

JRC TECHNICAL REPORT

JRC support to the European Joint Programme for soil (EJP SOIL)

Datasets, technical advice and scientific guidance

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2020



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EU Science Hub

<https://ec.europa.eu/jrc>

JRC122248

EUR 30450 EN

PDF ISBN 978-92-76-25322-8 ISSN 1831-9424 doi:10.2760/74273

Luxembourg: Publications Office of the European Union, 2020

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How to cite this report: Panagos, P., Jones, A., Van Liedekerke, M., Orgiazzi, A., Lugato, E. and Montanarella, L., *JRC support to the European Joint Programme for soil (EJP SOIL)*, EUR 30450 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-25322-8, doi:10.2760/74273, JRC122248

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Acknowledgements

Thanks to colleagues in D3: Cristiano Ballabio, Fernandez Ugalde Oihane and Simone Scarpa for participating in the discussions for the EJP SOIL. Thanks also to Maria Jose Amaral and Pilar Vizcaino Martinez (REA) for comments on the report. Thanks also to the EJP SOIL colleagues who participated in the two meeting (summer 2020) for proving feedback and proposals on the best collaboration between JRC and EJP SOIL.

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Abstract

DG AGRI is currently supporting under Horizon 2020 an European Joint Programming Initiative (JPI) on agricultural soil management to overcome current fragmentation in national research programmes and unleash the potential of agricultural soils to contribute to climate change mitigation/adaptation, while preserving or increasing agricultural functions. The EJP SOIL is a European Joint Programming Initiative co-funded by Member States on agricultural soil management contributing to key societal challenges including climate change and future food supply.

The EJP SOIL will look at how good agriculture soil management can contribute to food security, climate change mitigation/adaptation and ecosystem services through the preservation of soil organic content and water retaining capacity. This report provides **technical advice and scientific guidance** on the implementation of the EJP SOIL for an improved collaboration with JRC. The technical advice is a summary of the outputs of two meetings with the EJP SOIL partners in summer 2020. JRC also provides recommendations for a better collaboration in relation to the implementation of the LUCAS Soil Module, development of soil indicators and related data flows from EJP SOIL to ESDAC, development of the EU Soil Observatory plus some future research challenges. This report includes also the **metadata related to datasets available at European scale** for use by the EJP SOIL.

1 Introduction

The EJP SOIL will look at how agricultural soil management can contribute to food security, climate change mitigation/adaptation, biodiversity conservation and ecosystem services through the preservation of soil organic carbon and water retaining capacity (Visser et al., 2019). This report provides technical advice and scientific guidance on the implementation of the EJP SOIL for a better collaboration with the JRC. This report also describes the expectations of the JRC in relation to what EJP SOIL can contribute in relation to improving the current LUCAS Soil Module and provides guidelines on how EJP SOIL data can contribute to the development of the newly established EU Soil Observatory. The report includes the datasets available at European scale for the EJP SOIL. The activity makes visible references to the European Soil Data Centre (ESDAC), the European Soil Partnership and other relevant soil activities of the JRC.

The main objective of the EJP SOIL is to create an enabling environment to enhance the contribution of agricultural soils to key societal challenges such as climate change adaptation and mitigation, sustainable agricultural production, biodiversity protection, ecosystem services provision and prevention and restoration of land and soil degradation. In order to achieve this objective, it is of crucial importance to develop the necessary soil data and information base. WP6 of the EJP SOIL is addressing this issue in close collaboration with the JRC.

Starting point of such a data and information system are the available data, knowledge and experience collected over more than 20 years of activity of the European Soil Data Centre (ESDAC) at the JRC. Those datasets are made available in this report by providing description, metadata, URL location and scientific references as supporting documentation.

JRC interaction with the EJP SOIL is mainly focused on WP6. The overall objective of WP6 is the development of an agreed knowledge base and database to improve a) the effectiveness of European agricultural and environmental policies, and b) the European contribution towards international reporting on agricultural soils.

Specific objectives of WP6 are to: i) initiate and test a distributed system to integrate agricultural soil information across Europe and streamline the data flow to ESDAC, and to complement the LUCAS database with new protocols and national sampling strategies; ii) harmonise databases as baselines on agricultural soil quality indicators, properties, and management systems; iii) set the agricultural potential along with sustainable target values of SOC, agricultural soil degradation and fertility, as a function of different European pedo-climatic conditions and management systems; iv) enable accounting, monitoring and mapping at various scales of agricultural soil carbon, agricultural soil degradation rate, soil biodiversity in agricultural soils and fertility changes.

As a first step, a full inventory of relevant soil data and information has to be completed. From the side of the JRC this is consisting in a subset of the available data in ESDAC that are relevant to the objectives of the EJP SOIL. Such an inventory is a pre-condition for completing the main deliverable of the EJP SOIL of relevance for the future activities of the JRC: D6.3 – Proposal of methodological development for the LUCAS programme in accordance with national monitoring programmes.

The relevance of this deliverable to the JRC is related to the firm plan of the JRC to establish an EU Soil Observatory as a major contribution to the implementation of the various policies and strategies related to the new European Green Deal, especially in support of the new EU Soil Thematic Strategy.

This report is also a summary of two meetings between JRC and EJP SOIL taken place in June and September 2020. Regarding the structure, this report focusses on the collaboration between JRC and EJP SOIL in a) the LUCAS Soil Module b) the development of soil-relevant indicators c) the exchange of data d) the data flows to ESDAC e) the cooperation towards the implementation of the European Soil Observatory and f) research topics of common interest. The report also includes the JRC recommendations for this collaboration. Finally, the report includes two annexes a) detailed information on the LUCAS Soil Module and b) the list of datasets currently available in ESDAC.

2 LUCAS Soil Module

The Soil Module of the 'Land Use/Cover Area frame statistical Survey' (generally referred to as LUCAS Soil) is the only harmonised and regular collection of soil samples for the entire territory of the European Union (EU), addressing all major land cover types simultaneously. Traditionally, soil surveys in Member States (MS) reflected differences in scope, sampling approaches and analytical procedures.

Harmonized quantitative assessments of soil condition were lacking in the EU due to differences in between Member States in nomenclature, sampling design, protocols and laboratory procedures. In this context, a mechanism was sought to collect data across the EU in a harmonised manner in order to derive assessments of the effects of land management practices on soil. The LUCAS Soil Module is managed in the JRC and has already collected samples for 3 surveys (2009/12, 2015 and 2018); it also develops the 2022 Lucas Soil survey.

An eventual goal for the LUCAS Soil Module is to develop systematic links with Member States, specifically to:

- a) Assure data harmonization and comparability between national and EU-wide aggregated figures and indicators.
- b) Supplement LUCAS Soil nationally applying specific representativity criteria (increase density of points, national analytics, extended soil depth)
- c) Cross-validate results
- d) Provision of supplementary information beyond the scope of the LUCAS Survey (e.g. identify and contact land owners, collection of land management details, specific soil type, etc.)
- e) Ensure access to sites.

