



EUSO annual bulletin 2023

Broothaerts, N., Panagos, P., Arias Navarro, C., Ballabio, C., Belitrandi, D., Breure, T., De Medici, D., De Rosa, D., Fendrich, A., Havenga, C., Koeninger, J., Kreiselmeier, J., Labouyrie, M., Liakos, L., Maréchal, A., Martin Jimenez, J., Matthews, F., Michailidis, V., Montanarella, L., Muntwyler, A., Orgiazzi, A., Scarpa, S., Schillaci, C., Simoes Vieira, D., Van Eynde, E., Van Liedekerke, M., Wojda, P., Yunta Mezquita, F., Jones, A.

2024

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JRC137235

EUR 31893 EN

PDF ISBN 978-92-68-14188-5 ISSN 1831-9424 doi:10.2760/46142

KJ-NA-31-893-EN-N

Luxembourg: Publications Office of the European Union, 2024

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How to cite this report: European Commission, Joint Research Centre, Broothaerts, N., Panagos, P., Arias Navarro, C., Ballabio, C., Belitrandi, D., Breure, T., De Medici, D., De Rosa, D., Fendrich, A., Havenga, C., Koeninger, J., Kreiselmeier, J., Labouyrie, M., Liakos, L., Maréchal, A., Martin Jimenez, J., Matthews, F., Michailidis, V., Montanarella, L., Muntwyler, A., Orgiazzi, A., Scarpa, S., Schillaci, C., Simoes Vieira, D., Van Eynde, E., Van Liedekerke, M., Wojda, P., Yunta Mezquita, F. and Jones, A., EUSO annual bulletin 2023, Publications Office of the European Union, Luxembourg, 2024, <https://data.europa.eu/doi/10.2760/46142>, JRC137235.

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Abstract

Healthy soils are essential for achieving climate neutrality and providing healthy food. The publication of the EU Soil Strategy for 2030 and the proposed Soil Monitoring Law marked a major milestone for soil protection in the EU. It also highlighted the importance of the EU Soil Observatory (EUSO) as the principal provider of soil-related data and knowledge at EU-level. The present report highlights the main activities of the EUSO in 2023. Through its activities in 2023, the EUSO provided policy support to a wide range of policy areas, including the proposed Soil Monitoring Law. The EUSO also launched the EU Soil Health Dashboard, a comprehensive and easy understandable monitor of the state of soil health in the EU. Furthermore, in 2023, the EUSO contributed to sharing data and knowledge about EU soils, supported soil research and innovation, and supported citizen engagements regarding soil matters. The activities of the Working Groups in 2023, a key element of the EUSO, included providing policy support, advancing scientific knowledge, and stimulating the integration of data. The present report also summarizes the EUSO's activities planned in 2024. The EUSO will continue to provide policy support, e.g. on soil health assessment and soil monitoring. The EUSO Soil Health Dashboard will be updated with new available data and functionalities. In addition, the EUSO will continue to collaborate with Mission Soil research and innovation projects and continue to raise soil awareness among citizens.

Acknowledgements

This work was realised under the Administrative Arrangement JRC No 36283-2022 [AGRI-2022-0253, RTD LC-1158189]: Provision of scientific and technical support to DG AGRI and RTD in relation to the implementation of the soil monitoring tasks of HORIZON Europe Mission “A Soil Deal for Europe”. The authors are thankful to the Mission Soil projects for the collaboration and interaction.

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Executive summary

This report presents the main activities of the EU Soil Observatory (EUSO) in 2023, and highlights the main messages drawn from these activities. It also covers the planned EUSO's work and outcomes in 2024.

Policy context

Healthy soils are essential for achieving climate neutrality, halting the loss of biodiversity and providing healthy food. With the launch of the EUSO as part of the European Green Deal, the European Commission turned the spotlight on these vital aspects of healthy soils. Moreover, the publication of the EU Soil Strategy for 2030 and the proposed Soil Monitoring Law marked a major milestone for soil protection in the EU, which highlighted again the importance of the EUSO.

Given this context, the main objective of the EUSO is to provide the European Commission and the broader soil user community the knowledge and data needed to monitor, safeguard and restore soils at EU-level.

EUSO activities and outcomes in 2023

Through its activities in 2023, the EUSO (1) provided policy support (2) including support to the proposed Soil Monitoring Law, (3) contributed to the monitoring of soil health, (4) contributed to sharing data and knowledge about EU soils, (5) supported soil research and innovation, and (6) supported citizen engagements regarding soil matters:

1. The EUSO provided policy support to a wide range of soil related areas. This includes the proposed Soil Monitoring Law and the Impact Assessment of the proposed law, and the evaluation of the Horizon Europe Mission 'A Soil Deal for Europe'.
2. The EUSO contributed intensively to the design of the proposed Soil Monitoring Law. It contributed to weekly dialogues with the Directorate-General for the Environment and the European Environmental Agency, and responded to more than 100 scientific and technical questions related to the proposed law. More specific, the EUSO highlighted the need for action on soils, by demonstrating the extent of soil degradation in the EU.
3. The EUSO Soil Health Dashboard, launched in 2023, monitors the state of soil health in the EU through 18 indicators. It provides a spatial assessment of unhealthy soils in the EU and the related degradation processes. The resulting map shows, for the first time, where current scientific evidence converges to indicate areas that are likely to be affected by soil degradation. As such, it is a major contribution to soil literacy and soil monitoring in the EU.
4. The European Soil Data Centre (ESDAC), as a core part of the EUSO, has become the leading web platform for gathering and sharing data and knowledge about EU soils. ESDAC has grown substantially in 2023. Seventeen new datasets were added to the ESDAC platform. The number of datasets requests increased in 2023 with 18% compared to 2022 and 150% compared to 2018, reflecting the increased policy relevance and user demand.

5. In support to soil research and innovation, EUSO contributed directly to advanced scientific knowledge on EU-soils and published 45 new scientific papers in 2023. Furthermore, EUSO was actively involved in, and responsible for, the soil monitoring elements of the Horizon Europe Mission 'A Soil Deal for Europe' (Mission Soil) and contributed to its annual work programme. EUSO also worked in close collaboration with some of the Mission Soil projects.
6. Throughout the year, EUSO organized and contributed to activities to support citizen engagement and soil awareness raising. Highlights include the Third EUSO Stakeholders Forum, the European Mission Soil Week and the launch of a free online course on soil biodiversity.

Working Group activities in 2023

The EUSO Working Groups (WG) are a key element of the EUSO. These working groups consist of topical experts from academia, businesses and policy, who come together to discuss technical advances in their specific topic. In 2023, six working groups were active: (1) WG Soil erosion, (2) WG data sharing and integration, (3) WG Soil pollution, (4) WG Soil monitoring, (5) WG Soil biodiversity, and (6) WG Soil organic carbon monitoring reporting and verification.

The activities of the working groups in 2023 were diverse, including advancing scientific knowledge, stimulating technical advances and integration of data, and providing policy support. The main activity was the organisation of the Third EUSO Stakeholders Forum, an open and inclusive platform bringing together working group members, soil scientists, policy makers, regional and national bodies and interested citizens. The Stakeholders Forum had over 800 participants and over 50 oral presentations.

Planned developments for the EU Soil Observatory in 2024

The present report also summarizes the EUSO's activities planned for 2024. The EUSO's planned policy support includes continued development of soil health assessments and monitoring, new desertification assessment methodologies and the second Clean Soil Outlook. The EUSO Soil Health Dashboard will be updated with new available data and functionalities and with information on temporal soil health changes. Moreover, the ESDAC platform will be further reinforced by new datasets, to remain the single-stop-shop for soil related data in the EU. The platform will also grow with the input and support of relevant Mission Soil research projects. The EUSO will continue to collaborate and interact with these Mission Soil projects. Finally, the EUSO will continue to engage with stakeholders and citizens on soil-related topics and will bring together these stakeholders within the Working Groups and during the Fourth EUSO Stakeholders Forum and the European Mission Soil Week.

1 Introduction

1.1 The EU Soil Observatory

The EU Soil Observatory (EUSO) aims to be the principal provider of reference data and knowledge at EU-level for all matters related to soils. The EUSO is hosted within the Joint Research Centre (JRC) of the European Commission, Unit D.3 (Land Resources and Supply Chain Assessments).

The EUSO is a dynamic and inclusive platform that supports EU soil-related policymaking. EUSO provides the relevant Commission Services and the broader soil user community with the knowledge and data flows needed to safeguard and restore soils. Furthermore, the EUSO supports EU Research and Innovation on soils and aims to raise societal awareness of the value and importance of soils to the lives of citizens.

Overall, the EUSO supports EU soil policies by ensuring that the Commission can make full use of the information made available through integrated data flows by transitioning from simply monitoring to understanding. In this manner, the EUSO supports the implementation of all soil related objectives of the European Green Deal.

This report presents the activities of the EU Soil Observatory that have taken place in 2023 and highlights the main messages drawn from these activities. The report also shortly discusses the planned developments and activities for the EUSO in 2024.

1.2 Policy context

The EU Soil Observatory was launched in December 2020 as part of the European Green Deal. With the creation of EUSO, the European Commission turns the spotlight on the vital role of soils in achieving several objectives of the Green Deal, including climate change, halting the loss of biodiversity or achieving zero pollution.

Soil-related targets are found in many of the strategies published as part of the European Green Deal, in particular:

- the [EU Biodiversity Strategy for 2030](#)
- the [Farm to Fork Strategy](#),
- the [Zero Pollution Action Plan](#), and
- the [Fit for 55 Package](#).

Furthermore, the publication of the [EU Soil Strategy for 2030](#) in November 2021, and the proposed [Soil Monitoring Law](#) in July 2023 marked a major milestone for soil protection in the EU.

In parallel, the Horizon Europe research programme (2021-2027), includes a mission on soils. Entitled 'EU Mission: A Soil Deal for Europe' (Mission Soil), this mission is expected to significantly advance the state of knowledge and data available on soils in the EU and beyond.

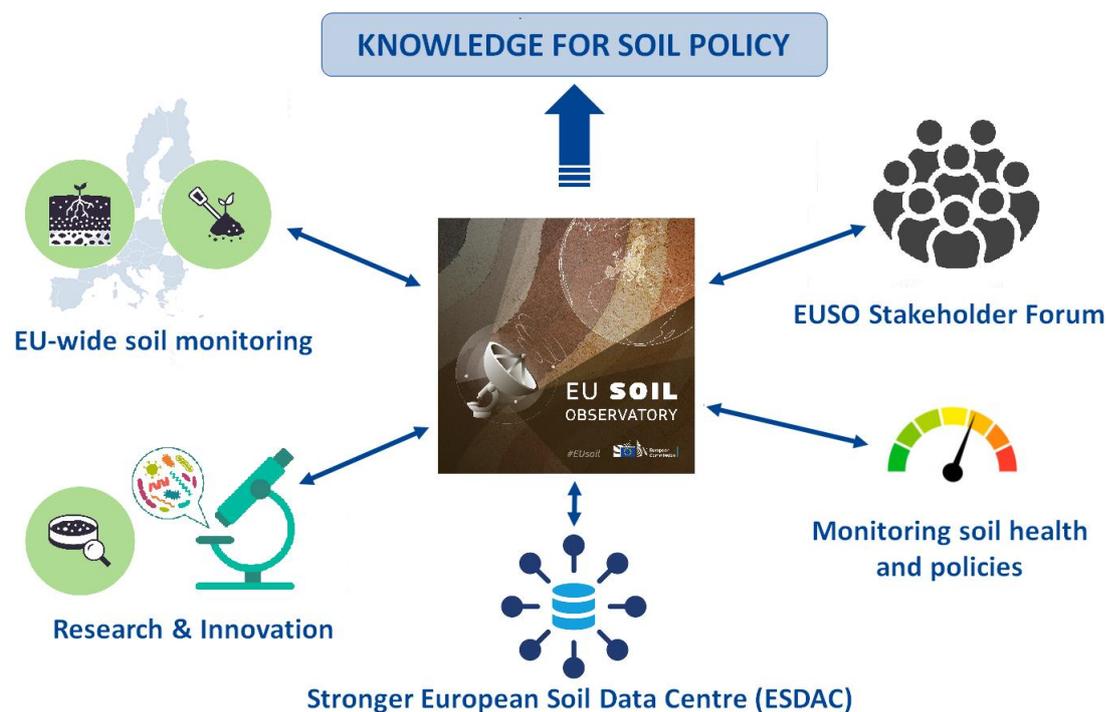
Active for three years, the EUSO plays a key role in supporting soil policy development, monitoring the state of soil health, supporting and interacting with research activities, and raising citizens' awareness of the need for soil protection.

1.3 Objectives of the EU Soil Observatory

The main objective of the EUSO is to be the principal knowledge hub for soil information and data to underpin EU policy development and implementation. To achieve this main objective, five sub-objectives has been defined (Figure 1):

1. Support the development of an operational EU-Wide Soil Monitoring System.
2. Monitor the state of soil health and the policies in place to enhance soil protection, through a Soil Health and Policy Dashboard.
3. Further consolidate and enhance the capacity and functionality of the European Soil Data Centre (ESDAC).
4. Support research and innovation through the implementation of Horizon Europe's Mission 'A Soil Deal for Europe'.
5. Provide an open and inclusive European Soil Stakeholders Forum that supports citizen engagements and the drive towards a societal change in the perception of soil.

Figure 1. The main objectives of the EU Soil Observatory.



Source: JRC analysis.

2 Activities and outcomes of the EU Soil Observatory in 2023

The EUSO activities aim to fulfil its main objectives (section 1.3). Through its activities, the EUSO provides policy support (section 2.1) including support to the Soil Monitoring Law (section 2.2), contributes to the monitoring of soil health (section 2.3), contributes to sharing data and knowledge about EU soils (section 2.4), supports research and innovation (section 2.5), and supports citizen engagements (section 2.6). Through these actions, the EUSO provides the requisite knowledge and data to underpin EU soil-related policy development and implementation.

2.1 Policy support

The EUSO contributed in 2023 extensively to a wide range of policy areas, which are listed below.

In addition, details on the EUSO's support to the Soil Monitoring Law are included in section 2.2. Details on the launched EUSO Soil Health Dashboard, providing policy makers a clear perspective into the state of the soil health in the EU, are included in section 2.3.

Communication COM(2023) 457 - EU Missions two years on: assessment of progress and way forward

The EUSO team supported DG AGRI in the evaluation of the Mission Soil in the Communication by the European Commission COM(2023) 457 and its Staff Working Document (SWD) (2023)260. The mission "A Soil Deal for Europe" has received positive feedback. The Communication builds on evidence provided by the EU Soil Observatory and its Soil Health Dashboard: about 60% of EU soils are considered unhealthy. Soils are losing their capacity to support food production, biodiversity and the regulation of water, nutrients and carbon cycles. Together with the Soil Strategy for 2030, the proposal for a Directive on Soil Monitoring and Resilience, and the EU Soil Observatory, the Mission forms part of a solid framework for soil protection and restoration, as also acknowledged by the European Parliament. More details and relevant documents are available at this [link](#).

Commission Staff Working Document on the evaluation of the Horizon Missions

Together with the JRC the Mission board conducted a review of the latest literature on soil health and food. The evidence brought by the JRC refers to specific challenges (Nitrates, organic carbon, peat, water erosion, compaction, salinization, land take and pollution). Such evidence is presented on pages 160-162 of the SWD and was co-developed with JRC contribution. In addition, the SWD makes many references to the EUSO and its role in the Mission Soil. Among others, as a novelty, funded projects interact from the start with the JRC to establish the mechanisms and requirements for the transfer of data and information to the EUSO. The EUSO will become the Mission's long-term repository for data. More details and relevant documents are available at this [link](#) and this [link](#).

