate stability	Pollutant detoxification
Carbon exchange capacity	Soil water holding capacity	Soil respiration
Soil essential nutrient	Soil aeration and porosity	Soil pathogens
Heavy and toxic metals	Soil infiltration	

According to the EEA Report 08/2022 – Soil Monitoring in Europe: Indicators and Thresholds for Soil Health Assessments, the evaluation of soil health requires a coherent set of chemical, physical and biological indicators, complemented by functional thresholds. The most widely applied indicators include soil organic carbon (SOC), pH (acidity/alkalinity), nutrient balance, contaminant levels (e.g. heavy metals, organic pollutants), erosion rates, soil compaction, land cover and sealing, and biological diversity of soil organisms. These parameters are directly linked to the capacity of soils to sustain fertility, regulate water and nutrient cycles, and provide essential ecosystem services such as carbon storage and pollutant filtration.

Importantly, the EEA report 08/2022 stresses the role of thresholds, defined as critical values beyond which soil functions are impaired. For instance, SOC values below defined thresholds signal reduced fertility and diminished carbon sequestration potential, while excessive compaction or erosion indicates degradation of soil structure and resilience. Although the current knowledge base is substantial, harmonization challenges persist, particularly regarding the definition and monitoring of soil biodiversity indicators. To ensure comparability across Europe, the monitoring framework recommends the adoption of stratified sampling schemes and tiered indicator sets.

The "DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Soil Monitoring and Resilience (Soil Monitoring Law)" (EU 2023) sets out the main criteria for assessing soil health, their values and assessment methods. Attention is paid to biological, chemical and physical indicators that reflect the ability of the soil to maintain productivity, biodiversity and ecosystem services. Regular monitoring is required using harmonised methods and threshold values, which allows for comparability between different regions, while taking into account the specific national and local context.

Economic Dimensions of Soil Health

Healthy soils generate both direct and indirect economic benefits. Directly, they enhance agricultural productivity, reduce input costs, and increase land value, while also opening opportunities for carbon credit schemes. Indirectly, soil health contributes to climate change mitigation, reduces risks to public health, supports biodiversity, and prevents costly environmental degradation.

Healthy soils constitute a critical component of terrestrial ecosystem functionality and provide essential services that underpin both ecological sustainability and economic productivity in Europe. Cropland and grasslands in the EU provide EUR 76 billion worth of ecosystem services per year. (*European Commission, 2021*). They enhance agricultural resilience by maintaining soil structure, nutrient availability, and microbial activity, thereby increasing crop yield stability and improving nutritional quality. Also hosts the largest carbon pool in the terrestrial ecosystem, playing an essential role in the global carbon cycle and the regulation of climate change. (EEA, EC, 2024). They regulate hydrological processes by promoting water infiltration, retention, and filtration, which reduces the incidence of surface runoff, erosion, and flooding. Furthermore, healthy soils sustain high levels of biodiversity, supporting microbial, fungal, and invertebrate communities that contribute to nutrient cycling, plant health, and overall ecosystem resilience. The conservation and restoration of soil health thus directly contribute to the maintenance of ecosystem services, food security, climate regulation, and the socio-economic well-being of European populations, demonstrating the multidimensional value of soil stewardship.

Conversely, soil degradation imposes significant economic costs and threatens environmental and societal well-being. As the EU's largest terrestrial ecosystem, healthy soils sustain many sectors of the economy while soil degradation is costing the EU several tens of billion euros per year. It has been estimated that about 60 to 70% of soils in the EU are not in a healthy state (based on a definition of soil health applied in the context of the Mission 'A Soil Deal for Europe', under the EU Horizon Europe research programme). Every year, about 1 billion tonnes of soil are washed away by erosion in Europe. Between 2012 and 2018 more than 400 km² of land was taken per year in the EU on a net basis.(EC, 2021). More broadly, soil degradation including nutrient depletion, contamination, and compaction – results in tens of billions of euros in losses each year, while undermining food security, reducing agricultural yields, and impairing ecosystem services. These costs extend beyond direct financial losses, encompassing increased expenditures for soil restoration, water treatment, climate adaptation measures, and mitigation of biodiversity loss. Moreover, degraded soils have indirect effects on human health by diminishing food quality and increasing exposure to pollutants, further amplifying economic and social burdens. The European Union's policy frameworks, including the Soil Strategy for 2030 and the „Farm to Fork Strategy, recognize the economic and societal importance of soil health. These strategies emphasize the reduction of nutrient losses, sustainable soil management, and the promotion of practices that enhance soil biological activity, fertility, and resilience. By implementing preventive and restorative measures, the EU aims to safeguard soil-dependent ecosystem services, minimize economic losses from soil degradation, and achieve long-term sustainability across agricultural, environmental, and economic sectors.

The economic role of soil health in the European Union can be examined through the lens of cost–benefit analysis and the differentiation between market and non-market values.

This framework illustrates that soil health functions as both a private asset and a public good. From an economic perspective, the challenge is to increase the number of policies that internalize externalities and reward practices that ensure both private profitability and public sustainability. (Table 3).

Table 3

Market benefits	**Non-market benefits**	**Costs of degradation**	**Short-term vs. long-term trade-offs**
Healthy soils increase agricultural productivity by improving nutrient availability, water retention, and soil structure. These processes reduce the need for synthetic fertilizers, irrigation,	Soils provide climate regulation through carbon sequestration, water purification, flood mitigation, and biodiversity conservation. These services are not reflected in conventional markets	Degraded soils lead to declining yields, higher input requirements, and greater exposure to climate extremes. Beyond private farm losses, society bears the costs of water treatment, disaster	Intensive land use may provide immediate yield gains but accelerates degradation, resulting in long-term productivity decline and higher costs of restoration. By contrast, investment in

Market benefits	Non-market benefits	Costs of degradation	Short-term vs. long-term trade-offs
and pesticides, thereby lowering production costs	but can be valued through avoided damage costs or willingness-to-pay studies.	recovery, and public health impacts.	soil health through sustainable practices (e.g. cover cropping, reduced tillage, organic amendments) can appear costly in the short term but yields significant net benefits over time.

Conclusion

Healthy soils sustain essential functions such as nutrient cycling, water regulation, erosion control, and carbon sequestration, which collectively underpin farm productivity and resilience. From an economic perspective, these functions generate tangible benefits: higher and more stable yields, reduced dependency on external inputs, and lower risks associated with climate variability and extreme weather events. At the same time, soil provides nonmarket ecosystem services, such as carbon storage, biodiversity habitats, and flood mitigation etc. Degraded soils, by contrast, impose hidden costs, including yield losses, higher input requirements, reduced water retention, and long-term productivity decline. Such processes not only affect farm income but also generate externalities, leading to higher public expenditure on environmental remediation, disaster recovery, and climate adaptation.

This report highlights that soil health is both an ecological foundation and an economic asset, underpinning agricultural productivity, ecosystem services, and long-term sustainability. However, the current scale of degradation in the EU shows that policy commitments must be reinforced with more practical tools and wider societal engagement.

First, soil research and monitoring need to be expanded and harmonized across Member States, ensuring that robust data on soil biological, chemical, and physical indicators are regularly collected and made comparable. This is essential for the successful implementation of the Soil Monitoring Law. Also, knowledge transfer and information channels should be strengthened. Farmers, land managers, and local communities require accessible advisory services and demonstration projects (e.g., living labs, lighthouses) that translate scientific findings into practical soil management practices. Public awareness and education must be expanded, as soil health is not only a technical issue but a societal one. Campaigns that communicate the links between soil, food quality, water resources, and climate resilience can build broader support for sustainable soil policies.

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