The JRC could collaborate with the EJP in some specific research issues that include:

- a) Representativity of EU sampling grid
- b) Development of supplementary (Level 2) sampling framework
- c) Implications of changing sampling protocol (e.g. 20 > 30 cm)
- d) Incorporation of subsoil parameters to topsoil data (e.g. benchmark soil profiles)
- e) Use of spectral analysis in field and laboratory conditions
- f) Integration of data from proximal/precision agriculture sensing system
- g) Adding/proposing new attributes which can better address policy needs on soil condition.

The requirements in the LUCAS Soil Module are driven by specific needs in the EU relevant policies. In the context of the EU Soil Thematic Strategy (COM(2006) 231), JRC collects soil data to provide harmonised baselines for soil properties and condition. Among them, soil organic carbon content is the most important attribute (Lugato et al., 2014). In addition to this, the data on coarse fragments and texture are inputs for soil erosion models (Panagos and Katsoyiannis, 2019) and the data on pH and nutrients (Nitrogen, Phosphorus, and Potassium) are important for estimating soil pollution (Ballabio et al., 2018; Ballabio et al., 2019). In the last LUCAS Soil Modules (2015, 2018), new attributes have been added to address the issue of salinization (Electrical conductivity), loss of biodiversity and estimation of bulk density (Jones et al., 2020; Fernández-Ugalde et al., 2020).

LUCAS Soil module has also been important for the development of the Common Agricultural Policy (CAP) context indicators on soil erosion and soil organic carbon stocks (Panagos et al., 2020), Sustainable Development Goals (SDGs) indicators and Land Use Change and Forestry (LULUCF) datasets.

In the new EU Green Deal, the LUCAS Soil Module can contribute to the assessment of phosphorus flows in European soils (Zero Pollution Strategy, Biodiversity Strategy), evaluation of heavy metals pollution and pesticides inputs (Zero Pollution Strategy, Farm to Fork Strategy). In addition, the emerging EU policies such as the Sustainable use of Pesticides Directive, the Fertilizer Directive, the Antimicrobial Action Plan and the EU plastic strategy may use the LUCAS Soil module results on pesticides, heavy metals (cadmium), micro-plastics, etc.

The first two surveys (2009/2012 and 2015) targeted physical and chemical properties, such as particle size distribution (texture), pH, organic carbon concentrations, nutrient concentrations (N, P, K, S), metal content (only

2009/2012), salinity (only 2015 onwards) and cation exchange capacity. In both modules, the visible and near-infrared spectra data were collected (Orgiazzi et al., 2018).

In the 2018 survey, bulk density, specific measurements for organic-rich soil and soil erosion visual assessments were carried out in the field while the core laboratory analysis was expanded to measure metal content, genetic composition (DNA), residues of plant protection products and antibiotics, and the presence of antimicrobial resistance genes (Figure 1). A detailed analysis of the soil analysed properties is presented in Annex A (LUCAS Soil Module).

Figure 1. LUCAS Soil Modules over the sampling years Dotted cells express the potential analysis of various modules

MODULE	Type of analysis	Year of survey				
		2009–2012	2015	2018	2021	→
MODULE 1 Physico-chemical properties	Coarse fragments (>2 mm)/% PSD ¹ : clay, silt, sand/% pH (CaCl ₂ , H ₂ O) Organic carbon/g kg ⁻¹ Carbonate content/g kg ⁻¹ Total nitrogen content/g kg ⁻¹ Extractable potassium content/mg kg ⁻¹ Phosphorous content/mg kg ⁻¹ Cation exchange capacity/cmol(+) kg ⁻¹ Electrical conductivity/mS m ⁻¹ Metals Multispectral properties Mineralogy					
MODULE 2 Soil biodiversity	Bacteria and Archaea (16S rDNA) Fungi (ITS) Eukaryotes (18S rDNA) Microfauna (nematodes) Mesofauna (arthropods) Macrofauna (earthworms) Metagenomics					
MODULE 3 Bulk density	Bulk density Soil moisture					
MODULE 4 Field measurements	Soil erosion by water and wind Thickness of organic layer in Histosols Soil structure					
MODULE 5 Pollution	Organic pollutants Pesticides residues					
Possibility to include new modules						

PSD¹, particle-size distribution.
Different modules form the overall structure of the survey; each module corresponds to different types of analyses. The analyses are repeated at a standard time interval, namely every 3 years. Types of analyses already established (full colour cells) for the campaign scheduled for 2018. Possible analyses for 2021 (dotted cells) are still under discussion and there will be the opportunity to implement the survey further by including new modules.

Further synergies between the LUCAS Soil Module in JRC and the EJP may also include: a) the sampling depth b) the sampling design and c) the field sampling protocol.

LUCAS Soil Module advised surveyors to collect a composite sample from a 'spade depth' – around 20 cm. This was done to capture the main soil characteristics for the most reactive part of the soil to management practices. It should be noted that in some cases (e.g. pesticide residues), even 20 cm is considered too deep as the focus is needed only on the uppermost 5 cm. A pilot exercise was carried out in Portugal in 2018 (at the invitation of PT) to increase the sampling depth to 30 cm in mineral soils. For organic soils in wetlands (including wetlands under forest, grassland and shrubs), the default depth of 20 cm can present problem; As such, the organic horizon in these soils can be significantly deeper than 20 cm.

The selection of LUCAS topsoil surveyed points follows a specific sampling design (already applied in 2009). The selection of points is based on the country (NUTS data originated from Eurostat), the soil types (as defined in the European Soil Database), the bioclimatic conditions (as defined by Bioclimatic Regions) and the Land Cover (as defined by CORINE Land Cover). As the LUCAS Soil module was meant to acquire soil data to support mapping purposes and at the same time provide the basis for a possible future EU soil monitoring system, a

multi-stage stratified random sampling approach (e.g. using soil type, land use and terrain information) was chosen (following McKenzie et al. 2008). A final consideration was that the core set of LUCAS points had been selected for the main survey by Eurostat through a stratified random sampling procedure from the overall 2 km grid. Discussion in the literature, propose that the soil sampling design is under-represented in croplands for the optimum soil organic carbon monitoring while it performs satisfactory in grasslands and woodlands.

Samples of around 0.5-1.0 kg are collected from designated locations by a process of composite sampling that represent the area characterised by the LUCAS point. In addition to the sample at the LUCAS point, four additional samples are taken at each site, two meters distant from the central point in the shape of a cross, preferably along cardinal compass points. The five samples were mixed. Surveyors were asked to remove vegetation residues and litter from the surface and to collect only the mineral topsoil.

In addition to the discussion on the soil analytical parameters to be included in LUCAS Soil Module and the discussions on soil depth, protocol and sampling design, we propose specific actions on how to have a better use of the LUCAS Soil Module in collaboration with EJP SOIL.

The details on the LUCAS Soil Module are described in Annex 1.