Mapping and Analysis of CAP Strategic Plans: contribution for soil

The EUSO team mapped the choices made in the CAP (Common Agricultural Policy) Strategic Plans approved in December 2022 and analysed the joint efforts and potential impacts of Member States' choices in relation to the nine specific objectives. As soil quality improvement is one of the 9 objectives, there is an analysis for soil fertility, soil organic carbon and soil erosion. The analysis used the data and maps of the ESDAC. Several Good Agricultural and Ecological Conditions (GAECs) contributing to improved soil management existed under the CAP 2014-2020, notably GAEC 4 on soil cover and GAEC 5 on land management for erosion control. The trend for soil erosion is confirming the impact of GAECs. More details and relevant documents are available at this [link](#).

Re-evaluation of the existing health-based guidance values for copper by EFSA

Fertilisers contain copper and may gradually enrich soil with copper that potentially enriches food crops. The long-term use of Plant Protection Products (PPPs) containing copper may also enhance soil copper concentrations and, indirectly, copper concentrations in food. The LUCAS Topsoil databases hosted on ESDAC includes data on copper and the analysis of the scientific work at EUSO (Ballabio et al., 2018) contributes to quantify the copper concentration in EU topsoils. The median total copper concentration in European agricultural soils is 15 mg/kg while it is 12 mg Cu/kg for all types of land cover on European soils. Soil copper concentrations are higher in southern Europe than in northern Europe. The mean total concentration of 49 mg/kg was reported in vineyards, with a very high variability between countries, climatic, geological and pedological factors (Ballabio et al., 2018). More details and relevant documents are available at this [link](#).

The strategy to fight desertification in Spain (Official by the government)

This strategy considers assessments and data coming from ESDAC. Among these data, there is the salinization map developed by JRC. Projections of soil loss due to water erosion in the agricultural areas of Europe by 2050 considering changes in erosivity of rainfall and land uses (Panagos et al., 2022) estimate that soil loss will increase between 13% and 22.5% in the EU and the UK, mainly due to the increase in the intensity of rains. This soil loss is expected to be greater in central and northern Europe, while the south of Europe shows smaller increases (between 5 and 12%) due to a decrease in patterns of precipitation and the relatively slight increase of the erosivity of rain compared to other areas of Europe. More details and relevant documents are available at this [link](#).

EU chemicals legislation and LUCAS

The results of the LUCAS soil survey support the policy needs of a number of EU policies such as the Soil Strategy for 2030, the Common Agricultural Policy, the EU Farm2Fork strategy, the Circular Economy Action Plan, climate legislation and EU policies on biodiversity and land degradation neutrality, the Sustainable Development Goals (SDGs), Europe in a wider world and the Green Agenda for the Western Balkans. In particular, in 2023 DG ENV published an external "Study on streamlining chemicals data, interoperability, dissemination, re-use and the use of all available data, and on the establishment of a data generation mechanism for the purpose of safety assessments in the context of the European Chemicals Regulatory Framework". The study considered the possibilities for generating new chemicals data through the establishment of a Data Generation Mechanism. The Soil monitoring under LUCAS is a source for generating new chemicals data at European scale. More details and relevant documents are available at this [link](#).

Contribution to the COM(2023) 395 - Mercury as regards dental amalgam and other mercury-added products

The Staff working document included an assessment of mercury in topsoils. Unlike in water bodies, where mercury tends to accumulate over time, in soils mercury tends to accumulate until an event (e.g. erosion, floods and forest fires) causes its release. Globally, it is estimated that there are approximately 10,000 tonnes of mercury in vegetation, 863,000 t in the active layer of the soil, 793,000 t in permafrost and 454,000 t in other types of soil. In the EU, the estimated mercury stocks in topsoil (0-20cm) are about 45,000 t according to the topsoils Land Use/Land Cover Area Frame Survey (LUCAS) survey. This is based on EUSO data. Note: to estimate impacts of policy measures, models were developed that allow quantitative statements on future export volumes, export values and mercury contents. Most estimates indicate that global mercury emissions to the

atmosphere stand at 2000 to 2500 t per year, with a persistence of up to two years, before deposition into water or soil. More details and relevant documents are available at this [link](#).

How pesticides impact human health and ecosystems in Europe - EEA publication

In 2020, one or more pesticides were detected above thresholds of concern at 22% of all monitoring sites in rivers and lakes across Europe. 83% of agricultural soils tested in a 2019 study contained pesticide residues. The LUCAS database includes data on pesticide residues in EU agricultural soils (Orgiazzi et al., 2022). A study based on data from the LUCAS 2015 survey found that 83% of topsoil samples contained one or more pesticide residues, while 58% contained mixtures of two or more pesticides. The most common mixture detected was the herbicide glyphosate and its metabolite aminomethylphosphonic acid (AMPA), representing 25% of all pesticide combinations in soil. The results of the JRC study have been used in the EEA publication on "How pesticides impact human health and ecosystems in Europe". This study is available at this [link](#).

Soil Atlas of Asia

JRC coordinated the development and drafting of the first-ever Soil Atlas of Asia (Figure 6). The preparation of the atlas started in 2018 and involved about 100 soil experts under the facilitation of the JRC, together with the UN Global Soil Partnership. Financial support for training and the Editorial Board were provided by the JRC and the Asian Food and Agriculture Cooperation Initiative, the latter managed by the Rural Development Administration of the Republic of Korea. The JRC coordinated and chaired annual editorial and progress meetings in Asia and virtually during the COVID period. Meetings would be arranged on a regional basis with an accompanying plenary. JRC collaborated with the Food and Agriculture Organization (FAO) on data harmonisation and the production of ancillary maps. JRC coordinated the editing and layout of texts. A high-level launch event was organised as part of the UN Global Soil Partnership Plenary Meeting (Rome, 12 July 2023), while further technical and scientific launch events are planned. The Soil Atlas of Asia is available at this [link](#).

Soil Health in the Staff Working Document "Drivers of food security"

The staff working document SWD (2023) 4 final (4.1.2023) aims at analysing the main drivers affecting food security from both the supply and demand sides. About 95% of food comes from terrestrial sources and depends on healthy soils, able to provide sufficient, safe and nutritious food and a range of vital ecosystems services, such as clean water, habitats for biodiversity, nutrient cycling and carbon storage. About 60-70% of EU's agricultural soils are currently either losing organic carbon, receiving more nutrients than they need, eroding or compacting, suffering secondary salinization, or some combination thereof (Veerman et al., 2020). There are potentially 2.8 million potentially contaminated sites (Pérez and Eugenio, 2018), 24% of land with unsustainable water erosion rates (P. Panagos et al., 2020), 23% of land with high density subsoil indicating compaction (Montanarella and Panagos, 2021), 25% of land at high or very high risk of desertification. More details and relevant documents are available at this [link](#).

Sustainable development in the European Union — Monitoring report on progress towards the SDGs in an EU context — 2023 edition

In 2023 the EUSO further developed the indicator 'estimated soil erosion by water' for SDG 2 'Zero hunger' and SDG15 'Life on Land' to show trends in soil erosion. The work of the EUSO contributes to assessing the trend of soil erosion that is a major threat for land degradation; there are signs of improvement across Europe. The EU land area at risk of severe soil erosion by water has shrunk slightly since 2010. 5.3% of EU land was estimated to be at risk of severe soil erosion by water in

2016. The share of non-artificial erosive areas estimated to be at risk of severe soil erosion by water fell from 6.1% to 5.3% between 2000 and 2016. In the EU, 196,853 km² of land was at risk of severe soil loss from water erosion in 2016 — an area equal to about 1.5 times Greece's total land area. In the 2023 Edition, there is an update of the 'Estimated soil erosion by water' with the data of 2016. In addition, modelling results up to 2070 show that water erosion could rise by up to two-thirds compared to today. More details and relevant documents are available at this [link](#).

Contribution to Court of Auditors' special report (2023-19) on "EU efforts for sustainable soil management"

For its audit on sustainable soil management in the EU, the Court of Auditors used the data and scientific evidence provided by the JRC in bilateral meetings. Such data included: soil erosion, soil biodiversity, manure data and soil organic carbon. About 25 % of EU land has erosion rates higher than the recommended sustainable threshold (2 t per hectare per year) (Panagos et al., 2020). Only Finland, Poland, Portugal, Slovakia and Sweden have more than 40 % of their area classified as low or low-moderate risk (Orgiazzi et al., 2016). In general, the audit concluded that there is a lack of data on the quantity and quality of manure (Köninger et al., 2021). Cross-compliance standards have the potential to address threats to soil and manure management. Conditions for direct payments are not sufficiently demanding for sustainable soil management. More details and relevant documents are available at this [link](#).

Sewage Sludge directive

A science for policy report was published in 2023 to bring forward a preliminary assessment of policy options for a possible review of the Sewage Sludge Directive. In this report the impact of application of sewage sludge in agricultural soils was modelled by using actual concentrations of heavy metals in soils from the LUCAS 2009 soil database. It is concluded that the land spreading of sewage sludge with content of heavy metals aligned to maximum limits laid down in the Sewage Sludge Directive over 10 consecutive years at 5 ton ha⁻¹ rate will largely effect on soil quality (Yunta et al., 2024). Following repeated applications, all agricultural soils will show average overall contamination rates above 70% only considering inputs from sewage sludge. Seven new NUTS regions would be labelled as contaminated and 57% of all NUTS regions would show average overall contamination rates above 90%. The science for policy report is available at this [link](#).

2.2 Supporting the Soil Monitoring Law

2.2.1 Introduction

Soil Monitoring Law

The proposed Soil Monitoring Law aims to address key soil threats in the EU, such as erosion, floods, landslides, loss of soil organic matter, salinisation, contamination, compaction, sealing, as well as loss of soil biodiversity by the systematic collection of data to better understand soil health. The EUSO project contributed intensively to the design and drafting of the proposed Soil Monitoring and Resilience Directive, which was adopted by the Commission in July 2023. The JRC coordinated weekly dialogues with Directorate-General for the Environment (DG ENV) and the European Environmental Agency (EEA) to assess progress and discuss critical issues, responded to more than 100 scientific and technical questions posed by DG ENV (many of which took several weeks of work to reply), and supported DG ENV in the discussions with the Regulatory Scrutiny Board and the Secretary General. In particular, the EUSO was central to defining the need for action on soil by

demonstrating the extent of soil degradation (60-70% of EU soils are affected - reference is often to Mission Soil proposal but JRC is cited as co-author of Annex 1). More details and relevant documents are available at this [link](#).

Soil Monitoring Law Impact Assessment

Under the Better Regulation Directive, the proposal for a new law aims to address key soil threats in the EU includes an Impact Assessment that considers environmental, social and economic consequences of the law, as well as who will be affected by the initiative. The EUSO project contributed intensively to the discussion and drafting of the Impact Assessment, in particular on terminology and definitions, the "Need for Action" (i.e. problem definition) and "Solutions" (i.e. baseline scenarios). The JRC contributed to weekly meetings with DG ENV and the contractor responsible for drafting the impact assessment to discuss critical issues and responded to scientific and technical questions. The JRC supported DG ENV in the preparation for the discussions with the Regulatory Scrutiny Board and the Secretary General. Scientific publications and data from the EUSO Soil Health Dashboard were included (the latter in an Annex) while the role of the EUSO is highlighted in supporting the monitoring assessment. More details and relevant documents are available at this [link](#).

European Parliament ENVI Committee Report on Soil Monitoring Law

As part of the trialogue process, the proposal for a Soil Monitoring Law has been discussed by the European Parliament's Committee on the Environment, Public Health and Food Safety (also known as the ENVI Committee). The draft report of the Committee, published in October 2023, set out more than 100 amendments to the draft act. Many amendments often include uncited references to JRC materials (e.g. amendment 1, 13 - eDNA for soil biodiversity, 28-soil ecological status, 52 - soil monitoring design), while many others (e.g. amendment 11) contain explicit references to the work and role of the JRC, which were not present in the original proposal from the Commission. Other amendments give added weight to the role of the JRC (e.g. amendments 12, 15, 42 refer to a more significant role for the LUCAS SOIL Module). More details and relevant documents are available at this [link](#).

2.2.2 Transfer functions

Following up the proposed SML and the need for a harmonized data collection on soil throughout Member States (MS), several efforts were made in the development of pedotransfer functions (PTF). Briefly, various LUCAS 2022 locations were double sampled and shared with 13 national partners of the EJPSoil-project. Results obtained between different laboratorial procedures will allow to compare, and expectably link, national monitoring systems with LUCAS outputs. Further developments are also ongoing to assess if PTF can also be developed for different field sampling collection methodologies. Some knowledge on PTF is already established for various soil physical and hydraulic properties, such as bulk density and water holding capacity, or even laboratorial methodologies. However, it currently does not cover the entire combination of laboratorial and field methodologies available in the EU for all soil descriptors present in the SML.

2.2.3 Sampling strategy for soil monitoring

To monitor soil characteristics and their temporal variations at the EU-level, the Soil Monitoring Law needs an effective monitoring programme. Such a monitoring programme should be able to monitor soil parameters under different land use/land cover scenarios and in response to climate change, with a focus on spatial and temporal aspects. Moreover, the samplings strategy must gather comprehensive data on the various soil properties present in the EU. The EUSO proposed a stratified sampling method that meets these requirements and accurately estimates the soil properties at the EU-level, while minimising the cost of sampling. The stratified sampling method selects the independent variables that correlate the strongest with the target variables (e.g. soil carbon content, pH, and nitrogen content). The efficiency of stratification is measured by the extent to which it minimises the cost of sampling while still maintaining sufficient accuracy in estimating the survey target variables. In the proposed stratified sampling method, the minimum sampling size is calculated by implementing the Bethel algorithm (Bethel, 1989) and the subgroups are divided following the methodology of Ballin and Barcaroli (2013).

2.2.4 Monitoring changes in soil organic carbon

The EU Soil Strategy 2030 aims to increase soil organic carbon (SOC) in agricultural land to enhance soil health and support biodiversity as well as to offset greenhouse gas emissions through soil carbon sequestration. Therefore, the quantification of current SOC stocks and the spatial identification of the main drivers of SOC changes is paramount in the preparation of agricultural policies aimed at enhancing the resilience of agricultural systems in the EU. In this context, changes of SOC stocks (Δ SOC) for the EU + UK between 2009 and 2018 were estimated by fitting a quantile generalized additive model on data obtained from the revisited points of the Land Use/Land Cover Area Frame Survey (LUCAS) performed in 2009, 2015 and 2018. The analysis of the partial effects derived from the fitted model shows that land use and land use change observed in the 2009, 2015 and 2018 LUCAS campaigns (i.e. continuous grassland or cropland, conversion grassland to cropland and vice versa) was one of the main drivers of SOC changes.