Soil Analysis and Spectrometry

The JRC is aware that new spectral methods for measuring SOC concentration and stocks are increasingly becoming available for field assessments (Nocita et al., 2014). We propose that EJP SOIL demonstrate operational robustness of using spectral systems to determine accurately soil properties and compatibility with ISO standards – with possible adoption for future (2026?) LUCAS Survey.

Integration of LUCAS Soil Module and national Soil Monitoring Networks (SMN).

In some Member States, there are soil surveys for assessing soil attributes (mainly soil organic carbon). The IPCC reporting and other policy needs would request robust estimates of Soil Organic Carbon (SOC). Two options can be explored: a) filling the gaps with national surveys as there are sampling areas not yet sampled by previous LUCAS campaigns b) defining common sampling points with existing monitoring networks in the Member States and compare the results. A mixed strategy may also be possible. This integration (complementarity of LUCAS with national SMN) is a good way of towards the development of the future EU Soil Observatory.

Harmonization of soil biodiversity protocols for analysis/sampling

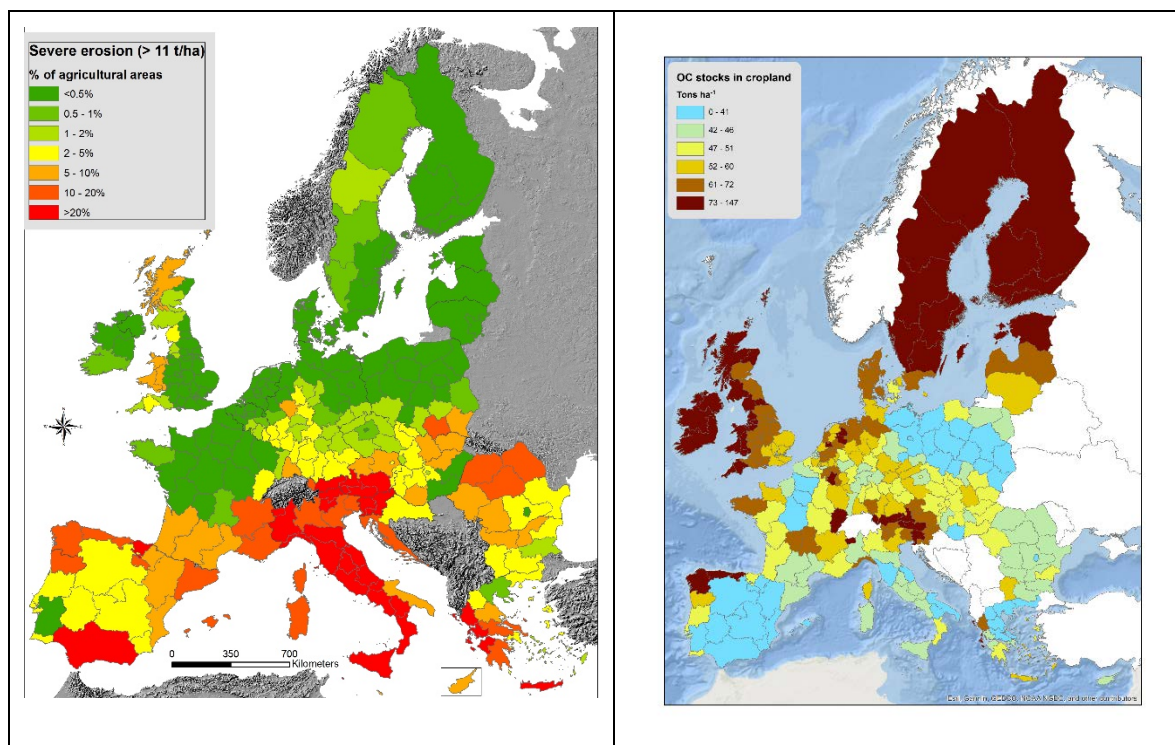
ESDAC intends to gather and possibly make available all national protocols for sampling and analysing soil biodiversity. This effort would represent a first step towards the harmonisation of the strategies for monitoring soil biodiversity at European level. The JRC could benefit from the long time series, likely available at national level, and the completeness of soil biodiversity data (e.g. analysis of invertebrate communities). EJP SOIL and other national/regional research entities can benefit from the methodologies already established by the JRC and LUCAS Soil Biodiversity dataset (data collected in LUCAS Soil Module 2018).

3 Soil Indicators

JRC develops datasets on soil threats and soil functions at EU level for policy support. The datasets are important advancements in the current knowledge of soil properties and processes at continental scale.

The JRC Sustainable Resources Directorate (D) and in specific the Land Resources unit has developed a series of indicators related to soil erosion and soil organic carbon (Figure 2) to support the Common Agricultural Policy (CAP 2014 -2020), the Sustainable Development Goals (SDGs), the Resource Efficiency Scoreboard and the 7th Environment Action Programme (EAP) (Panagos et al., 2020). In addition, those two indicators are used in the impact Assessment of the future CAP post-2020.

Figure 2. Examples of soil erosion indicator (left) and soil organic carbon stocks (right)



The development of indicators is based on models developed in JRC such as RUSLE (Panagos et al., 2015) and Century (Lugato et al., 2014). Soil erosion and soil organic carbon indicators include both the current state and trends (Panagos et al., 2020). JRC expects a close collaboration with EJP to improve those indicators with national data on soil erosion and soil organic carbon. JRC has expressed the interest to have a close collaboration with the EJP SOIL on the management practices and land cover datasets (higher resolution than CORINE Land Cover) that can enhance current estimates on soil erosion and soil organic carbon.

JRC highlighted the priorities on developing indicators for soil biodiversity and soil diffuse contamination. Those emerging indicators are fitting with the new priorities of the European Commission in the EU Green Deal (Biodiversity Strategy 2030, Zero Pollution) (Montanarella and Panagos, 2021). The expertise of the EJP SOIL can contribute to quantify and develop assessments at continental scale on diffuse contamination and soil pollution.

The soil compaction and soil salinization are among the soil threats that JRC has not updated the status and trends during the last decade. According to Jones et al. (2012) and Stolte et al (2015), 23-36% of EU agricultural soils suffer from soil compaction. Excess levels of salts are believed to affect around 3.8 million ha in Europe (EEA, 1995). Therefore, JRC will apply modelling activities and assessments on soil compaction and soil salinization to update the obsolete past estimated figures.

JRC also is advancing in new research needs for the development of soil fertility and land degradation indicators. JRC has made a proposal for the development of soil fertility indicators based on nutrients (nitrogen,

phosphorus, and potassium), soil organic carbon and other soil properties (Panagos et al., 2020). This can be a basis for further development and scientific collaboration on this issue.

4 INSPIRE harmonisation

As EJP SOIL intends to build the data infrastructure using the INSPIRE Technical Data Specifications for Soil, it is advised to be in close contact with technical representatives at the JRC INSPIRE team, that follows up on INSPIRE technical progress in Europe. This team has built the so-called thematic communities, also one for soil, and is also available to expand the number of official soil Code-lists, with new ones, if required by certain soil communities. ESDAC is a member of the INSPIRE soil technical community, and advises the EJP SOIL to become a member as well, jointly or individually by participating EJP SOIL organizations. ESDAC is keen on advising the EJP SOIL on data matters. Note that, as an example and experiment, ESDAC transformed the full European soil database to the format specified in the INSPIRE Technical Specifications. This was not a straightforward exercise and could only be done by informatics experts. The result (GML) was impossible to work with, as no tools exist to handle such GML data.

INSPIRE provides specifications for a data infrastructure at structural level, not semantic level. A main problem that the EJP SOIL data management must face is **the semantic harmonization**, not the structural harmonization which is already defined in INSPIRE. A challenge for the EJP SOIL will be to agree on the semantics of data contents, not only on agreed Code-lists, but also on the meaning of the values of variables. For instance, the values of 'organic carbon' provided by various organizations may mean different things, depending on how it was calculated. To agree beforehand on the meaning of variables and values is key to the harmonization and thus comparability of the data.

At this stage of the project (October 2020), it is not defined yet which data (type, format) will need to be exchanged, and therefore it is difficult to give specific recommendations in relation to INSPIRE data exchange. However, one may expect as types of data: (soil) sample data, soil profile data, soil-related polygon maps, soil-related raster maps. All but raster maps are structurally defined in INSPIRE. For rasters, the project could define its own convention, but for easy interoperability, it is recommended that the raster-cells are defined according to the INSPIRE suggested scheme. (<https://inspire.ec.europa.eu/id/document/tq/gg>)

5 EJP data flow to the European Soil Data Centre (ESDAC)

According to WorkPackage-6 (WP6) of the EJP SOIL, it is envisaged that the project will set-up a distributed information system to collect data from participating organizations, including soil monitoring data. It is also mentioned in WP6 that the European Soil Data Centre could be a consumer of such data and a user of the system. It is not explicitly mentioned what the exact purpose of such a system will be and which users it should serve.

The viewpoint of ESDAC on soil data flow from the EJP SOIL to ESDAC is that ESDAC looks for simple and sustainable solutions. To that end, ESDAC will be available to host from EJP SOIL all **finished** products, together with metadata, preferably in INSPIRE format. With 'finished products' is meant: maps/databases/geodatabases, and (eventually at the end of the project) the EJP SOIL website contents. A good example of a finished product is the Global Soil Organic Carbon (GSOC) map of FAO-GSP, which is a product that has gone through an elaborated chain of processes, and has been established backed-up by solid metadata. It is expected that EJP Soil, and not ESDAC, will prepare and deliver these products.

ESDAC is available for hosting the **EJP SOIL website contents** after the project has finished, on the condition that all content is transformed in statically linked static pages. The website contents should be compliant with the rules (e.g. privacy, intellectual properties, etc.) set by the European Commission.

For any of these finished products that will be stored in ESDAC, a **legal clearance** from all involved parties is required, meaning that, whenever ESDAC will publish them, that will be done legally correct, so that JRC-ESDAC will not be liable for doing so.

ESDAC will not host any system that is based on incorporating data dynamically, such as it is planned in the EJP SOIL distributed system: it is very complex, requires maintenance, will be a prototype in the context of EJP SOIL only. It is very likely that it will not be a robust working system; at the end of the EJP SOIL life cycle and in the absence of further funding, problems may arise to keep such a system alive.

ESDAC is not going to interfere with the EJP SOIL data policy. ESDAC only wants clear statements, from duly authorized persons, as mentioned above, that what ESDAC is going to publish on its website can be published without liability for the European Commission.

Coming to the **finished data products** technical aspects, possible data flows (outputs) of the EJP SOIL towards ESDAC will be maps/datasets. For major interoperability inside and outside the project, ESDAC advises to make the maps/datasets available as rasters (grids), according to the INSPIRE defined grid system. Data could also be made available in other formats, e.g. polygon data as shapefiles. ESDAC is not keen on distributing geo-data in GML format, as is required/advised in INSPIRE. Concerning soil profile data, we would advise a format that is usable by users, not necessarily the complex INSPIRE format, which will be again GML, which theoretically is a very good format, but is too complex to be used by final users (who are mostly not informatics-skilled).

If the major concern of the EJP SOIL is to make progress in the thematic areas of the project then, data policy, information system development and data formats should be driven by common sense and geared towards quick progress. INSPIRE principles like metadata provision, easy data viewing and download of datasets are highly valid, and should be implemented. However, adhering strictly to the data formats dictated by the INSPIRE Technical Data Specifications for Soil, may be cumbersome and slow the EJP Soil data management processes as in Europe, at this stage (October 2020) there is still insufficient capacity to deploy such specifications.

As mentioned, ESDAC will not host the central hub of the distributed system that is envisaged in the EJP SOIL, but it can provide URL/API links to what is already published by member states (e.g. WMS, WFS links). ESDAC will be a portal from where finished data products can be downloaded, and can possibly provide API links to the systems of the various EJP SOIL data providers. The responsibility for hosting the complete system (central hub) should be at an organization designated by the EJP SOIL management. ESDAC will be a portal to only link to what is available at central level and at (distributed) national level.

Although ESDAC will not directly interfere with the EJP SOIL distributed system development, and given that in the EJP-WP6 description, it is not explicitly mentioned what the exact purpose of such a system will be, what the system and user functionality will be and which users it should serve. ESDAC would recommend that, before any development takes place, EJP would develop first a vision of such a system, describing already in general terms its purpose, envisaged functionality and targeted users, which then could feed in more specific technical design documents.

A detailed overview of the final data products in ESDAC is provided in Annex 2.

6 EU Soil Observatory

The European Joint Programming (EJP) Initiative on agricultural soils is a preparatory activity towards the establishment of the EU Soil Observatory. Especially WP6 of the EJP SOIL is developing the necessary specifications and procedures in order to fully integrate existing soil monitoring activities at EU scale, like LUCAS Soil Module with on-going and future soil monitoring activities at National scale within EU Member States. The following deliverables of the EJP SOIL will be highly relevant for the JRC and its EU Soil Observatory:

D6.2 – Report on national and EU regulations on agricultural soil data sharing and national monitoring activities (Month 18)

After studying national and EU regulations an agreement for agricultural soil data sharing and the integration of LUCAS data between national data holders and ESDAC will be elaborated. Particular attention will be devoted to respect the legal rights of data holders and the INSPIRE regulation. The policy will also consider the collection of data to enhance the LUCAS geodatabase.

D6.3 – Proposal of methodological development for the LUCAS programme in accordance with national monitoring programmes (Month 18)

In conjunction with the JRC, the LUCAS Soil Database development will be facilitated through synergizing LUCAS and national strategies of sampling for agricultural soil monitoring. The shared strategy will avoid overlapping with national monitoring and may also suggest new sampling points and new measurements.