2.3 EUSO Soil Health Dashboard

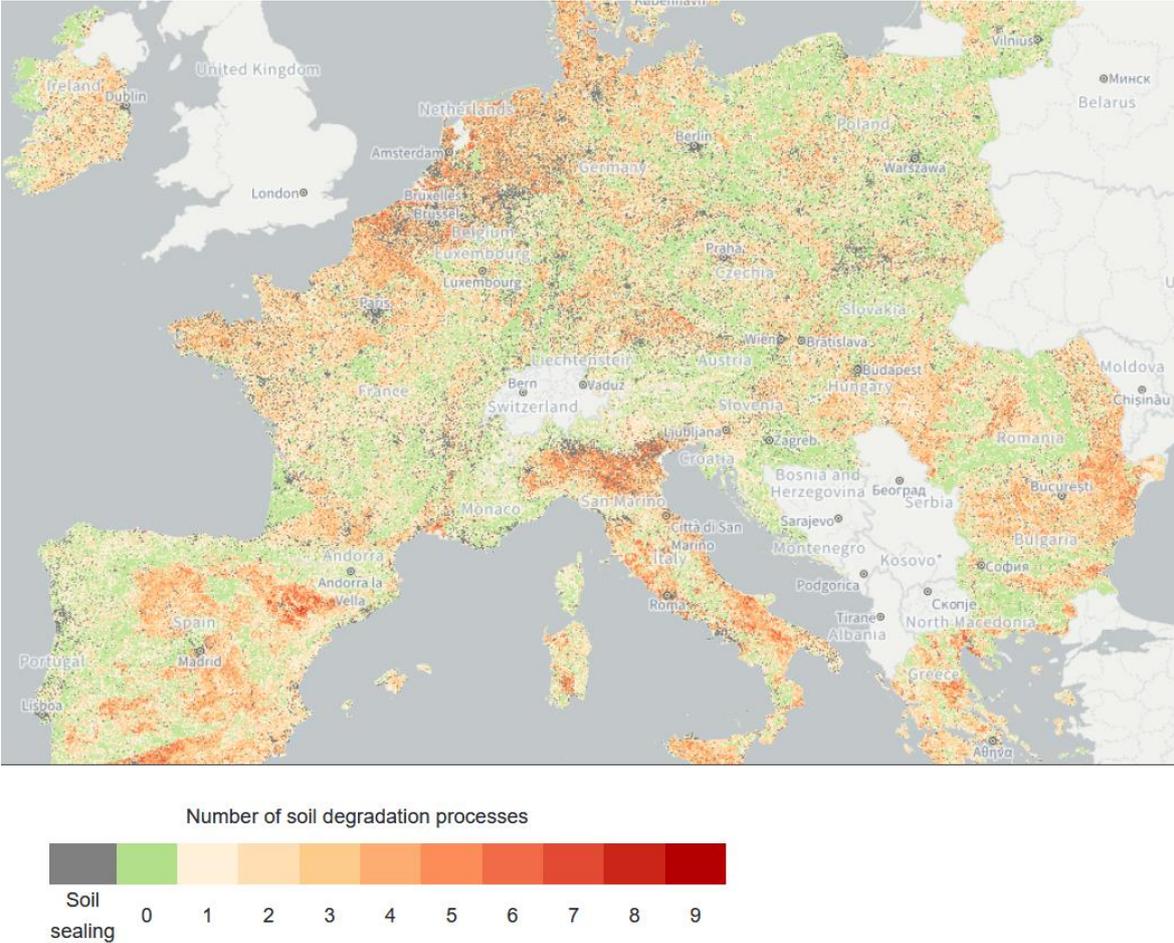
Launched in February 2023, the [EUSO Soil Health Dashboard](#) is now a key component of the EUSO. It monitors the state of soil health in the EU and is a major contributor for soil literacy and supporting the need for a Soil Monitoring Law.

The EUSO Soil Health Dashboard provides a spatial assessment of where unhealthy soils may be located in the EU and which degradation processes affect them. The EUSO Soil Health Dashboard uses a convergence of evidence methodology, which spatially combines datasets to highlight the intensity and location of 18 soil degradation processes. The resulting map shows, for the first time, where current scientific evidence converges to indicate areas that are likely to be affected by soil degradation.

The EUSO Soil Health Dashboard consists of 4 key features:

1. Convergence of evidence map: the convergence of evidence map shows in which areas scientific evidence converges to indicate areas that are likely to be affected by soil degradation processes (Figure 2). For each pixel, the map indicates the number of soil degradation processes likely to be present (Table 1). For each process, a threshold value is used to estimate when soils can be considered healthy or unhealthy. These thresholds have been based on a combination of scientific estimates and adopted critical limits. They represent an estimate of the point beyond which most soils can reasonably be considered unhealthy or vulnerable to a certain process. Given the very wide range of soil types, some EU-wide thresholds are subject to a degree of uncertainties, and this uncertainty should be considered when interpreting the dashboard. All data, sources, threshold values and associated uncertainties are transparently provided in the dashboard and can be accessed through this [link](#). Although the map is subject to a degree of uncertainty and underlying assumptions, it provides, for the first time, an indication of where unhealthy soils may be located in the EU.

Figure 2. Convergence of evidence map of the EUSO Soil Health Dashboard, indicating the number of soil degradation processes likely to be present in the EU.



Source: JRC analysis.

Table 1. Groups of soil degradation processes included in the convergence of evidence map. More information, underlying data and threshold values are available at this [link](#).

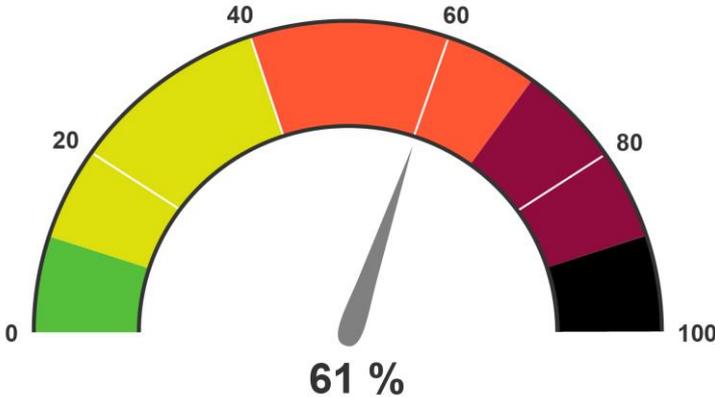
Soil degradation process	Indicator
Soil erosion	water erosion
	wind erosion
	tillage erosion
	harvest erosion
	post-fire recovery
Soil pollution	copper excess
	mercury excess
	cadmium excess
	zinc excess
Soil nutrients	nitrogen surplus
	phosphorus deficiency
	phosphorus excess
Loss of soil organic carbon	distance to maximum SOC level
Loss of soil biodiversity	potential threat to biological functions
Soil compaction	soil compaction
Salinization	secondary salinization
Loss of organic soils	peatland degradation
Soil consumption	soil sealing

Source: JRC analysis

- Speedometer: the speedometer indicates the proportion of land likely to be affected by one or more soil degradation processes or by soil sealing in the EU (Figure 3). It is based on the convergence of evidence map. As discussed with the map, the speedometer is subject to a degree of uncertainty. It is likely an under-estimate as it is based on soil degradation indicators for which data is available; however, scientific evidence is lacking for many other soil degradation processes which are not reflected in the current speedometer.

Figure 3. Speedometer of the EUSO Soil Health Dashboard, indicating the proportion of land affected by soil degradation in the EU.

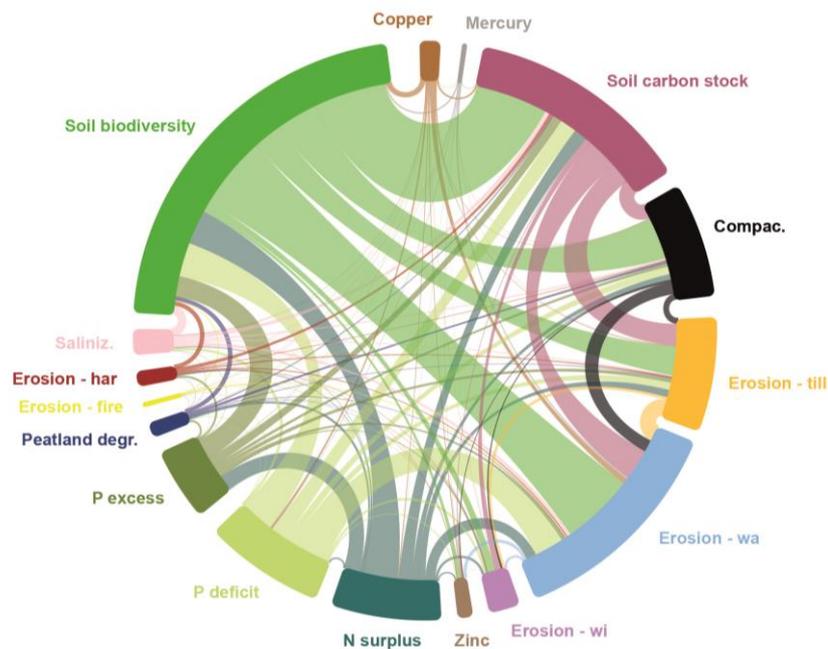
Proportion of land affected by soil degradation in the EU



Source: JRC analysis.

3. Dependency wheel: the dependency wheel shows the extent of the overlapping area between pairs of soil degradation processes of the convergence of evidence map (Figure 4). This diagram provides insights in the type and magnitude of soil degradation combinations occurring in the EU.

Figure 4. Dependency wheel of the EUSO Soil Health Dashboard, indicating the extent of the overlapping area between pairs of soil degradation processes in the EU.



Source: JRC Analysis.

4. Soil degradation indicators: for each individual soil degradation process, statistics and maps are presented through an interactive display where users can select the process and scale. Statistics and maps are available on national (NUTS 0) and regional level (NUTS 2).

First results of the EUSO Soil Health Dashboard show that, based on current available datasets, more than 60% of EU soils are unhealthy (Figure 3). The EUSO Dashboard also shows that most unhealthy soils are subject to more than one type of soil degradation, an important finding for the soil restoration agenda. Loss of soil organic carbon (ca. 48% of EU soils), loss of soil biodiversity (ca. 38%), and soil erosion by water (ca. 32%) are the most prevalent types of soil degradation.

The targeted audience of the EUSO Soil Health Dashboard are policy makers in charge of soil protection as well as the soil research communities. Land managers, NGOs and citizens may also see the EUSO soil health dashboard as a useful source of information to understand prevailing soil issues in the country or region they are interested in, and benchmark with other areas. However, the tool cannot be used on a local level, given the uncertainty of the available datasets and the use of EU-wide thresholds to determine the soil health status.

The assessment of the state of soil health in the EU will be updated regularly in the upcoming years, according to the availability of new data (e.g. Horizon Europe's Mission Soil projects) and with the implementation of EU and national soil policies (particularly the proposed Soil Monitoring Law). In the future, the EUSO dashboard will also include a soil policy dashboard, to report on the state of the implementation of the soil policy of the EU and Members States.

2.4 Enhancing the capacity and functionality of the European Soil Data Centre

2.4.1 New datasets

The European Soil Data Centre (ESDAC) has become the leading web platform for gathering and disseminating soil scientific data and knowledge in the EU. As such, ESDAC is at the core of the EU Soil Observatory by providing the scientific and data management foundation on which other activities can build.

ESDAC has grown substantially in 2023, both in terms of content hosted and number of users. 17 new datasets were added to the ESDAC platform, all accompanied with a scientific publication (Figure 5). These datasets are listed below.

The [ESDAC platform](#) currently hosts 110 datasets, over 6000 maps, 500 scientific documents (including 345 scientific publications), 7 atlases (Figure 6), and a wide range of soil related material.

Post-fire soil erosion in Europe

Annually, millions of hectares of land are affected by wildfires worldwide, disrupting ecosystems functioning by affecting on-site vegetation, soil, and above- and belowground biodiversity, but also triggering erosive off-site impacts such as water-bodies contamination or mudflows. In a JRC [study](#), we present a soil erosion assessment following the 2017's wildfires at the European scale, including an analysis of vegetation recovery and soil erosion mitigation potential. Results indicate a sharp increase in soil losses with 19.4 million tonnes additional erosion in the first post-fire year when compared to unburned conditions. Over five years, 44 million tonnes additional soil losses were estimated, and 46% of the burned area presented no signs of full recovery. Post-fire mitigation could attenuate these impacts by 63 to 77%, reducing soil erosion to background levels by the 4th post-fire year. Those insights may help identifying target policies to reduce land degradation in post-fire areas. Data are available at this [link](#).

Measured data on Total Phosphorus in EU

As part of LUCAS 2009/2012, the laboratory analysis of samples included Total Phosphorus. Measured data for 21,681 samples across the EU and the UK are made available. The available P was already distributed with the [dataset on chemical properties](#). The Total P spatial distribution in the EU agricultural soils follows similar spatial patterns to the ones of available P with a mean concentration of 572 mg P kg⁻¹. This means that the ratio between available P and Total P is about 1:17 in European agricultural lands with high regional variation. In addition, we provide a consolidated file of LUCAS 2009/2012 including the Total P. Point data and maps are available at this [link](#).

Cover Crops across Europe

Despite the growing importance given to cover crops as a sustainable agricultural practice (9-13 million ha in the EU), the availability of spatial data for them is scarce. The best information available are regionally aggregated survey data, which, although indicative, hinder the development of spatially accurate studies. In a collaborative [research study](#) of JRC with INRAE, Paris-Saclays University and LSCE from France, we developed a disaggregation model to derive cover crops at high resolution. The model combined satellite data (Sentinel-1) with aggregated survey data to

generate a high-resolution map of cover crops for Europe and the United Kingdom for the reference year 2016. The map was validated with parcel-level data in France, where overall good results were found, with regional variations. This dataset includes the median, standard deviation, 5th and 95th percentiles of the predicted cover crop fraction. Data are available at this [link](#).

Bacterial and fungal biomass

Data related to land-use- and climate-mediated variations in soil bacterial and fungal biomass across Europe and their driving factors. Bacterial biomass decreased with land use in the following order: grasslands > croplands > forests and was found to be the highest in temperate environments. Similar patterns were found for biomass of Gram-positive and Gram-negative bacteria and Actinobacteria. Soil fungal biomass was greater in forests than in croplands and grasslands, and was favoured by colder environments. The fungi to bacteria ratio (F/B) decreased as follows: forests > croplands > grasslands, with soils in colder climates showing greater F/B ratios in croplands and forest. Data include measurements of soil FAME (fatty acid methyl esters) contents for bacteria and fungi (513 points of LUCAS SOIL 2018). These are data accompanying a [study](#) carried out by a research team including staff of JRC. Data are available at this [link](#).

Projected Land Conservation Impacts on Global Soil Erosion and Pollination Sufficiency

Potsdam Institute for Climate Impact Research in collaboration with JRC and other institutes combined the open-source land-system model MAgPIE (Model of Agricultural Production and its Impact on the Environment) with the Spatial Economic Allocation Landscape Simulator and the Global Soil Erosion Modelling (GloSEM) platform to assess how different land conservation measures focused on climate and biodiversity protection could drive changes in soil loss by water erosion, pollination and landscape heterogeneity. Land-system interventions consider the goals of the Paris Agreement and the Kunming-Montreal Global Biodiversity Framework. This [study](#) published in Nature Communications makes also available the data on global soil erosion and pollination sufficiency. The data are available at this [link](#).

Soil microbial diversity across Europe

The dataset includes 16S and ITS raw DNA sequences for 885 samples collected as part of the LUCAS 2018 Soil survey biodiversity module. It is based on measured DNA and soil biological data. Based on this analysis the EUSO, in collaboration with other research Institutes, has developed a first-ever assessment of soil microbial diversity across Europe. This assessment shows interplaying effects of vegetation, climate and soil properties on microbial communities and the associated potential functions. The results have been published in a [Nature Communications paper](#). This study indicates that a higher richness and diversity detected in more disturbed areas, such as croplands and grasslands, could also mean more potential plant pathogens. Data are available at this [link](#).

Zinc concentrations in EU topsoils

Zinc (Zn) plays a crucial role in various biological processes and is a subsequently an essential micronutrient for living beings. Zinc can also be toxic when present in excess. In this [research paper](#) published recently, we applied a machine learning model on 21,682 soil samples from the LUCAS topsoil 2009/2012 database to assess the spatial distribution in Europe of topsoil Zn concentrations measured by aqua regia extraction, and to identify the influence of natural drivers and anthropogenic sources on topsoil Zn concentrations. The mean estimated Zn concentration in Europe was 41 mg kg⁻¹. We identified clay content as the most important factor explaining the distribution of soil Zn in Europe. Presence of deposits and mining activities mainly explained the occurrence of relatively high Zn concentrations. Data are available at this [link](#).

Continent-wide DNA analysis of soil Eukayotes

Soil eukaryotes play a crucial role in maintaining ecosystem functions and services, yet the factors driving their diversity and distribution remain poorly understood. Croplands exhibited greater biodiversity despite intensive land use. Croplands were also more homogeneous compared to the composition of other ecosystems. High numbers of taxa of eukaryotic groups overlapped in croplands, grasslands and woodlands. For most of the groups, croplands hosted the most unique taxa. The dataset includes 18S raw DNA sequences for 885 samples collected as part of LUCAS 2018 Soil survey for the biodiversity module. Raw DNA sequences are available in ESDAC and deposited also on National Centre for Biotechnology Information Sequence Read Archive database. Additional details on the DNA extraction, amplification and sequencing, and the protocols for measuring soil properties and sources of climatic data can be found in the [relevant publication](#). The dataset is available at this [link](#).