D6.4 – Software framework for a shared agricultural soil information system (Month 24)

The transmission of national data requires the adoption of dedicated software enabling to trans-codifying and streamline operable and harmonized national agricultural soil data to ESDAC. This system could then be further expanded to become the backbone of the EU Soil Observatory (EUSO).

Since the development of the EU Soil Observatory starting in 2021 will be in parallel with the work-programme of the EJP SOIL, there will be the need for close coordination between the EJP SOIL and the activities of the JRC in this sense. The project coordinator of the EJP SOIL will be invited to join the Advisory Board of the EU Soil Observatory (EUSO).

The EUSO will be providing regular reports on the status and trends of EU soil resources and will cover the main soil functions and threats to soil health as listed in the EU Soil Thematic Strategy:

Soil functions

- Biomass production
- Nutrient cycling and pollution buffering by storing, filtering and transforming nutrients, substances and water
- Water quantity regulation (for floods and droughts)
- Climate regulation through carbon sequestration and other greenhouse gas emissions
- Habitat for biodiversity pool
- Platform for human activities
- Preserving cultural heritage
- Source of raw materials

Soil threats

- Soil erosion
- Soil organic matter decline
- Soil pollution
- Soil sealing
- Soil compaction
- Soil acidification

- Soil salinization
- Soil biodiversity loss

Prioritization of activities to reduce the risk of landslides will follow in line with the revised EU Soil Thematic Strategy as anticipated by the EU Biodiversity Strategy for 2030. Main tasks and activities will be further refined and adapted by the EUSO Advisory Board by developing a general multiannual plan and a detailed annual activity plan.

DG ENV, supported by EUSO together with the EEA and other relevant data providers on ecosystem monitoring and restoration, will develop the regular reporting on land degradation and restoration in the EU following the recommendation of the recent report by the European Court of Auditors (ECA, 2018). EUSO among others will support ESTAT in the reporting of the relevant indicators for the soil related SDGs, especially for target SDG 15.3 for achieving land degradation neutrality in the EU.

The EUSO will provide soil information in support of EU policies such as new CAP (DG AGRI), Zero Pollution (ENV) and the Farm to Fork (DG SANTE) Strategies, together with the Circular Economy Action Plan, especially in relation to soil erosion, soil nutrients, soil organic carbon, soil sealing and contaminated sites, and soil contamination by agrochemicals, pesticides, organic wastes and industrial emissions (Fig. 3).

Figure 3. Sustainable soil management in the EU Green Deal and the role of the European Soil Observatory.



As long as Member States and the European Commission will not request otherwise, EUSO offers regular reporting to the OECD on soil erosion.

As a novelty, EUSO pursues the calculation of Life cycle-based indicators on soil in the context of the EU's resource foot print, as requested by ESTAT, including as well the implications for soil quality loss.

The EUSO will be supporting with the necessary data and information the European Green Deal, especially for the Biodiversity Strategy 2030 for soil biodiversity and for the European Climate Law by providing the regular monitoring of soil organic carbon stocks and peatland areas for achieving the target of net zero greenhouse gas emissions by 2050 (Montanarella and Panagos, 2021). In this context, the EUSO will contribute to international initiatives like the Global Soil Biodiversity Initiative, the Global Peatland Initiative, the 4p1000 initiative, Soil Carbon International Consortium and the FAO RECSOIL: Recarbonization of global soils initiative. It will contribute to the regular reporting and assessments by IPCC and IPBES on climate change and biodiversity.

The EUSO will support the implementation of the Soil Health and Food Mission's main goal that by 2030, at least 75% of all soils in each EU Member State are healthy and are able to provide essential ecosystem services (Mission Board Soil health and food, 2020).

7 Future Research challenges – scientific collaborations

In this section, JRC presents a list (non-exhaustive) of forthcoming research issues that JRC will address in the next 2 years. Those topics can be seen purely as potential scientific collaborations between peers (EJP SOIL researchers and JRC researchers). Those topics are not recommendations for future calls.

Soil Biodiversity

The actions taken to ensure biodiversity protection and those to assure food security often do not correspond. This is particularly true for agricultural soils and the organisms that populate them. Nonetheless, the available knowledge shows that a trade-off between food production and conservation of soil-living communities can be reached (Bach et al, 2020).

The development of a reliable soil biodiversity indicator, to be applied at large-scale (i.e. European) for evaluating the effects of different soil management strategies, still remains a scientific challenge. In order to achieve such an ambitious goal, a database including harmonised data collected in agricultural soils subjected to different managements and on long-term time series (i.e. annual sampling, possibly at different time points), should be developed. Data should include information on the overall soil food web, from microorganisms (e.g. bacteria and fungi) to macrofauna (e.g. earthworms). DNA-based techniques (e.g. meta-barcoding) should be combined to standard sampling methodologies to cover as much as possible the entire soil-living community.

Best Conservation practices

A common interesting research field is to collaborate in the application of best management practices for soil conservation. JRC develops models on soil erosion, soil organic carbon and other soil functions where management practices are very important components. We could expect from EJP SOIL a closer feedback on the efficiency of those management practices and how may have a better geographical distribution. The feedback can include the quantification of how efficient are the soil conservation practices (e.g. reduced tillage, cover crops, plant residues, contour farming, stone walls, grass margins) in reducing soil erosion based on pan-European long-term experiments.

Land degradation and restoration

As part of the “2030 Agenda for Sustainable Development”, Sustainable Development Goal (SDG) 15 is to: *“Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss”*. In practice this indicator addresses the issue of “Life on land”. Target 15.3 of this indicator aims to combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world by 2030. In order to measure the progress, the SDG 15.3 has established the Indicator 15.3.1 “Proportion of land that is degraded over total land area” considering 3 sub-indicators Vegetation productivity, Land Cover, Soil Organic Carbon. The development of a Land Degradation indicator (SDG 15.3.1) at continental scale is a challenge to be addressed by the scientific community.

Mobile app

The creation of a harmonized soil information system, which could become the backbone of the EU Soil Observatory, would be an unprecedented step forward to assess and monitoring the soil status. However, big and complex datasets are often accessed by specialists, while the final end-user (farmer, land manager etc.) may not be reached by this information flow at all or in a simpler operative way.

A mobile app (mESO) specifically designed can improve this weak link. By the mobile GPS signal, the application can query data from the soil information system in that geographical position to:

- Visualize a map of different soil indicators
- Report soil indicator trends if data-series are available
- Score the soil functions (in a visual simple way)

- Suggest actions for remediating critical soil parameters or functions

At the same time, the app should allow the end-user to insert available soil and related data. Part of those crowdsourced data will be verified with remote sensing or future LUCAS surveys. This participatory approach can strongly enriched the soil information system. Moreover, the end-user's data can be used to further validate the soil information system, since many layers come from different modelling techniques (geospatial, process-based, fusion approaches) holding a degree of uncertainty.