European sediments collaboration (EUSEDcollab) database

The EUSEDcollab database contains monitored catchment data from contributions involving over 30 European institutions. The focus of the database is small to medium catchments, containing water discharge and sediment delivery time series measurements with research applications in soil erosion, sediment delivery and runoff studies. The EUSEDcollab database includes data from 255 catchments (10 countries) covering 25 million ha of agricultural soils. Through this initiative of the EUSO, catchment datasets were harmonised to give new research opportunities and to mitigate against the loss of historical measured data. All details are presented in the associated [scientific data paper](#). The dataset is available at this [link](#).

Global rainfall erosivity (GloREDA) Database

The Global Rainfall Erosivity Database (GloREDA) is a multi-source platform containing rainfall erosivity values for almost 4000 stations globally. The database was compiled through a global collaboration between a network of researchers, meteorological services and environmental organisations from 65 countries. GloREDA is the first open access database of rainfall erosivity (R-factor) based on hourly and sub-hourly rainfall records at a global scale. In February 2023, the EU Soil Observatory (EUSO) working group on soil erosion made a call for contributions towards the extension of GloREDA. The published GloREDA 1.2 includes a) Annual R-factor data from almost 4,000 stations in 65 countries worldwide, b) 44,424 monthly erosivity values, and c) high resolution monthly erosivity maps. More information about GloREDA can be found in the relevant [publication](#). The dataset is available at this [link](#).

Multiple co-occurring erosion processes on global cropland

This dataset is the first-ever assessment at global scale combining the threat of water, wind, tillage and harvesting to reveal the cumulative impact on arable land. We present datasets for each of these erosion processes and their cumulative effects at 1km resolution for global croplands (1.48 billion ha). In essence, this dataset includes the first ever global susceptibility assessment for wind, tillage and harvest erosion. This contributes to assess the spatial distribution of individual and combined (additive) threats to soil due to four erosion processes across the world's areas suitable for farming; this work is documented in the relevant [publication](#). The dataset is available at this [link](#).

Changes in Soil Organic Carbon in Croplands and Grasslands between 2009-2018

This dataset (map) illustrates the variations in soil organic carbon within the 0-20 cm depth range for croplands and grasslands across the EU and UK between 2009 and 2018. These estimates were

obtained using a quantile Generalised Additive Model fitted to data from revisited points of the Land Use/Land Cover Area Frame Survey (LUCAS) conducted in 2009, 2015, and 2018. The calibrated model was subsequently employed to upscale predictions using gridded covariates. A comprehensive description of the methodologies can be found in the reference [article](#). In the EU + UK, the estimated current (2018) topsoil (0–20 cm) SOC stock in agricultural land below 1000 m a.s.l was 9.3 Gt, with a Δ SOC of -0.75% in the period 2009–2018. The highest estimated SOC losses were concentrated in central-northern countries, while marginal losses were observed in the southeast. The dataset is available at this [link](#).

Dataset of EU research projects in soils

The analysis of soil research is particularly relevant given the increased political attention on soils at EU and global levels. This dataset includes a collection of EU Research projects in soils ($n = 1101$ projects) funded by the successive European Commission Framework Programs (FP) for research and innovation (from FP1 to Horizon2020). We also make available online a [list](#) of 200+ Horizon soil-related projects. The dataset has been created collecting information from the Community Research and Development Information Service and the official portal for European data. The development of this dataset is a result of a [research study](#). The dataset is available at this [link](#).

Cadmium in topsoils of the European Union

Using the 21,682 soil samples from the 2009/2012 LUCAS soil survey, we estimated the spatial distribution of the concentration of Cadmium (Cd) in the EU and UK topsoil as documented in the [publication](#). Applying an ensemble of machine learning models supported by a variety of environmental descriptors, we created maps of Cd distribution at a resolution of 100m. The ensemble approach included 5 models and increased the prediction accuracy to R^2 of 0.45. The approach used resulted in a high predictive power for the Cd distribution, while also identifying hotspots of Cd contamination. Natural factors influencing Cd levels include soil properties (pH, clay), topography, soil erosion, and leaching. As anthropogenic factors, we identified phosphorus inputs to agricultural lands as the most important for Cd levels. The data are available at this [link](#).

Global Soil Erodibility

This dataset encompasses global soil erodibility (K) factor maps, with the K factor being estimated through the Wischmeier and Smith (1978) method. The equation incorporates permeability information crudely and indirectly, mainly relying on soil texture details, potentially overlooking factors like vegetation, biopores, and clay minerals. To address this limitation, we incorporated soil hydraulic properties (Ksat) in the K-factor by merging Ksat with soil texture and organic carbon into a modified K-factor dataset. Therefore, we developed K-factor maps of 1 km spatial resolution both for the original methodology, the one used in GloSEM and the modified one (Ksat) as documented in the [publication](#). The three datasets and their uncertainties are available at this [link](#).

Phosphorus cycle in European agricultural soils

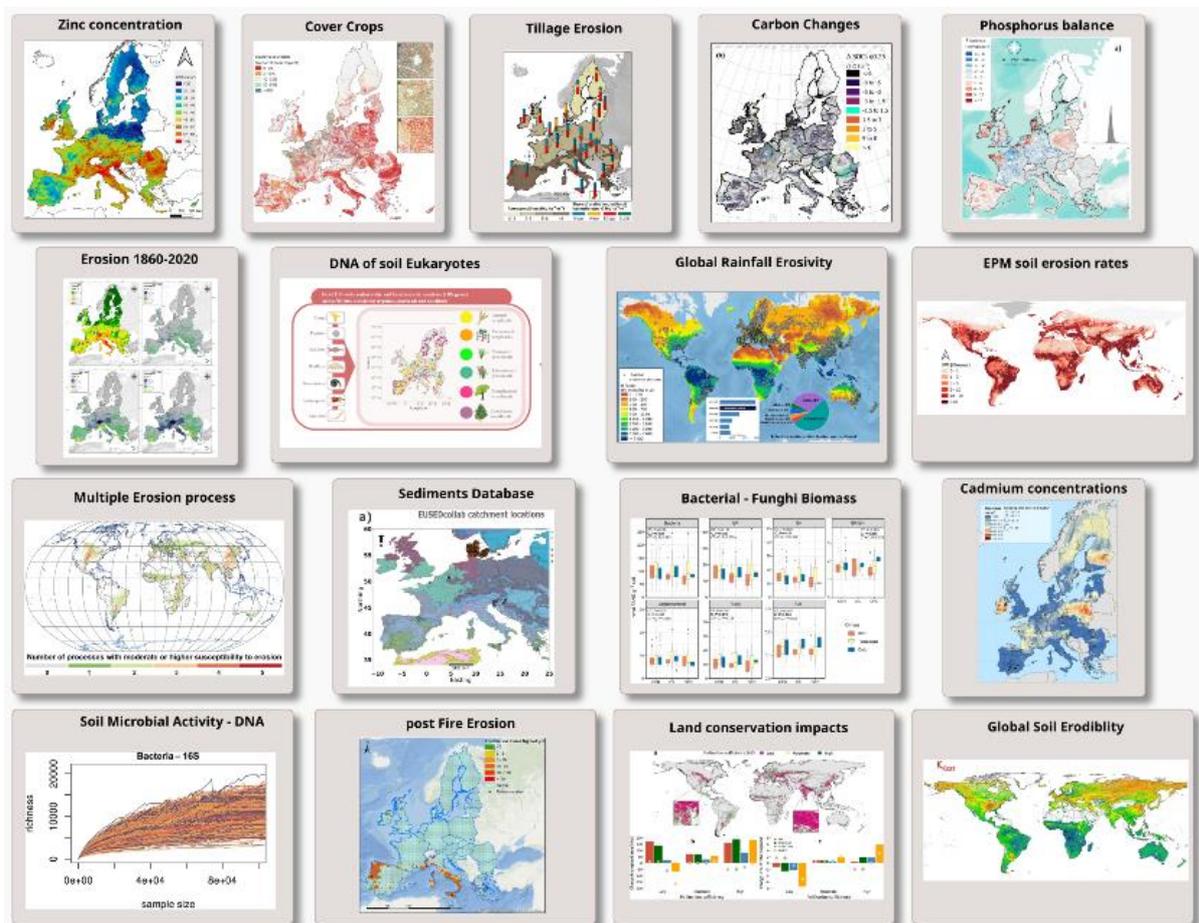
Process-based biogeochemical models are valuable instruments to monitor the Phosphorus (P) cycle and predict the effect of agricultural management policies. Therefore, we upscaled the calibrated DayCent model at the European level using data-derived soil properties, advanced input data sets, and representative management practices. Our results depicted a P budget, total soil P, and available P content consistent with literature and national statistics. Agricultural management scenarios revealed a range of potential changes in the P budget by 2030 and 2050, influenced by the interlink of P with biogeochemical carbon and nitrogen cycles. Available datasets include Current

P Budget and Soil Pools, Projected P Budget and Soil Pools for the EU and UK as well the datasets corresponding to the figures of the related [publication](#). The data are available at this [link](#).

Global application of erosion potential method (EPM)

Most of the modelling applications are using Universal Soil Loss Equation (USLE)-type models. In the activities of the EU Soil Observatory working group on erosion, it is underlined that the soil erosion modelling community should also make a step towards inter-comparison of global multi-models, gaining new insights from the advantages and disadvantages found in the compared models. Here, we evaluate the applicability of the Erosion Potential Model (EPM) and its modified version (mEPM) for the estimation of the gross and net erosion rates at a global scale. The sensitivity analysis shows that the model results have the highest variability due to the soil protection (land cover) coefficient followed by the soil erodibility parameter. Therefore, as expected, the gross erosion rates by the EPM and mEPM are higher compared to the USLE-type models. Description of the application of EPM model at global scale is described in the [publication](#). The data are available at this [link](#).

Figure 5. Datasets added to ESDAC in 2023.



Source: JRC analysis.

Figure 6. Atlases available in ESDAC; with indication of the year of launch and the publication languages.



Source: JRC analysis.

2.4.2 ESDAC performance in 2023

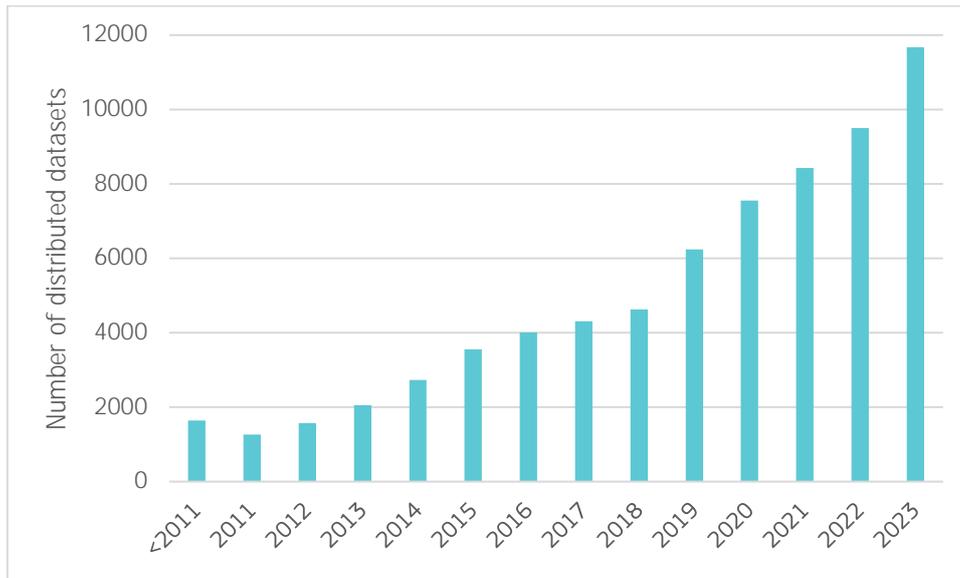
The ESDAC website had ca. 562 000 page-visits in 2023, which is the double of the page-visits in 2022.

In terms of usage, ESDAC responded to 11675 dataset requests during 2023 which is 18% higher than in 2022 (Figure 7). In 5 years (i.e. compared to 2018), the number of ESDAC distributed datasets increased with ca. 150 %. Compared to 2011 (Panagos et al., 2012), the distributed datasets in 2023 are an order of magnitude higher.

62% of these distributed datasets were downloaded in an EU-country, 38 % in a non-EU country. Most data requests were coming from Italy, Germany, Spain, France, China, United Kingdom, Netherlands, Portugal, India, United States and Greece, with more than 400 requests each in 2023 (Figure 9). Regarding institutional type of the users, 57% of the distributed datasets were downloaded for use in academia, 17% for use in private companies, 16% in research organisations and 5% in public administration (Figure 8). Users' category 'others' (4%) includes NGO's, international organisations and individuals.

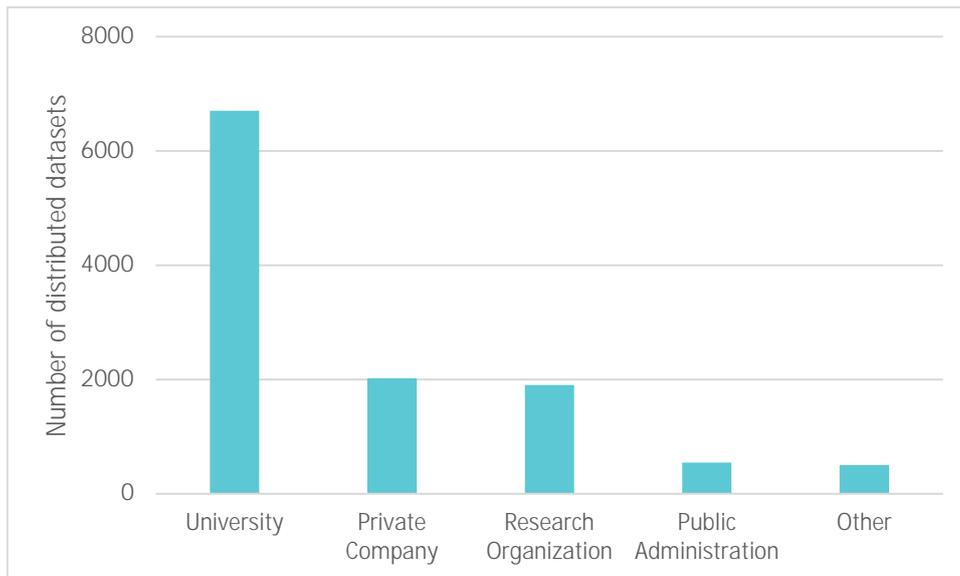
In terms of data distributed in 2023, 'Soil threats', 'LUCAS point data and soil properties', 'Global data', and 'European Soil database and delivered products' have a share of ca. 20 to 25% each (Figure 10). Related to soil threats, especially datasets on soil erosion are distributed. The publication of the 2018 LUCAS Module (Fernandez-Ugalde et al., 2022) contributed to a significant number of requests for the LUCAS point data. The publication of new global datasets on soil erosion in 2023 (see section 2.4.1) had an important impact on the datasets distributed on Global data (Figure 10).

Figure 7. Trend in ESDAC distributed datasets.



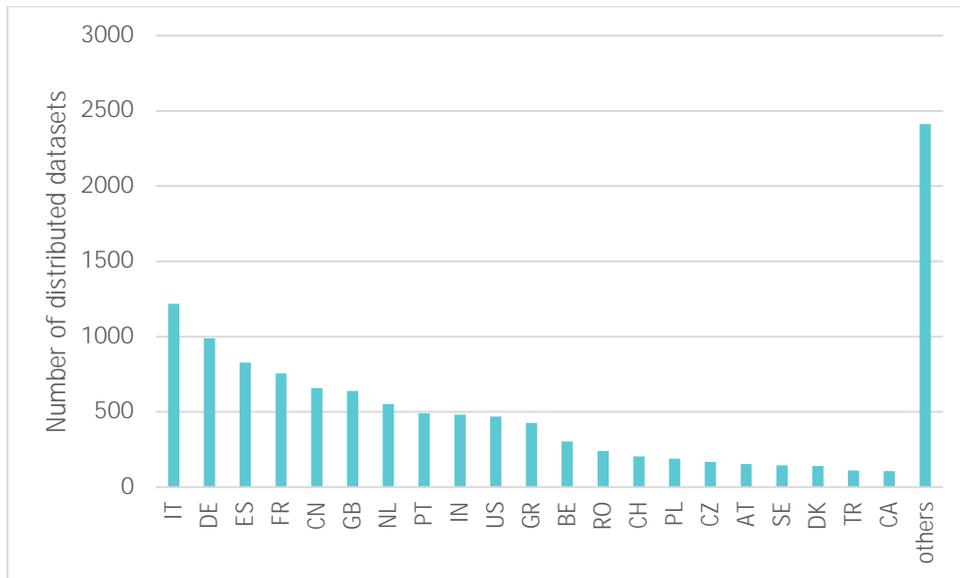
Source: JRC analysis.