Spectrometry for measuring Soil organic carbon and other properties

The LUCAS spectra library is the largest continental database including 2 data points (2009, 2015). The JRC is aware that new spectral methods for measuring SOC concentration and stocks are increasingly becoming available for field assessments. We explore the potential of soil spectroscopy for determining accurately soil properties and demonstrate an operational robustness.

CO₂ emissions of organic soils

Organic soils play an important role in climate change mitigation, contributing today to a source of about 70 Mt of CO₂eq at the EU level. It is imperative, then, to better quantify and understand which management practices can be more effective to abate these CO₂ fluxes. Losses in drained organic soils can be up to 40 t/ha of CO₂eq per year, representing a layer loss of some cm in a 5-year time-horizon (respiration-induced subsidence). This research challenge is expected to be addressed in the future either with scanning techniques on the field or by measuring soil respiration.

8 Concluding remarks - Recommendations

This section includes the concluding remarks and expectations from JRC in relation to the EJP SOIL. Here, there are some optional recommendations that can be useful towards a closer collaboration between JRC and the EJP SOIL.

In relation to LUCAS Soil Module, the main recommendations are:

- Close collaboration in discussing the following **technical aspects** of LUCAS a) the sampling depth b) the sampling design c) the field sampling protocol.
- **Integration of National Monitoring Networks** on soil with LUCAS Sol Module and testing the complementarity of the two approaches.
- Development and best use of the largest continental **Spectra library (LUCAS)**. The EJP SOIL could demonstrate the **operational robustness of using spectral systems** to determine accurately soil properties
- Integration of national **soil biodiversity monitoring methodologies and related datasets**, if any, to LUCAS Soil Biodiversity 2018.

In relation to soil indicators, the main recommendations are:

- In the context of forthcoming policy needs (new Sol Thematic Strategy, post-2020 CAP, Zero Pollution), JRC indicated their priorities on developing indicators for **soil biodiversity, soil diffuse contamination, soil compaction and soil salinization**.
- A research challenge is to advance in the development of a well-established indicator for **soil fertility**.

In relation to INSPIRE, the main recommendations are:

- Make close contact with technical representatives at the JRC INSPIRE team, especially those covering the theme SOIL. Also, subscribe to the **INSPIRE soil technical community**.
- Implement INSPIRE for **metadata, discovery, view and download**.
- Be cautious to adopt the INSPIRE specifications for **real data exchange**, as the GML format is quite complex and may slow down operations.
- Start definition of **soil data semantics** to be used for data exchange (not only codelists, but also variable values). Use formats that users (not only informatics persons) can use. When defining raster/grid formats, use the **INSPIRE grid system**.

In relation to future EJP SOIL data flows to ESDAC, the main recommendations are:

- Define '**finished products**' that can be published on the ESDAC website. Make sure that the final 'finished products' are covered by **extensive metadata**. Make sure that the final 'finished products' are **legally covered** so that they can be published by ESDAC.
- If the EJP SOIL **website needs porting to ESDAC** (after the end of the project), make sure that its content can be transformed to statically linked static pages.
- **Data formats** of the finished products should be such that they can be deployed by ordinary users (not only IT people).
- Before any development of a distributed system, EJP should develop first a **vision** of such a system, describing already in general terms its purpose, envisaged functionality and targeted users, which then could feed in more specific technical design documents.

In relation to the development of the new European Soil Observatory (EUSO), the main recommendations are:

- Build **a common vision and develop complementarities** between national monitoring networks and EU
- Identify what were the **barriers concerning the past initiatives** (e.g. data access and use by EU, harmonization of methods, impact on national policies)

- The project coordinator of EJP SOIL is invited to join the **Advisory Board of the EU Soil Observatory** (EUSO).
- Identify the relevant National soil monitoring systems in Member States to be **networked** within the EU Soil Observatory

Finally, JRC will advance in some research challenges in the next two years and the following topics can be seen as scientific synergies:

- **Land Degradation indicator** as defined by the UNCCD and applying further modifications in the EU context.
- **Validation of pan-European models** and advancing knowledge of best management practices for soil health.
- Development of a **soil app** to contribute to a harmonized soil information system.
- Scientific synergy on **CO2 emissions from organic soils**.

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List of abbreviations and definitions

API	Application Programming Interface
CAP	Common Agricultural Policy
EAP	Environment Action Programme
EJP	European Joint Programme
ESDAC	European Soil Data Centre
ESP	European Soil Partnership
EUSO	European Soil Observatory
FAO	Food Agriculture Organization
GML	Geography Markup Language
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
LUCAS	Land Use / Land Cover Area frame Survey
LULUCF	Land Use Change and Forestry
SDG	Sustainable Development Goals
SMN	Soil Monitoring Networks
URL	Uniform Resource Locator

Annex 1: LUCAS Topsoil Module: Background, current design, future developments

Introduction

An eventual goal for the LUCAS Soil Module is to develop systematic links with Member States, specifically to:

1. assure data harmonization and comparability between national and EU-wide aggregated figures and indicators.
2. supplement LUCAS Soil nationally applying specific representativity criteria (increase density of points, national analytics, extended soil depth)
3. cross-validate results
4. provision of supplementary information beyond the scope of the LUCAS Survey (e.g. identify and contact land owners, collection of land management details, specific soil type, etc.)
5. ensure access to sites

Some specific research issues that could already be targeted include:

- representativity of EU sampling grid
- development of supplementary (Level 2) sampling framework
- implications of changing sampling protocol (e.g. 20 > 30 cm)
- incorporation of subsoil parameters to topsoil data (e.g. benchmark soil profiles)
- use of spectral analysis in field and laboratory conditions
- integration of data from proximal/precision agriculture sensing system.

These issues are dealt with in more detail in the following sections in light of the historical evolution of LUCAS SOIL module and proposals for future development.

Background to the LUCAS Soil Module

The Soil Module of the 'Land Use/Cover Area frame statistical Survey' (generally referred to as LUCAS Soil) is the only harmonised and regular collection of soil samples for the entire territory of the European Union (EU), addressing all major land cover types simultaneously. Traditionally, soil surveys in Member States (MS) reflected differences in scope, sampling approaches and analytical procedures.

In most countries, soil mapping and classification was developed from an agricultural perspective by a soil science community coming from the agronomy sector (e.g. France). In other countries, environmental elements (e.g. UK) or geological considerations (e.g. Germany) gave rise to different scientific (and user) perspectives. This resulted in the developments of national nomenclatures for soil type, sampling design and protocols, and laboratory procedures. These differences were further exacerbated by historical reasons in Central European countries who operated under the Soviet system. This made harmonised quantitative assessments of soil condition at EU level difficult due to inherent bias in data from different countries.