Figure 8. Number of ESDAC distributed datasets in 2023 according to institutional type.



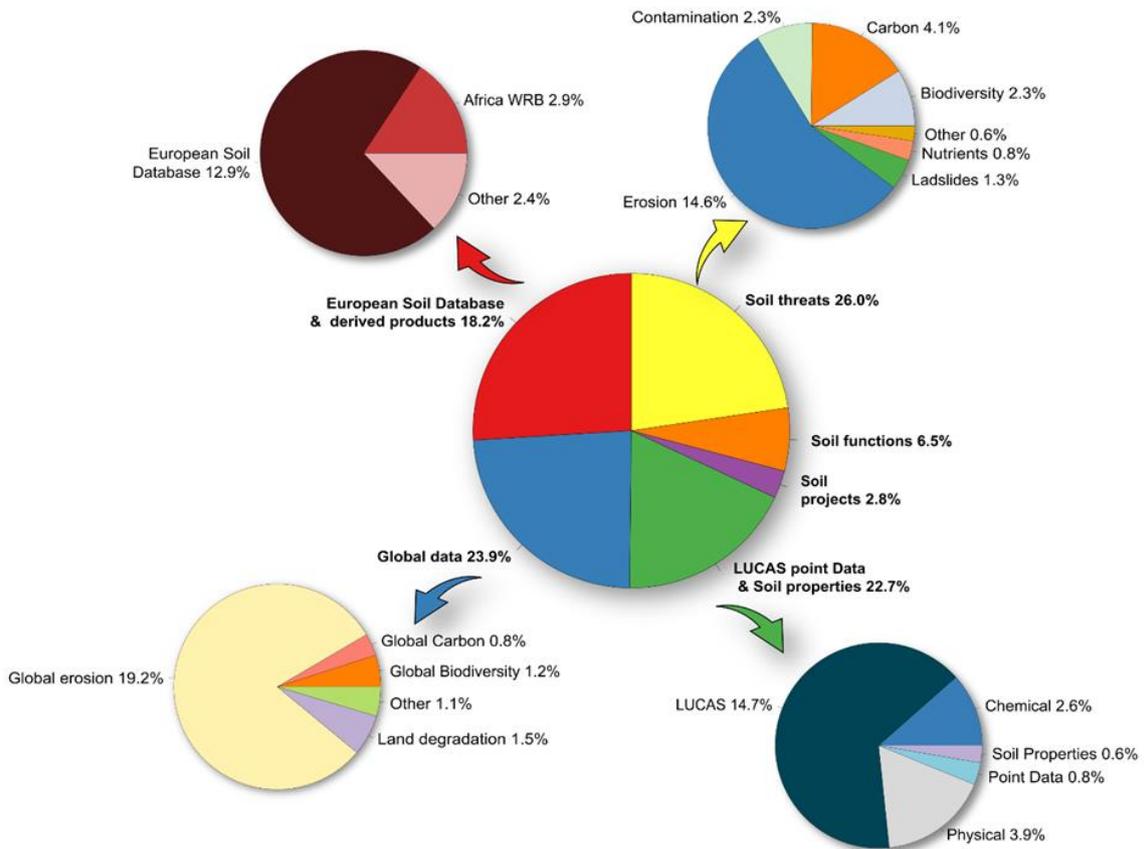
Source: JRC analysis.

Figure 9. Number of ESDAC distributed datasets per country in 2023 (land codes can be found in list of abbreviations).



Source: JRC analysis.

Figure 10. Data distribution per category of dataset in ESDAC.



Source: JRC analysis.

2.5 Supporting soil research and innovation

2.5.1 Research at EUSO

The EUSO contributes directly to advanced scientific knowledge on soils in the EU through its in-house research activities. In 2023, the scientists at EUSO have published 45 papers in Scopus-indexed journals (Box 1) and several technical reports (Box 2). EUSO team members are underlined in the boxes.

Box 1. Papers in Scopus-indexed journals published by the EUSO team in 2023. EUSO team members are underlined. Highlights of the five most important publications were added.

Labouyrie, M., Ballabio, C., Romero, F., Panagos, P., Jones, A., Schmid, M.W., Mikryukov, V., Dulya, O., Tedersoo, L., Bahram, M. Lugato, E., Orgiazzi, A. 2023. Patterns in soil microbial diversity across Europe. Nature Communications, 14(1): 3311. <https://doi.org/10.1038/s41467-023-37937-4>

- Bacterial and fungal diversity increases with land use intensification.
- Increase in pathogens in agricultural soils.
- Strong effect on biodiversity of soil properties, vegetation cover and climate.
- Taxonomical and functional diversity should be considered simultaneously for monitoring purposes.

von Jeetze, P.J., Weindl, I., Johnson, J.A., Borrelli, P., Panagos, P., Molina Bacca, E.J., Karstens, K., Humpenöder, F., Dietrich, J.P., Minoli, S. and Müller, C., 2023. Projected landscape-scale repercussions of global action for climate and biodiversity protection. Nature Communications, 14(1): 2515. <https://doi.org/10.1038/s41467-023-38043-1>

- Land conservation and increased carbon uptake on land are needed to achieve climate targets.
- Carbon-focused land restoration action and the enlargement of protected areas may be insufficient. Should be combined with actions outside of protected areas.
- Conserving at least 20% semi-natural habitat within farmed landscapes could be achieved by relocating cropland outside protected areas, without additional carbon losses from land use change, primary land conversion or reductions in agricultural productivity.

van der Putten, W.H., Bardgett, R.D., Farfan, M., Montanarella, L., Six, J. and Wall, D.H., 2023. Soil biodiversity needs policy without borders. Science, 379(6627): 32-34. <https://doi.org/10.1126/science.abn7248>

- Soil biodiversity is crucial for healthy soils, but is degrading due to land use intensification, climate change and environmental pollution.
- Most soil protection policies overlook how soils across national borders and continents are connected by human activities.
- Policy should focus not only on soils within (union of) nations but also on preventing negative footprints on each other's soils.

Königer, J., Ballabio, C., Panagos, P., Jones, A., Schmid, M.W., Orgiazzi, A. and Briones, M.J., 2023. Ecosystem type drives soil eukaryotic diversity and composition in Europe. Global Change Biology, 29(19): 5706-5719. <https://doi.org/10.1111/gcb.16871>

- Soil biodiversity is driven by ecosystem type.

- A higher diversity of fungi, protists, nematodes, arthropods, and annelids was observed in croplands than in less intensively managed systems.
- Long-term environmental variables should be included in monitoring and conservation programs.

Borrelli, P., [Panagos, P.](#), Alewell, C., [Ballabio, C.](#), de Oliveira Fagundes, H., Haregeweyn, N., Lugato, E., Maerker, M., Poesen, J., Vanmaercke, M. and Robinson, D.A., 2023. Policy implications of multiple concurrent soil erosion processes in European farmland. *Nature Sustainability*, 6(1): 103-112. <https://doi.org/10.1038/s41893-022-00988-4>

- Co-occurrence of soil erosion processes (soil erosion by water, wind, tillage and harvesting) is shown for European arable land.
- 43 M ha of EU arable land are vulnerable to a single driver of erosion, 15.6 M ha to two drivers and 0.81 M ha to three or more drivers.
- The results serve as a basis for developing an efficient monitoring network and informing targeted mitigation strategies under the CAP 2023–2027.

[Labouyrie, M.](#), [Ballabio, C.](#), Romero, F., [Panagos, P.](#), [Jones, A.](#), van der Heijden, M.G.A., [Orgiazzi, A.](#) 2023. Publisher Correction: Patterns in soil microbial diversity across Europe. *patNature Communications*, (2023), 14 (1): 4298. <https://doi.org/10.1038/s41467-023-39596-x>

Kati, V., Kassara, C., [Panagos, P.](#), Tampouratzi, L., Gotsis, D., Tzortzakaki, O., Petridou, M., Psaralexi, M., Sidiropoulos, L., Vasilakis, D. and Zakkak, S., 2023. The overlooked threat of land take from wind energy infrastructures: Quantification, drivers and policy gaps. *Journal of Environmental Management*, 348: 119340. <https://doi.org/10.1016/j.jenvman.2023.119340>

Borrelli, P., Alewell, C., Yang, J.E., Bezak, N., Chen, Y., Fenta, A.A., [Fendrich, A.N.](#), Gupta, S., [Matthews, F.](#), Modugno, S., [Vieira, D.](#), Haregeweyn, N., [Panagos, P.](#) 2023. Towards a better understanding of pathways of multiple co-occurring erosion processes on global cropland. *International Soil and Water Conservation Research*, 11(4): 713-725. <https://doi.org/10.1016/j.iswcr.2023.07.008>

[Matthews, F.](#), Verstraeten, G., Borrelli, P., Vanmaercke, M., Poesen, J., Steegen, A., Degré, A., Rodríguez, B.C., Bielders, C., Franke, C. and Alary, C., [Liakos, L.](#), [Panagos, P.](#) 2023. EUSEDcollab: a network of data from European catchments to monitor net soil erosion by water. *Scientific data*, 10(1): 515. <https://doi.org/10.1038/s41597-023-02393-8>

[Panagos, P.](#) and [Orgiazzi, A.](#) 2023. Let's give a voice to young soil researchers. *European Journal of Soil Science*, 74(6): e13441. <https://doi.org/10.1111/ejss.13441>

[Panagos, P.](#), Hengl, T., Wheeler, I., Marcinkowski, P., Rukeza, M.B., Yu, B., Yang, J.E., Miao, C., Chattopadhyay, N., Sadeghi, S.H. and Levi, Y., [Liakos, L.](#), [Ballabio, C.](#) 2023. Global rainfall erosivity database (GloREDA) and monthly R-factor data at 1 km spatial resolution. *Data in brief*, 50: 109482. <https://doi.org/10.1016/j.dib.2023.109482>.

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In 2023, the EUSO team made contributions to or took the lead in specific research projects. These research activities are listed below:

- SOLACE is a JRC Exploratory Research Project that investigate potential relationship between the occurrence of specific cancers and levels of soil pollution. Preliminary outcomes of the project were released to analyse the potential links between soil pollution and cancer prevalence. Impact of anthropogenic activities such as the application of sewage sludge on agricultural soils was assessed and the preliminary results were introduced and discussed in the “seventh International symposium on Environmental biotechnology and engineering (7ISEBE)” in May 2023 and in the

“International Conference and Exhibition on land and water remediation markets and technologies (RemTech)” in September 2023. Additionally, the preliminary evaluation of the metal pollution rate in Europe by using the LUCAS topsoil database was introduced in the 1st Joint international conference, 16th International Conference of Biochemistry of Trace Elements and 21st International conference of heavy metals. Relevant findings includes an association between higher lung cancer mortality and higher concentration of arsenic or cadmium in the soil, and an association between lung cancer mortality in men and concentration of cadmium in the soil.

- The Africa Soil Health Project (AFSOH) is funded by JRC’s Antoine Royer Award, an exploratory research grant to provide scientific research and policy support to Africa. The two-year project, started in November 2023, aims to assess the overall soil health of agricultural land on the African continent. Soil functions in focus are, among others, carbon sequestration, productivity and habitat provision. For these functions, suitable properties will be identified by exploring and compiling data from existing map products and repositories. Spatially explicit indicators will be developed allowing for a regional assessment of the soil health status. Close interaction with the ongoing H2020 project Soils4Africa and the work of African partner organizations ensure the dissemination with local actors and policy makers. The results of AFSOH are laying the foundation for the development of an African Soil Health Dashboard. While drawing on the experience of the European Soil Health Dashboard, African soils face different pressures and drivers than European soils. AFSOH identifies these particularities and paves the way to a convergence of evidence map similar to its European counterpart.
- Collaborative Doctoral Partnership (CDP): The CDP is an initiative of JRC to establish strategic collaborations with higher education institutions that grant doctoral degrees. The CDP is characterised by research excellence and high international reputation. In 2023, EUSO hosted and mentored six doctoral candidates in the context of CDP:
 - Julia Königer (in collaboration with Vigo University, Spain). Towards a reliable European assessment of soil biodiversity status under current land-use changes. Successfully finished the collaborative doctoral training programme and obtained the doctoral degree in 2023.
 - Francis Matthews (in collaboration with KU Leuven, Belgium) Dynamic modelling of soil erosion and sediment delivery in Europe. Delivery Q1 2024: Public defence on February 1, 2024.
 - Anna Muntwyler (in collaboration with the Swiss Federal Institute of Technology in Zürich, Switzerland). Modelling the Phosphorous cycle in EU agricultural soils and assessing land impact and mitigation options of organic agriculture. Delivery Q1 2024.
 - Arthur Fendrich (in collaboration with Paris-Saclay, France). Erosion effects on carbon and nutrients balance. Delivery Q2 2024.
 - Maeva Labouyrie (in collaboration with Zurich University, Switzerland). Soil microbial diversity and ecosystem functioning assessment across Europe. Delivery Q1 2025.
 - Vasilis Michailidis (in collaboration with Aarhus University, Denmark). Quantify soil carbon and nitrogen dynamics in relation to agricultural land management practices and climate change scenarios. Delivery Q3 2025.

2.5.2 Interaction with Mission Soil research projects

The EU Mission 'A Soil Deal for Europe' (Mission Soil) is one of five missions funded under the EU Research and Innovation Programme Horizon Europe. Its goal is to create 100 Living Labs and Lighthouses by 2030 to promote sustainable land and soil management in urban and rural areas. Funded projects gather partners from all over Europe to work together towards achieving the Mission Soil objectives. The projects funded under the Mission Soil are available at this [link](#).

The EUSO is actively involved in and responsible for the soil monitoring elements of the Horizon Europe Mission 'A Soil Deal for Europe' and contributes to the mission annual work programme. EUSO is also a beneficiary of the research activities in the Mission Soil projects and works in close collaboration with some of the Mission Soil projects. In 2023, several collaborations and interactions between the EUSO and the Mission Soil projects started. The most important ones are highlighted below.

HuMUS

The Healthy Municipal Soils (HuMUS) project engages and activates municipalities and regions to protect and restore soil health. In December 2023, HuMUS has launched an [open call](#) for pilot projects with the aim of fostering new spaces of dialogue for the participatory governance of soil health and quality issues at regional and/or local levels in Europe. A total budget of €600 000 will be allocated to fund 20 pilot project proposals led by municipalities, regions or other public entities. Participation is open also to private and non-governmental stakeholders at local and regional levels, such as agricultural enterprises, associations of land managers (e.g., farmer associations), civil society organisations and research institutions throughout Europe. In addition to the funding, the HuMUS partners will provide coaching, mentoring and advice to support like-minded initiatives and contribute to raising awareness about the value of soil and the importance of tackling related issues in a participatory fashion.

AI4SoilHealth

The AI4SoilHealth project aims to accelerate the collection and use of soil health information using AI technology to support the Soil Deal for Europe and the EUSO. AI4SoilHealth and EUSO have worked together for the development of the Global Soil Erodibility dataset. Both parties have worked together for the Global K-factor development. This dataset encompasses global soil erodibility (K) factor maps, with the K factor being estimated through Wischmeier and Smith (1978) method. In addition, measured values of saturated hydraulic conductivity (Ksat) have been incorporated into the original method to formulate the Ksat-based soil erodibility (Kksat factor) map. A third k-factor dataset, originally part of the GloSEM (Borrelli et al., 2017) is also included.

ECHO

The ECHO project aims to engage citizens in protecting and restoring soils by building their skills and enhancing their knowledge on soils. Citizens will actively contribute to the project's data collection, promote soil stewardship, and foster behavioural change across the EU. ECHOREPO, a long-term open access repository with a direct link to the EUSO, will enable the citizen science data collected during ECHO to be available for use not only by scientists, but also by the general public, policy makers, farmers, landowners and other end-users, providing added value to existing data and other relevant soil monitoring initiatives. ECHO and EUSO made a [call](#) for contribution on "repository of citizen science projects on soil". In collaboration with EUSO, ECHO will make a review on previous citizen science projects, initiatives and activities that have engaged citizens to monitor soil. The aim

is to have an overview of the current state of the art, creating a repository of potentially useful resources from past citizen science initiatives in the field.

SOIL O-LIVE

The SOIL O-LIVE project, focussing on soil biodiversity and functionality of Mediterranean olive groves, collaborates with EUSO (collaboration agreement No 36648). The collaboration covers among others: a) Development of models and data for monitoring soil health in olive plantations; b) Transfer of project Data, knowledge and indicators to EU Soil Observatory; c) Building capacity for policy support in soil related EU policies and d) Scientific synergies as joint publications, workshops, seminars and exchange of data and knowledge.

SoilWise

The SoilWise project aims to build the Missions knowledge repository and advancing the EUSO. SoilWise will provide an integrated and actionable access point to scattered and heterogeneous soil data and knowledge in Europe, and will design a repository for at least a decade to support EUSO evolution accordingly.

2.6 Supporting citizen engagement

2.6.1 EUSO Stakeholders Forum

The EUSO organises every year the EUSO Stakeholders Forum. It is an open and inclusive event bringing together soil scientists, policy makers, regional and national bodies and interested citizens. It also aims to support citizen engagement and the drive towards a societal change in the perception of soil. The third edition of the EUSO Stakeholders Forum took place in two parts, with the Working Group meetings on 15-17 November 2023 (online) and the European Mission Soil Week on 21-23 November 2023 (in-person in Madrid, see section 2.6.2). More details on the outcome of the working group meetings are presented in section 3.

The programme, presentations and recordings of the Third EUSO Stakeholders Forum are available on the EUSO website: <https://esdac.jrc.ec.europa.eu/euso/third-euso-stakeholders-forum>.

2.6.2 European Mission Soil Week

From 21 to 23 November 2023, the Spanish National Research Council (CSIC, Madrid) hosted the 1st European Mission Soil Week. The event was the result of the joint efforts of Directorate-General for Agriculture and Rural Development (DG-AGRI), the EUSO and the EU-funded project PREPSOIL. The first edition was particularly significant in the context of the proposed EU Directive on Soil Monitoring and Resilience, the Nature Restoration Law and Carbon Farming initiatives. Recognised by the Spanish Presidency, the event brought together members of the European Soil Community to discuss how soil research, citizen engagement and EUSO's work can contribute to the green transition. The closing day was dedicated to presenting EUSO's work and latest updates (Figure 11), with an address by JRC's Deputy Director-General Salla Saastamoinen, and including Fernando Miranda, Secretary General of the Spanish Ministry of Agriculture and Food, and Eloísa Del Pino Matute, President of the Spanish National Research Council. Also, the outcome of the EUSO Working Groups meetings (see section 2.6.1 and section 3) were presented and discussed. On average, each day 300 people participated in person and 400 people participated on-line. Also on social media, the Mission Soil Week had a high visibility. Its hashtag reached almost 1.6 million people.

The programme and presentations/recordings of the European Mission Soil Week can be accessed through this [link](#) and this [link](#) respectively.

Figure 11. Summary of EUSO's work and updates, presented at the European Mission Soil Week.



Source: European Mission Soil Week 2023 (graphics: carlottacat.com).

2.6.3 Other activities to raise soil awareness and citizen engagement

EUSO/ESDAC monthly newsletter

Since its initial operational stage in 2009, the ESDAC publishes a monthly newsletter with the main highlights per month. Highlights include new datasets published in ESDAC, important policy developments, and activities involving the EUSO. In 2023, 12 monthly newsletters were published. The newsletter is sent to more than 13 000 subscribers, including interested people from academia, businesses and policy as well as interested citizens. Archive of newsletters, subscription form and more information can be found through this [link](#).

Course “Soil, a burst of life: the hidden world beneath our feet”

In 2023, the EUSO team develop the free online course "Soil, a burst of life: the hidden world beneath our feet". The course covers soil biodiversity, and explains how many organisms live in soil, what these organisms do and why it is important to protect them. Videos, activities and quizzes drive participants through the incredible world living beneath your feet. Available courses are in English, French, German, Spanish, Italian, Portuguese and Dutch. Targeted audience are science teachers, high school students and the general public. Registration and participation are free. Details can be found on [EU Academy](#).

JRC Summer School on the evaluation of air, soil and water pollution in support to the European Green Deal: a holistic approach

The JRC co-organised in partnership with Novi Sad University a summer school on “the evaluation of air, soil and water pollution in support to the European Green Deal: a holistic approach”. The aim of

this training was to develop green skills for a more sustainable and resource-efficient society. The EUSO contributed to the sessions on soil health. Attendees were advanced students and young scientists from the Western Balkans region, i.e., Serbia, Montenegro, Kosovo, Bosnia & Herzegovina, North Macedonia and Albania with a strong interest in the protection of environment, air, soil and water. More information can be found on this [link](#).

Publication of EUSO Young Soil Researchers Forum special issue

In 2023, EUSO finalised the publication of the EUSO Young Soil Researchers Forum virtual thematic issue in the European Journal of Soil Science (EJSS). This special issue resulted from the 1st Young Soil Researchers Forum hosted in 2021 as part of the EUSO Stakeholders Forum (Figure 12). At that time a call for abstracts was launched targeting young soil scientists who are carrying out a PhD or have just obtained it in the field of soil sciences. Around 100 abstracts were submitted and 58 were selected for oral presentation during the event. Subsequently, the possibility to publish the research associated to the presentation was offered to the involved community of young scientists. As result of that, nine papers were reviewed and accepted for publication and the thematic issue completed with an editorial from the EUSO team with a title that says it all: “Let’s give a voice to young soil researchers” (Panagos and Orgiazzi, 2023). Overall, the initiative was very well received and generated positive feedback to EUSO. It demonstrated the wish of new scientist generation to be involved in the science-policy debate on soil themes. Therefore, a new edition of the Young Soil Researchers Forum will be organized in 2024 or in 2025. The virtual thematic issue is accessible at this [link](#).

Figure 12. The EUSO Young Soil Researchers Forum in a nutshell.



Source: Panagos and Orgiazzi (2023).

Soil Health and Food Production - Brazilian Embassy in Brussels

On 5 December 2023, Panos Panagos of EUSO participated in an event organised by the Brazilian Embassy on the occasion of the World Soil Day: Soil Health and Food Production. This event served to foster and strengthen ties in the important EU-Brazil dialogue, both in the research and agro-environmental domains. Panos presented the EUSO and its support to the implementation of the

Mission Soil “A soil Deal for Europe”, with a focus on the EU Soil Health Dashboard for soil health assessment and its importance in monitoring EU soil-related policies.

Council questions on the Soil Monitoring Law

On 14 December 2023, the Spanish Presidency organised a Council Working Party on the Environment to discuss the Commission's proposed Soil Monitoring Law. Team members of the EUSO moderated and answered a full day of questions from Member States on technical aspects of the proposal. Questions covered the design of an integrated soil monitoring system, laboratory techniques, key indicators and critical thresholds relating to soil pollution, organic carbon levels, erosion rates, soil biodiversity and land take, and their consequences for the supply of ecosystem services. This meeting was a very important step in the trilogue process for the Law.

EUSO Presence at the EU Soil Day organised by the Region of Murcia

On 6 November 2023, the Region of Murcia, together with the European Regions Research and Innovations Network, the HuMUS project, and with the important support of the EU Spanish Presidency, organised the EU Soil Day at the EU Committee of the Regions in Brussels. The event represented an important overview to discuss the overall EU Soil Agenda. Experts from the EUSO team took part in the event and delivered a presentation highlighting JRC's contribution to policy and research development on soil science, providing an exhaustive frame on its efforts in preserving and restoring European soils.

European Healthy Soils Conference

Serenella Sala and Panos Panagos participated in the European Healthy Soils Conference (13-15 September 2023, MuttENZ, Switzerland). In her keynote closing speech, Serenella presented a) how soil features within the Green Deal; b) the objectives of the EUSO; c) the new Soil Monitoring Law and d) a holistic approach to soil health through the newly released EUSO Soil Health Dashboard. She also highlighted how soils are cross-cutting within many policy initiatives (e.g. Carbon Farming, Farm to Fork, Biodiversity Strategy, Zero Pollution). Given the increasing interest in soil health from some of the major players in the biotechnology and food sector, the event attracted a lot of interest from the private sector and was very well attended, with over 150 participants and 30 international speakers, including people from the EU Mission Soil Secretariat and the FAO.

Kick-off meetings of projects funded by the EU Mission Soil

On behalf of the EUSO, Panos Panagos gave keynote speeches at the kick-off meetings of 2 important projects funded by the EU Mission Soil: SoilWise (25 September 2023, Brussels), which aims to build the Mission's knowledge repository and advance the EUSO, and MARVIC (26 September 2023, Ghent), which aims to support the monitoring, reporting and verification (MRV) of the soil carbon and greenhouse gas balance and the proposal for a Regulation on an EU certification for carbon removals. Both meetings were attended by colleagues from the EU Mission Soil Secretariat (DG AGRI.F2), the European Research Executive Agency and project partners (50 for SoilWise, 100 for MARVIC). DG CLIMA was also present at the MARVIC kick-off. These projects are important for the implementation of the EU Mission Soil and contribute to the development of the EUSO.

Launch of the Soil Atlas of Asia

The EUSO team members attended the launch of the first ever Soil Atlas of Asia during the opening of the 11th Plenary Assembly of the Global Soil Partnership at FAO headquarter in Rome on 12 July 2023. The launch was attended by about 200 in-presence and 850 online participants. Coordinated

by EUSO in conjunction with the FAO's Global Soil Partnership, the 208-page atlas is the result of 5 years' challenging work collating state-of-the-art contributions from ca. 100 Asian soil experts.

Mission Soil Manifesto

The EUSO has contributed to a broad acceptance of the EU Mission Soil Manifesto. The Manifesto highlights the urgent need for action to protect soil health. It represents a key step for further local engagement by mobilising regions, municipalities, businesses, schools, and other stakeholders, as well as citizens. The Manifesto aims to bring regional and local policymakers, stakeholders and citizens together into a vibrant community that cares for soil health. It aims to foster local knowledge, innovation and investment by raising awareness. Signatories of the proposed document will recognise the need for action for soil health and will be able to engage for improving soil health. They will have access to the latest research results, along with the opportunity to take part in knowledge sharing activities and events to exchange best practices for our soils. The Manifesto can voluntarily be signed by representatives of municipalities, regions, private or public companies and organisations, NGOs and philanthropic organisations, schools and education institutions, as well as by research institutions. Also, individuals can sign the Manifesto and become "Friends of the Mission Soil". All details available at this [link](#).

3 Working Group activities

The EUSO Working Groups are a key element of the EUSO. These Working Groups (WGs) aim to discuss technical advances in a particular topic. The Working Groups are composed of relevant topical experts from academia, businesses or policy, and are co-chaired by EUSO staff and external partners. Each Working Group develops its own work agenda, aiming to provide relevant advances to current scientific and policy questions.

In 2023, six Working Groups were active (Figure 13): (1) WG Soil Erosion, (2) WG Data sharing and integration, (3) WG Soil pollution, (4) WG Soil monitoring, (5) WG Soil biodiversity, and (6) WG Soil organic carbon monitoring reporting and verification. In the next sections, their activities and progress during 2023 are described.

The main activity in 2023 was the Third EUSO Stakeholders Forum. The Stakeholders Forum brought together the working group members with other soil scientists, policy makers and interested citizens. The Stakeholders Forum had over 800 participants and more than 50 oral presentations.

The programme, presentations and recordings of the Third EUSO Stakeholders Forum are available on the EUSO website: <https://esdac.jrc.ec.europa.eu/euso/third-euso-stakeholders-forum>.

Figure 13. EUSO Working Groups active in 2023.



Source: JRC analysis.

3.1 WG Soil erosion

The Working Group Soil erosion was established in 2021 and is co-chaired by EUSO staff and external partners. The WG Soil erosion includes more than 50 members, experts from academia, businesses or policy with recognised experience in the topic. The objectives of the WG Soil erosion are to develop an object oriented (bottom-up) approach for estimating soil erosion and erosion-related soil health indicators at farm scale. In addition, the WG develops integration of soil erosion with complementary issues such as soil contamination, nutrient losses and food security. Finally, the WG proposes ways to improve large-scale assessments on soil erosion and propose sustainable soil conservation practices.

The major achievements of the WG Soil erosion in 2023 are:

- The EUropean SEDiments collaboration (EUSEDcollab) database was compiled, containing a compilation of sediment data from monitored catchments in Europe. Multiple European research institutes contributed to the dataset. The resulting publication (Matthews et al., 2023) can be accessed through this [link](#).
- The off-site costs of removing sediments from reservoirs in the EU was quantified. It was estimated that removing more than 1 billion of m³ of sediments due to erosion may cost about 5 – 8 billion euros per year (Panagos et al., 2024a). This quantification contributed to the impact assessment of the proposed Soil Monitoring Law. The associated publication can be accessed through this [link](#).
- A database of multiple concurrent soil erosion processes was compiled. This first-ever assessment at European scale combines the threat of water, wind and tillage erosion and SLCH to estimate the cumulative impact on arable land. It is a basis for developing a comprehensive monitoring system for soil health. The resulted publication of Borrelli et al. (2023) can be accessed through this [link](#).
- The open access Global Rainfall Erosivity Database (GloREDA) was compiled. GloREDA is the first open access database of rainfall erosivity (R-factor) based on hourly and sub-hourly rainfall records at a global scale. The database was compiled through a global collaboration between a network of researchers, meteorological services and environmental organisations from 65 countries, mobilised through the WG Soil erosion. The resulting publication of Panagos et al. (2023) can be accessed through this [link](#).

The main meeting of the WG Soil erosion was during the Third EUSO Stakeholders Forum (15-17 November 2023), during which the WG discussed with policymakers from DG ENV and DG AGRI the future needs for research in relation to soil conservation. The main policy drivers are the Soil Monitoring Law and the Mission ‘A Soil Deal for Europe’. As a common ground for all policy developments, there is an urgent need for updated and more frequent assessments of soil erosion at European scale, updated indicators to better monitor soil erosion, enhanced knowledge of all erosion processes (water, wind, gully, tillage, piping, landslides, crop harvesting, etc.) and the effectiveness of best management practices to mitigate erosion based on different pedo-climatic conditions and cropping systems in Europe.

The WG Soil erosion invited several Mission Soil projects, involved in soil erosion related work packages, to participate in the Stakeholders Forum. AI4SoilHealth is working on a new soil erosion indicator considering soil stock, and the BENCHMARKS project explores erosion drivers at different scales and appropriate indicators. The Soil O-LIVE project focused on monitoring soil erosion in areas with olives, recognising their significant impact in the EU economy.

Also, scientists were invited to the Stakeholders Forum to present the future challenges in improving soil erosion estimation processes at European Scale. These contributions address major research gaps and support a better quantification of all erosion processes. Matthias Vanmaercke (KU Leuven) presented the latest achievements in modelling gully erosion globally, while Anita Bernatek-Jakiel (Jagiellonian University) the latest advances on the dataset and map built for Europe on piping erosion. Arthur Fendrich evidenced new methodologies for mapping cover crops, with a case study for France.

In 2022, the WG Soil erosion organised a successful workshop on “soil erosion in the EU” (Figure 14). A special issue was organised with the submission of 15 papers. In 2023, 9 papers in this

[special issue](#) were accepted and published (Panagos et al., 2024b). The ongoing collaboration and research efforts underscore the commitment to address soil erosion challenges.

Figure 14. The soil erosion workshop in a nutshell.



Source: JRC analysis.

The WG Soil erosion launched in 2023 a call for soil erosion plot data in the EU, targeting soil erosion by water data from European field experiments (EU_ERPlot). Data submissions from contributors across the European continent who wish to share access to their soil erosion measurements are welcome. The objective of this network is to make data open and accessible to the community, towards the improvement of the understanding of soil erosion processes, model development, and ultimately preserve past and present data records, in a harmonized format and updatable platform. Deadline for the first stage: 31.3.2024

3.2 WG Data sharing and integration

The Working Group Data sharing and integration (chaired by C. Ballabio, co-chaired by C. Schillaci) aims to provide relevant guidance on EU-wide soil data to promote best practices and convey data and knowledge into the EUSO and ESDAC to guarantee long-term availability. In the two previous EUSO stakeholders forum editions, the WG on soil data was chaired by Marc van Liedekerke, who retired recently from the European Commission JRC; we take the occasion to thank Marc for having set the scene for this WG and for being a crucial pillar of ESDAC, the most significant soil data and knowledge repository of the EU. During the Stakeholders Forum of 2023, the participation of the Mission Soil funded projects was important to discuss concrete solutions to the challenges the WG is facing.

This involves that Mission Soil funded projects will be EU scale data and knowledge providers to supply the high demand of soil data for the primary and secondary research and development at EU scale. The EU backbone soil survey LUCAS offers a virtuous case study in how soil monitoring at continental scale is integrated within the development of soil knowledge and actionable recommendations for policy.

The main activity of this WG during the third EUSO Stakeholders Forum focussed on the role of the Mission Soil funded projects that will interact with the EUSO Data and knowledge development and harmonisation strategy. Due to the time constraints of the session, we have been focussing on selected project that widely acknowledge the EUSO as a data beneficiary and which identified suitable mutual interactions to present their preliminary result. In particular, the Soil-Wise project, related to the open-access knowledge and data repository to safeguard soil was presented with a joint presentation from project coordinators, Panos Ilias, Tomáš Řezník, Fenny van Egmond. Soil-Wise will provide an integrated and actionable access point to scattered and heterogeneous soil data and knowledge in EU, under the FAIR (Findable, Accessible, Interoperable and Reusable) framework, to improve trust, willingness, and ability to share and re-use soil data and knowledge. Soil-Wise recognises existing workflows and repositories for specific user needs and aims to work with them to enhance their discoverability, approachability and interconnection. An open, modular, scalable and extensible knowledge and data repository building on existing and new technologies will be provided while respecting data ownership, access policies and privacy. Artificial Intelligence and Machine Learning techniques will be employed to interlink scattered data and knowledge, automatise the processes, infer new knowledge and increase FAIRness. SoilWise applies infrastructure thinking instead of project thinking to design a repository for at least a decade to support EUSO evolvement accordingly.

New Mission Soil project with a strong data focus, presented their roadmaps. These projects willing to interact closely with the WG Soil data integration and EUSO/ESDAC platforms:

- SOIL O-LIVE PROJECT – was presented by the coordinator, Professor Antonio J. Manzaneda University of Jaén Spain. The project will assess the environmental condition of olive grove soils on a large scale in the major Mediterranean olive production areas. SOIL O-LIVE will examine how pollution and land degradation affect olive groves' soils, investigate the connection between soil health and the quality and safety of olive oil, implement effective soil amendments and ecological restoration practices, and establish strict ecological thresholds for healthy European olive groves
- MARVIC project coordinator Hui Xu, from ILVO Belgium, presented the roadmap for data distribution. The project will develop a framework for designing harmonized, context-specific Monitoring Reporting and Verification systems for carbon removals by agricultural activities.
- EJPSOIL – Work Package 6 leader Dr. Maria Fantappiè, presented the current advancements in harmonising soil information and soil data exchange. This work package will a) develop a prototype distributed system to integrate agricultural soil information across Europe and streamline the data flow to ESDAC, b) provide thematic databases and maps of agricultural soil indicators, properties, and maps of agricultural soil properties and management systems, c) set target values of agricultural SOC, agricultural soil degradation and fertility, and d) develop methods to account, monitor and map agricultural soil carbon, fertility and degradation.
- Finally, the H2020 PRIMA Section 1 Project coordinators Professor Claudio Zucca, University of Sassari, for the SOILS4MED project (SOIL health monitoring and information systems FOR sustainable soil management in the MEDiterranean region), and Professor Sergio Saia, University of Pisa for the SHARInG-MeD project (Soil Health and Agriculture Resilience through an Integrated Geographical information systems of Mediterranean Drylands), presented their project main challenges and data acquisition, management and interaction with EUSO plans.

3.3 WG Soil pollution

The Working Group on soil pollution aims to provide a better characterisation of the Soil Pollution through the Soil Monitoring & Resilience Directive.

The main activity of this WG was during the Third EUSO Stakeholders Forum (15-17 November 2023), with an on-line meeting focusing on the two main aspects of soil pollution characterisation and management. The first, an assessment of the Soil Monitoring Law as a potential instrument to improve the soil health at the European level, its interactions and contributions to the global pollution assessments and its implications for the industry. The presentations were provided by the German Environment Agency, FAO and the NICOLE Regulatory Working Group. The second, insights on geochemical soil databases and more details on soil pollution indicators through the EUSO Soil Health Dashboard, as well as new methods that could be applied to characterise diffuse and point type sources of soil pollution. From the JRC side, the latest updates on soil pollution matters were presented, namely the inclusion of Copper, Mercury and Zinc indicators to the EUSO Soil Health Dashboard. This allowed to set the scene for a future soil health assessment and reporting within the proposed SML. The presentations were provided by the EuroGeoSurveys, JRC, CIEMAT Spain, the Slovakian Environment Agency and Wageningen University.

A summary of the presentations, with their key-points and the main messages from the discussions were then provided at the Mission Soil Week on 23 November 2023 in Madrid. First, the contributors for the work on soil pollution were acknowledged, coming from different frameworks such as academia, institutions, industry, policy makers and citizens. Then, the main research topics as regards soil pollution were defined. The first one on how to improve the Soil Monitoring Law, providing for instance lists of substances, thresholds, monitoring data sharing methodologies or considerations about new emerging substances and a dedicated watch list mechanism. A very important question was raised on how soil parameters and their change are induced by certain soil pollution conditions. The second topic focused on a definition of new Soil Health Dashboard priorities as regards soil pollution: contaminated land, contaminated sites, risk assessment, antimicrobial resistances genes, organic pollutants with a potential focus on PFAS, and finally pesticides. A topic to be considered was also soil remediation. The next guiding question focused on the multi-media (air, water, soil) approach. The role of EU-wide LUCAS Soil programme and national monitoring schemes, deepening on how to ingrate and harmonise these platforms.

The role of the Soil Monitoring Law is crucial in protecting terrestrial ecosystems. Additionally, a global supranational dimension should be considered, given that the soil pollution problems are also transboundary. The industry pointed out that the topics of soils fit for use, reuse and circularity should be further explored and then implemented. Public awareness should be improved, to be taken care of by public administration. New methods, such as remote sensing should be investigated, allowing for better, faster and more economic characterisation at a bigger scale.

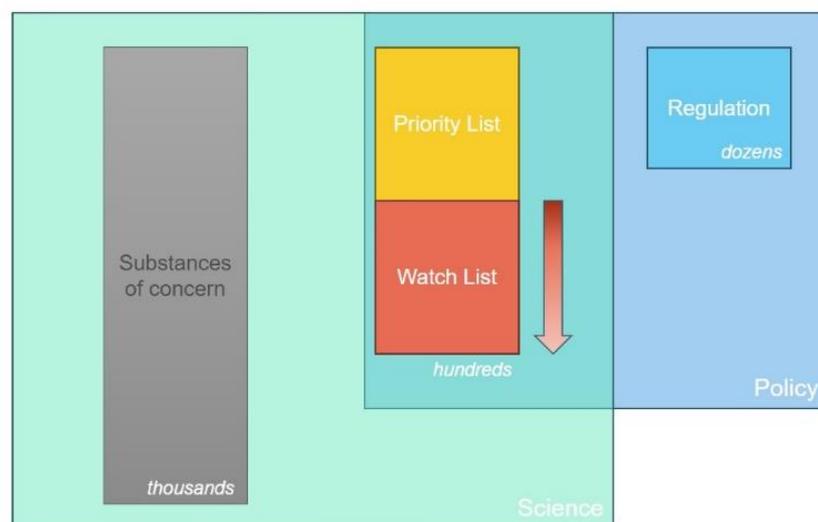
The quality of different indicators was discussed, different groups of pollutants, and the 'polluter pays principle'. Human health and bioavailable fraction were also discussed in the context of the risk assessment. Among future developments and contributions from EUSO for Soil Pollution, the inventory of contaminated sites and watch list mechanism seem to present increased relevance and urgent to develop.

The key challenges were defined. The first one is how to best collaborate in such a complex environment and which platform to use to exchange information amongst academia, administration, industry and citizens. The second one, how to bring forward academic considerations into a policy realm, proposing a watch list procedure (Figure 15). Such a watch list conceptual

structure intends to smoothly build a bridge between science and policy, defining hundreds of priorities and watch list substances to be then proposed as dozens of substances of concern into the policy. This procedure will be used to develop a procedure that aims to collect information for any emerging pollutant with a pathway to soil, regardless of their nature. This will be done by monitoring such compound at EU scale, by assessing their extent and impact, choosing finally the substances to be watched more regularly and rigorously at the EU scale.

Finally, the importance of bringing a community together (e.g. Mission Soil, EJP Soil), making pollution data synthesis (e.g. Meta analysis) and call for evidence on the next LUCAS Soil pollution module were explored.

Figure 15. Watch list conceptual structure as applied by WG Soil Pollution.



Source: JRC analysis.

3.4 WG Soil monitoring

The Working Group on soil monitoring aims to develop an EU integrated soil monitoring system to assess the impact of the EU Soil Strategy and related policies.

The main activity of this WG was during the Third EUSO Stakeholders Forum (15-17 November 2023). The session of the WG focussed on the role of citizen science for soil monitoring and aimed to highlight relevant methodological aspects and identify associated challenges with citizen science for soil monitoring. The sessions were attended by more than 100 participants. Key messages included that existing citizen science generated data can be integrated into ESDAC. Time limitations often constrain the dissemination of citizen science project outputs, and the maintenance of outputs can be resource intensive. Other potential pitfalls are complications with the sharing of data under the General Data Protection Regulation (GDPR) framework. Future research should assess quality control and quality assurance of citizen science generated data. However, the resource effectiveness compared to conventional soil data coming from soil experts and national monitoring programmes cannot be compared directly, given that awareness and knowledge creation is a shared objective under citizen-science soil monitoring. Lastly, an open question was how citizen science projects and participation can be scaled up in terms of geographic coverage (national, international) and the number of participants. Given that citizen science projects have a different structure and skill requirements compared to conventional research projects, attention should be paid to how

citizen science projects are funded and that team members with appropriate skills such as science communication are involved.

3.5 WG Soil biodiversity

In 2023, the Working Group on soil biodiversity fulfilled one of the actions on soil biodiversity reported in the EU Soil Strategy for 2030, namely the publication of the first assessment of soil biodiversity in the European Union. Two studies were published in high-impact journals.

The first one focused on bacteria and fungi (Labouyrie et al., 2023). Briefly, microbial biodiversity metrics (i.e., alpha and beta diversity) and distribution of potential functional groups (e.g., symbiotic fungi and bacterial pathogens) were measured along a gradient of increasing land-use (from croplands to grasslands and woodlands). Over 79,000 bacterial and 25,000 fungal Operational Taxonomic Units were found in the 715 sites analysed across 24 European countries. The lowest bacterial and fungal diversity was detected in less-disturbed environments (i.e. woodlands) compared to grasslands and more disturbed environments (i.e. croplands). Highly disturbed environments contained significantly more bacterial chemoheterotrophs, harboured a higher proportion of fungal plant pathogens and saprotrophs, and had less beneficial fungal plant symbionts compared to woodlands and extensively managed grasslands. Drivers (soil properties, climate and land cover) of soil microbial diversity at EU scale were also assessed. Based on the analyses, guidelines for possible environmental policy actions for soil biodiversity conservation were proposed.

The second article focused on eukaryotes, from protists to anellids (Königer et al., 2021). Briefly, an unprecedented amount of observational data of soil eukaryomes was examined (787 sites across Europe) to gain insights into the impact of a wide range of environmental conditions (e.g. climatic and edaphic) on their community composition and structure. The ecosystem type (i.e. cropland, grassland and woodland) shaped the diversity of fungi, protists, rotifers, tardigrades, nematodes, arthropods, and annelids. Higher diversity of all eukaryotic groups was observed in croplands compared to less intensively managed systems (i.e. woodlands). Eukaryotic communities in croplands were more homogeneous compared to those of other ecosystems. A high proportion of overlapping taxa between ecosystems was recorded. That may indicate a DNA accumulation from previous land uses, hence mimicking the land transformations occurring in Europe over the last decades. Finally, long-term factors (i.e. past land cover and historical climate data) turned out being more relevant in shaping soil eukaryotic communities than variables measured at the sampling time. The obtained findings allowed to propose additional recommendations for future monitoring programs and conservation efforts.

A forthcoming publication (expected for mid-2024) will present the work on the distribution of both antimicrobial resistant and antibiotic biosynthesis genes in EU soils. The ubiquitous utilization of antimicrobials in medicine, veterinary activities, and agriculture made antibiotic resistance one of the greatest global challenges to human health necessitating searching for new antimicrobials and monitoring and predicting sources of resistance and ways of its dissemination. The analyses carried-out will lead to guidelines not just for more sustainable soil management (e.g. manure application) but also for possible discovery of new antibiotics. Results will also allow to accomplish the second action of EU soil strategy on soil biodiversity (i.e. assessing antimicrobial resistant genes distribution in EU soils).

Ongoing Working Group's projects include the analysis of pesticide effects on biodiversity and mapping of soil biodiversity at European scale. The group aims to publish those results in 2024.

Other research initiatives exploring the DNA dataset generated by LUCAS 2018 Soil Biodiversity survey are in place such as the study of connection between biodiversity and primary productivity, distribution of genes involved in nutrient cycles, as well as the impact of climate change scenarios on soil biodiversity.

Future work will also involve examining the implications for soil biodiversity monitoring in relation to the proposed EU Soil Monitoring Law. The current focus on soil biomass and respiration may further expand to a more comprehensive set of indicators, also including DNA data. In this context, a ground for collaborations with EU Mission Soil projects addressing soil biodiversity (i.e. SOB4ES and BIOservicEs) was established.

Finally, recognizing the extent and potential of the LUCAS Soil Biodiversity dataset a call for collaboration was launched at the WG meeting over the Third EUSO Stakeholders Forum (15-17 November 2023). Two ways of collaborations may apply: (I) ideas for new applications of the LUCAS Soil Biodiversity dataset and (II) data contribution to further expand LUCAS dataset. The goal is to enlarge and obtain the best out of the largest soil biodiversity dataset in Europe. That will contribute to properly legislate (soil) biodiversity, providing standardised methods, not just for the EU Soil Monitoring Law but also European environmental and agricultural policies (e.g. Nature Restoration Law and Common Agricultural Policy) that may impact on soil life conservation.

3.6 WG Soil organic carbon monitoring, reporting and verification

The Working Group on soil organic carbon monitoring, reporting and verification (WG SOC MRV) aims to engage with stakeholders involved in the monitoring, reporting and verification of soil organic carbon from a range of perspectives to address the technical challenges in establishing an eventual monitoring system that address a range of policy needs. Soil organic carbon (SOC) has gained international attention due to its relevance to food security and climate change mitigation and adaptation. Rapid expansion of the voluntary carbon market is evidenced by the number of carbon registries and private companies that have recently published measurement, reporting, and verification (MRV) protocols with important differences in their approaches to measurement and estimation of SOC and to key accounting issues. These differences pose a risk of non-equivalent credit creation, which would undermine confidence in the integrity of crediting programs. To upscale carbon farming successfully and to establish long-term business perspectives, it will be essential to standardise the methodologies and rules for MRV soil organic carbon.

The working group had 2 meetings with their members in 2023. One meeting on 17 April 2023 and one during the Third EUSO Stakeholder Forum (15-17 November 2023).

Meeting 17 April 2023

During the meeting, the organization, tasks and planning of the WG were discussed. In addition, new projects were presented, funded by the Commission, with which the WG will actively collaborate. It was also an opportunity to provide some policy updates. The main messages of the meeting were:

- Soil organic carbon MRV and carbon farming is a key area of research and innovation funded by the Mission Soil. Funded actions are foreseen to be linked and work together and should consider and build on relevant previous initiatives on soil carbon monitoring and the EUSO. The WG provides a forum for key stakeholders involved in soil programmes linked to carbon sequestration to exchange information on relevant research activities and results.

- The main objective of the meeting was to inform members about upcoming and ongoing EU-funded research and innovation projects on SOC MRV. One of the takeaways of the meeting was the key role of the WG in bringing all projects together, to strengthen collaboration and avoid duplication of efforts.
- The European Research Executive Agency is setting up of a platform to support the implementation of the Horizon Europe Mission ‘A Soil Deal for Europe’. The platform will provide the European Commission with support services for the coordination, monitoring and assessment of the various strands of activities carried-out under the mission to ensure that the mission is successful and impactful. These support services will be referred to as ‘Mission Implementation Platform (MIP)’. There will be cluster groups that the MIP will lead and promote, one on C farming. This WG should work in close collaboration with MIP. The added value of EUSO WG is to include non-mission projects and potentially reaching more stakeholders than the MIP.
- Agenda and presentations of the meeting of the working group can be found at this [link](#).

Third Stakeholder Forum – 15 November 2023

With more than 150 online participants, the WG meeting was organised around the objective: How can Research and Innovation support the EU Commission’s proposal for C removal certification?

Christian Holzleitner (Head of Unit for Land Economy and Carbon Removals, Directorate-General for Climate Action, European Commission) updated members on the EU Commission’s proposal, which aims to create a common EU standard with a reliable integrity certification framework.

R&I is essential to achieve the objectives set by policy, Claire Chenu (Research Director at INRAE and professor of soil science at Agroparistech) presented her views on a high-resolution and dynamic soil organic carbon monitoring system for agricultural soils.

When policymakers create laws that affect millions of Europeans, they should do this based on scientific state-of-the-art knowledge. Scientists of JRC carry out research to provide independent advice to EU policymakers and put science at the heart of European policies. During the meeting, JRC in-house latest studies and activities to support the proposal for C removal certification were presented, including a new publication on measuring changes in soil organic carbon stocks in croplands at EU level using LUCAS data.

Soil carbon MRV and carbon farming is a key area of research and innovation funded by the EC. Funded actions are foreseen to be linked and work together and should consider and build on relevant previous initiatives on soil carbon monitoring and the EUSO. During the forum, different R&I projects linked to carbon sequestration were presented. This was an excellent opportunity to exchange information on relevant research activities and results.

At the end of the session, members had the opportunity to discuss the working group highlights and the roadmap for 2024. The event concluded with successful and fruitful deliberations.

Roadmap for 2024

- The working group will continue to participate in and provide support to Horizon Europe projects (MARVIC, MRV4SOC, CREDIBLE...)
- There is a plan to organise a conference to assess the state of knowledge on soil carbon for policy makers. Young scientists will be encouraged to participate. An Open call for abstracts will be announced soon.

4 Planned developments for the EU Soil Observatory in 2024

In 2024, the EU Soil Observatory (EUSO) will continue to work on fulfilling its main objectives (see section 1.3), including (1) providing policy support to soil related areas, (2) monitoring the state of soil health, (3) enhancing the capacity and functionality of the ESDAC, (4) supporting soil research and innovation, and (5) supporting citizen engagement on soil-related topics. The sections below highlight the main EUSO's activities and developments planned for 2024.

4.1 Policy support

The EUSO will further support EU soil-related policymaking. Some of the planned deliverables are listed:

- Clean Soil Outlook: The second edition of the Clean Soil Outlook is part of the Zero Pollution Outlook Report, aiming to protect citizens' health from environmental pollution. Soil pollution is recognized as a major contributor to the loss of both aboveground and belowground biodiversity, with implications on the quality and supply of ecosystem services. The Clean Soil Outlook will provide a second assessment of the state of play and an outlook for the future.
- Soil health indicators for supporting the Common Agricultural Policy (CAP): Development of impact indicators for monitoring the implementation of the CAP. This deliverable will include impact indicators on soil erosion and soil organic carbon, as well as new soil health indicators such as soil nutrients and soil biodiversity.
- Soil health assessments: Integrating soil health assessments (e.g. erosion, soil carbon, soil biodiversity) to support the implementation of the EUSO and assess land degradation in the EU. The soil health assessments will contribute to support the EU Soil Strategy for 2030, the EU Biodiversity Strategy for 2030, the Farm to Fork Strategy and the Zero Pollution Action Plan.
- Land degradation methodology and indicator: This deliverable will assess soil degradation and desertification in the EU and will contribute to a better understanding of these processes in the EU. These actions relate to the recommendations of the European Court of Auditors, noting that the European Commission or Member States do not effectively address the risk of desertification in the EU.
- LUCAS soil spectroscopy: This deliverable will report to what extent visible- and near-infrared (VNIR) spectroscopy can enhance/replace traditional analytical measurements. Soil property predictions based on VNIR data will be evaluated in context of the error variance from ISO methods that are currently used. Associated costs of the status-quo scenario and that of spectral acquisition and the processing of soil spectra will be compared.
- LUCAS soil laboratory analysis: This deliverable will ensure the implementation of the laboratory analyses on the soil samples collected during the LUCAS 2022 survey. This will entail market assessments of the diverse services required to develop and publish the technical and administrative documents for a public procurement exercise.
- Soil property database for Africa: The Soils4Africa H2020 Project is applying and adapting methodologies, developed by the JRC for the LUCAS Soil Module, to develop a Soil Information System for agricultural land of Continental Africa. Data will be collected from more than 20 000 locations and will be analysed for key soil properties to establish a baseline of soil health. So, the impacts of agricultural intensification can be assessed.

- Progress on Member State's cooperation on soil monitoring: This deliverable includes technical support to all Mission Soil monitoring activities. JRC will create a mechanism for technical support to coordinate soil monitoring activities, discussions and exchanges between Member States, Associated Countries, the JRC, the EEA and other scientists.
- Spatial Agricultural and Soil Information System: This prototype system will provide a GIS-platform for 'Integrated Administration and Control System' data integrated with ESDAC data and with other geographic information.
- Soil fertility index: This deliverable will contribute to the EU Taxonomy Regulation with a methodology for users to define whether land can be used for construction considering its soil fertility status. The objective is to define the soil properties and their interactions that are most important for crop productivity in the EU. The soil properties that come out of this exercise will form a first basis to define a soil fertility index at the parcel level.

4.2 Monitoring the state of soil health

Future developments of the EUSO Soil Health Dashboard are planned in 2024. These developments will complete the assessment of the state of soil health in the EU. It will also provide better experience for dashboard users. The planned developments include:

- New available datasets will be added to update the assessment and monitoring of the state of soil health in the EU. Datasets will become available from Mission Soil research projects and from EUSO's research activities (see also section 4.4).
- Information on temporal changes of soil health will be added, for those datasets for which time series are available.
- New functionalities will be added to the dashboard, such as allowing users to set the thresholds determining healthy/unhealthy soils and providing more insights in source data and associated uncertainties.
- A soil policy dashboard will be added, to report on the status of the implementation of soil policies of the EU and Members States. Such an action tracker will inform on the status of the policy objectives of the EU Soil Strategy for 2030 and the proposed Soil Monitoring Law.

4.3 Enhancing the capacity and functionality of the European Soil Data Centre

In 2024, further steps will be taken to enhance the capacity and functionality of the European Soil data Centre (ESDAC). As such, ESDAC will be further developed to be the single-stop-shop for soil related data in the EU. This includes:

- Adding new datasets, coming from in-house research activities and from Mission Soil research projects (see also section 4.4).
- Promoting ESDAC as the reference place for soil related data and promoting available datasets. This to ensure that stakeholders and citizens find their way to ESDAC for soil related data. This will lead to an increased number of distributed datasets on the ESDAC platform.
- Incorporating functionalities such as a Web Mapping Application and Services and an Application Programming Interface for a further system development of the ESDAC platform.

4.4 Supporting soil research and innovation

The EUSO will continue to contribute to advanced scientific knowledge on soils in the EU. In-house research to be delivered in 2024 includes:

- Assessment of pesticide risks: It will be assessed how observational data, such as those collected from the LUCAS SOIL Module, could be used as a basis for developing supplementary indicators to support the Harmonised Risk Indicator under Directive 2009/128/EC. The deliverable has two components: a prototype indicator, and the Interim Report on procurement and coordination of the laboratory analysis of the 2022 survey and modelling of pesticides in soils.
- EU Soil Strategy 2030 Actions Tracker: The EUSO will provide the Council with an actions tracker that lists the status of the policy objectives of the EU Soil Strategy for 2030. The policy tracker will complement the EU Biodiversity Strategy Actions Tracker, both in terms of content and user-interface.
- An assessment of the soil biodiversity.
- A model study of the multiple land degradation pathways in Europe.

In addition, EUSO will continue to collaborate and interact in 2024 with relevant Mission Soil projects. Existing collaborations (see section 2.5.2) will be strengthened, and new collaborations will be started. Some examples are listed:

- The SoilWise project. SoilWise will provide an integrated and actionable access point to scattered and heterogeneous soil data and knowledge in Europe and will design a repository for at least a decade to support EUSO evolution accordingly.
- The Soil Health Benchmarks project. Benchmarks aims to build a European network to advance soil health research, monitoring soil health and advocate for sustainable land use.
- The PREPSOIL project. PREPSOIL facilitates the developments of the Mission Soil across European regions, by helping key players to reduce soil degradation, while increasing soil awareness and soil literacy.
- The MARVIC project. MARVIC aims to develop and test a framework for the design of harmonized, context-specific monitoring, reporting and verification systems for assessing soil carbon stock changes and greenhouse gasses emissions in agriculture.
- MRV4SOC project. MRV4SOC will monitor carbon farming through its three-pillar method of monitoring, reporting and verification.
- Credible project. Credible aims to build consensus on the methodologies that could maximise the capacity of soils to act as carbon sinks. Credible functions as a knowledge hub for driving carbon farming forwards.

4.5 Supporting citizen engagement

EUSO will continue to engage stakeholders and citizens on soil-related topics. To do so, EUSO will (co-)organise several activities to engage soil awareness among citizens and to bring together stakeholders. Highlights for 2024 include the Fourth EUSO Stakeholders Forum and the European Mission Soil Week. Also the activities of the Working Groups will be continued in 2024, including providing policy support, advancing scientific knowledge, and stimulating the integration of data.

5 Conclusions

This report highlights the main activities and outcomes of the EU Soil Observatory (EUSO) in 2013. The EUSO, hosted within the Joint Research Centre, aims to be the principal provider of soil-related data and knowledge at EU-level. Furthermore, the EUSO supports EU soil-related policymaking. As such, it supports the implementation of all soil related objectives of the European Green Deal, and more specific, the implementation of the EU Soil Strategy for 2030 and the proposed Soil Monitoring Law.

Through its activities in 2023, the EUSO provided policy support to a wide range of policy areas, including the proposed Soil Monitoring Law and the Impact Assessment of the proposed law, and the evaluation of the Horizon Europe Mission 'A Soil Deal for Europe'. The EUSO also launched the EU Soil Health Dashboard, a comprehensive and easy understandable monitor of the state of soil health in the EU. The dashboard shows, for the first time, where current scientific evidence converges to indicate areas that are likely to be affected by soil degradation. The dashboard will be updated in 2024, to include new available data and functionalities. In addition, in 2023, the EUSO contributed to sharing data and knowledge about EU soils and supported soil research and innovation. Moreover, the EUSO supported stakeholder involvement and citizen engagements regarding soil matters, through the organisation of the Third EUSO Stakeholders Forum and the European Mission Soil Week.

Also in 2024, the EUSO will provide policy support to a wide range of areas. In addition, the ESDAC platform will be extended with new datasets resulted from both in-house research activities and Mission Soil research projects. The EUSO will continue to engage stakeholders and citizens on soil-related topics and will bring together these stakeholders within the Working Groups and during the Fourth EUSO Stakeholders Forum and the European Mission Soil Week.

Overall, in 2023, the EU Soil Observatory has succeeded in achieving its objectives and has successfully taken up its role to be the principal provider of soil-related data and policy support at the EU-level. Also in 2024, EUSO will continue to take up this role. EUSO will further support EU soil-related policymaking and will provide data and knowledge to monitor, safeguard and restore soils. As such, EUSO will continue to play its significant role in the implementation of the EU policy objectives in relation to soils.

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List of abbreviations and definitions

AT	Austria
BE	Belgium
C	Carbon
CA	Canada
CAP	Common Agricultural Policy
Cd	Cadmium
CDP	Collaborative Doctoral Partnership
CH	Switzerland
CN	China
COM	Communication by the European Commission
CSIS	Spanish National Research Council
CZ	Czech Republic
DE	Germany
DG AGRI	Directorate-General for Agriculture and Rural Development
DG ENV	Directorate-General for the Environment
DG CLIMA	Directorate-General for Climate Action
DK	Denmark
DNA	Deoxyribonucleic acid
EC	European Commission
eDNA	Environmental DNA
EEA	European Environmental Agency
EFSA	European Food Safety Authority
ENVI	European Parliament's Committee on the Environment, Public Health and Food Safety
EPM	Erosion potential method
ES	Spain
ESDAC	European Soil Data Centre
EU	European Union
EUSEDcollab	European sediments collaboration
EUSO	EU Soil Observatory
FAME	fatty acid methyl esters

FAO	Food and Agriculture Organization
F/B	fungi to bacteria ratio
FP	Framework Programs
FR	France
GAEC	Good Agricultural and Ecological Conditions
GB	United Kingdom
GDPR	General Data Protection Regulation
GloSEM	Global Soil Erosion Modelling
GloREDA	Global rainfall erosivity database
GR	Greece
Gt	Gigaton
ha	hectare
INRAE	National Research Institute for Agriculture, Food and the Environment
IN	India
IT	Italy
JRC	Joint Research Centre
K	soil erodibility
kg	kilogram
km	kilometre
Ksat	hydraulic conductivity
LUCAS	Land Use/Cover Frame area Survey
LSCE	Laboratoire des Science du Climat et de l'Environnement
MAGPIE	Model of Agricultural Production and its Impact on the Environment
mEPM	modified erosion potential method
MIP	Mission Implementation Platform
mg	milligram
MRV	monitoring, reporting and verification
MS	member state
NGO	Non-Governmental Organisations
NL	Netherlands
NUTS	Nomenclature of Territorial Units for Statistics

P	Phosphorous
PL	Poland
PRIME	JRC Productivity and Impact Evaluation
PPP	Plant Protection Product
PT	Portugal
PTF	pedotransfer functions
Q1-Q4	quarters
RO	Romania
R-factor	Rainfall-runoff erosivity factor
SE	Sweden
SDG	Sustainable Development Goals
SLCH	Soil loss due to crop harvesting
SML	Soil Monitoring Law
SOC	Soil Organic Carbon
SWD	Staff Working Document
TR	Republic of Türkiye
UK	United Kingdom
US	Uniyed States of America
USLE	Universal Soil Loss Equation
VNIR	visible- and near infrared
WG	Working Groups
WG SOC MRV	Working Group on soil organic carbon monitoring, reporting and verification
Zn	Zinc

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