While countries such as Belgium, France, Germany and Romania were still active, by the mid-2000s, comprehensive soil mapping and monitoring had stopped in many countries, which meant that policy decisions at EU level were based on outdated information. While the Joint Research Centre (JRC) managed to coordinate the development of harmonised soil database for Europe at a scale of 1:1 million (using the World Reference Base¹ as a high-level correlation system), the structure of the database did not permit the precise geographic representation of soil characteristics. Despite the efforts of the EC, it was not possible to proceed with more detailed integration.

This meant that harmonised geolocated information on soil characteristics at a plot level for the EU was lacking. As an example, an exercise carried by the JRC to collect harmonised data on soil organic carbon and erosion vulnerability through the European Environment Agency's (EEA) EIONET members showed that many Member States², in the absence of direct soil-related policy incentives, were reluctant to share data outside legal

¹ <http://www.fao.org/3/i3794en/i3794en.pdf>

requirements.² In this context, a mechanism was sought to collect data across the EU in a harmonised manner in order to derive assessments of the effects of land management practices on soil.

The following sections outlines the policy needs for soil and describes the initial basis and continued evolution of the LUCAS Soil to address them.

² <https://esdac.jrc.ec.europa.eu/themes/eionet-data-collection-2010>

Policy needs and emerging policy drivers

Regular monitoring provides a unique perspective on pressures affecting soils. In this respect, LUCAS Soil was originally conceived to reflect a specific EC need by collecting data to characterise soil condition and health in relation to land use practices and other activities (e.g. industrial emissions) that are driven by specific (or a lack of) policy instruments. Over time, the LUCAS Soil module has evolved to support further policy needs through a flexibility that permits both the collection of new field data and additional laboratory analysis, that reflects a diverse user base.

1. Initial policy considerations

The initial requirements for the LUCAS Soil module were driven by the needs of the EU Soil Thematic Strategy, which highlighted a series of key threats to soil functions. To address these issues, specific soil data were required to provide a harmonised baseline of soil characteristics and condition. In this respect, the following parameters were considered for specific threats:

- loss of organic matter – requires baselines and changes of organic carbon content (concentration), particle size distribution & coarse fraction (to estimate stocks) for specific land cover types
- erosion – models require soil erodability data, calculated from particle size distribution, coarse fraction and soil organic carbon content
- pollution- measured through, pH (for acidity), presence of nutrient levels (critical loads) and heavy metal content
- salinization - pH, sodium (only from 2018) & electrical conductivity (only from 2015)
- loss of soil biodiversity – assessed through soil pollution and indicators of intensive agriculture (land use data from LUCAS), soil nutrients (N,P,K)
- soil sealing – not directly addressed through LUCAS Soil; main LUCAS recorded land use change to artificial
- landslides – not assessed until 2018 survey

In addition, base saturation and cation exchange capacity were included as indicators of soil fertility and other pedological relationships.

As a consequence of the samples collected during the initial LUCAS Soil survey, the JRC has made the raw data available through the European Soil Data Centre while producing and distributing a series of novel pan-EU datasets^{3,4} describing the physical and chemical characteristics of soil (e.g. particle size, pH & carbonates, organic carbon concentrations, nutrient status, drivers of soil fertility and metal content⁵).

In turn, these data were used to develop more elaborate datasets, assessments and research programmes. These include the modelling of soil erosion vulnerability^{6,7}, to improve assumptions underpinning carbon modelling⁸) and the impacts of land management scenarios (e.g. land use change, rotation practices, residue management, tillage, fertilizer applications and the use of cover crops – disaggregated from a range of Eurostat and FAO databases, including the FSS) on fluxes of soil organic carbon^{9,10} and nitrogen¹¹ from all agricultural LUCAS points.

³ <https://esdac.jrc.ec.europa.eu/content/topsoil-physical-properties-europe-based-lucas-topsoil-data>
⁴ <https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data>
⁵ <https://esdac.jrc.ec.europa.eu/content/copper-distribution-topsoils>
⁶ <https://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015>
⁷ <https://www.sciencedirect.com/science/article/pii/S0264837715003257>
⁸ <https://esdac.jrc.ec.europa.eu/content/soil-organic-matter-som-fractions>
⁹ <https://esdac.jrc.ec.europa.eu/content/soil-ghg-fluxes-using-lucas-soil-daycent>
¹⁰ <https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity>
¹¹ <https://esdac.jrc.ec.europa.eu/content/n2o-emissions-agricultural-soils>

2. Emerging policy drivers

Increasingly, LUCAS Soil is being asked to contribute also to new policy needs. The 2018 survey reflected several new policy angles such as a large-scale assessment of plant protection products in the soils of the EU (with the scope of forming the basis of an indicator to support the CAP and Sustainable Use of Pesticides Directive), the presence of veterinary antibiotics and antibiotic resistant genes, plastic pollution and soil genetics (as a proxy indicator of soil biodiversity and as an indicator of the impact of land management on soil as a biome). Finally, discussions are ongoing on how to utilize LUCAS Soils data to quantify the supply of terrestrial ecosystem services (e.g. nutrient cycling, water quality regulation, drought resilience).

In this context, the LUCAS Soil Module has evolved as an expandable resource that reflects the diverse policy needs of a range of Commission services through the addition of new properties (both by laboratory analysis and field investigations) and sampling locations during successive sampling campaigns. For the 2022 Survey, these could include:

- Support the implementation of Regulation on Monitoring-Reporting-Verification (MRV) of greenhouse gas emissions from land use, land use change and forestry (LULUCF): LUCAS Soil will provide an independent validation dataset of SOC stocks and changes at NUTS2 level for arable topsoils (and depending on budget availability, for managed grasslands at NUTS2/NUTSO) – to achieve this LUCAS will require additional sampling points as described in Section 4 to ensure the required statistical robustness.
- Priorities of the Green Deal I – LUCAS Soil data on soil biodiversity are highly relevant to the Biodiversity Strategy through the provision of novel indicators quantifying both the role of soil as a habitat (i.e. edaphic biodiversity – generally spatial distributions are not well understood) and assess the impact of human activity such as agricultural land management practices (e.g. agrochemicals, tillage), industrial emissions or sewage sludge applications, on soil dwelling communities. These indicators (scheduled for mid 2021) will be based on metagenomic analysis carried out on LUCAS Samples that will provide an overview of the microbial soil communities present. The characteristics of these communities data (richness, abundance, composition) will then be assessed against chemical and physical soil properties (e.g. pH, texture class, N levels, Carbonates, SOC) and measures of human activity (e.g. pollution levels, erosion, compaction, crop types/rotation, etc.) to understand how soil biodiversity is affected by land use and pollution. In addition, the publication of the genetic database from the LUCAS 2018 Survey will be a major resource to Horizon Europe research programmes on soil biodiversity, microbiome and medicine (e.g. antibiotics, antibiotic resistance genes,...).
- Priorities of the Green Deal II – both the Zero Pollution Strategy and the Farm2Fork Strategy highlight the importance of reducing soil pollution to ensure an environmentally friendly and healthy food system. In this respect, LUCAS Soil has already provided a baseline of heavy metals in soil and is currently developing the largest harmonised assessment of plant protection residues (around 100 active ingredients and metabolites in over 3,000 locations – approximately one-third of all LUCAS agricultural points) and selected antibiotics from across the EU. These observed data will be assessed against agricultural practices (e.g. from LUCAS, FSS, IACS, erosion models, etc.). The eventual outcomes will provide a unique perspective on the use (i.e. types, concentrations) and eventually risks, associated with the use of pesticide and veterinary products, by highlighting the key drivers and the validity of risk assessment procedures. In addition, data will be used to validate models of pesticide flows to water bodies and plant uptake scenarios (public health). Data from the 2018 Survey will begin to become available from the autumn of 2020 (full dataset 2022), LUCAS Soil has also the flexibility to investigate other substances of concern such as plastic, POP, PFAS, etc. Other policy areas of relevance are the Sustainable Use of Pesticide Directive, Fertilizer Directive, the Antimicrobial Action Plan and the EU Plastic Strategy.
- Priorities of the Green Deal III – healthy functional soils are at the heart of the Climate Law and the Circular Economy Action Plan. LUCAS can provide independent validation and scenario analysis of soil organic carbon stocks within the carbon removal actions and measure the impact of measures to ensure soil resource efficiency. These could include the application of composts and sludges, safe reuse of manures, efficient use of phosphorous, reuse of extraction materials, loss of fertile soils from land take.
- Common Agricultural Policy (CAP) – LUCAS can provide independent verification of CAP Impact Indicators (at NUTS 2) on soil erosion and soil carbon while contributing to those on biodiversity and pesticide use. 2022 Survey will establish a baseline, with subsequent surveys providing inputs for mid-

term and final review. In parallel, increased integration with national initiatives will allow LUCAS data to support MS reporting obligations set out under National Strategic Plans.

- The National Emission Ceilings (NEC) Directive sets reduction commitments for a set of airborne pollutants, which in turn, can give cause soil acidification and pollution. LUCAS Soil data may help countries to undertake their reporting on metal concentration in soils (i.e. Cd, Pb, Hg and, if available, As, Cr, Cu, Ni, Se and Zn – all available in LUCAS) together with a set of persistent organic pollutants (POPs), including selected polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB).
- LUCAS Soil data have high potential to support the EU's implementation of the UN Sustainable Development Goals. Currently, in the context of EU-SDG and OECD, LUCAS Soil and ICP Forests are the only Europe-wide data sources involving soil sampling and analysis, which are used to populate soil-related indicators (ICP Forests soil data are mostly applied nationally, while LUCAS Soils currently solely populates the Europe-wide indicators on SOC and soil erosion). Depending on the further discussion of soil-related indicators, LUCAS Soil offers potential for various SDGs on zero hunger, health, clean water and sanitation, climate action, life in water and life on land. It can be expected that closer connection with national monitoring and reporting can improve the availability of soil information for these additional SDG targets.

Current design of the LUCAS Soil module

1. How did the soil sampling framework evolve

The drive to collect soil samples under the umbrella of LUCAS was initially led by DG Environment, who provided funding for the 2009 survey. At that time, the main LUCAS survey was planned for 23 EU MS (Bulgaria, Cyprus, Malta and Romania were excluded, while Croatia was not a Member State at the time).

The initial premise for the soil module was to collect a baseline dataset on a range of soil characteristics such as organic matter content, nutrient status, fertility, acidification and soil pollution (metals).

Given budgetary considerations, an approach was developed with the aim to collect samples from 10% of the sites where field visits (i.e. verification) were to be carried out during the main LUCAS Survey. In 2009, this amounted to 235,000 possible locations for 23,500 soil samples.

The initial option for identifying soil-sampling locations was to take samples along a regular grid. Tests were made by systematically selecting a subset of the LUCAS master grid points according to a geometrically even distribution (i.e. every x km). A similar approach had been applied in several national soil monitoring programmes (e.g. Denmark, UK). Grid sampling is a valid approach for surveys as it is unbiased and does not require prior knowledge of the area. It is also simple and relatively quick to implement. However, discussions with geostatisticians highlighted a number of considerations. For example, regular grids may not capture the spatial variability of the target. There appears to be no consensus on how to determine an appropriate grid size, while maps and statistics may be unduly biased by localized irregularities and systematic errors.

As the LUCAS Soil module was meant to acquire soil data to support mapping purposes and at the same time provide the basis for a possible future EU soil monitoring system, a multi-stage stratified random sampling approach (e.g. using soil type, land use and terrain information) was chosen (following McKenzie et al. 2008). This approach had been applied in other established soil monitoring systems (e.g. France, Hungary, Poland)¹².

Land cover type was obtained by aggregating classes from the CORINE LANDCOVER 2000 dataset (CLC2000, 100 m resolution). Six broad land cover classes were distinguished: arable land with annual crops, arable land with permanent crops, grassland, woodland, shrub land and bare. The amalgamated CLC2000 dataset was then used to calculate the area of each land cover type in each MS that participated in the survey. The number of selected points should then be proportional to the percentage of land cover for each country¹³.

A further consideration at the time was, that as a result of the availability of soil data collected during 2006 for forested land as part of the BIOSOIL exercise (BIOSOIL was a demonstration project under ICP Forests). This project was a test for the development of operational soil monitoring at a large scale (Hiederer and Durrant 2010). As a result of the availability of recently acquired soil data from forests, a decision was taken to transfer 1/3 of the initial 'forest' points in the LUCAS 2009 survey to arable and grassland areas (with the view that BIOSOIL data would eventually be integrated with the LUCAS database, a task which is still outstanding, and which is challenged by the difficulty of handling inter-laboratory bias).

A final consideration was that the core set of LUCAS points had been selected for the main survey by Eurostat through a stratified random sampling procedure from the overall 2 km grid. Soil points were then selected from this population.

The set of LUCAS points selected for the 2009 sample were then assigned aggregated land cover values from CLC2000 and randomly selected to create the soil sampling sites.

Given the lack of information regarding accessibility of sites, a decision was taken to define secondary locations (i.e. backup sites should the initial LUCAS soil point not be reachable). In this case, the surveyor had a freedom to choose the point where to collect the soil sample according to their daily route from two alternative locations (the combination of target and backup points were referred to as triplets).

These backup points were selected by defining landscape elements that had common land cover and topographic conditions (the latter included altitude, slope, curvature and aspect parameters derived from 90 m elevation data from the Shuttle Radar Topography Mission). Within these landscape elements, a random selection was applied to select the backup points that matched the attributes of the target.

¹² <http://www.fao.org/3/a-x7585e.pdf>

¹³ Tests were made as the possibility to use soil data as part of the point selection processes. However, the 1:1 million soil database of Europe only provides an indication of the coverage of a particular soil type within a mapping polygon. In this case, there could be no certainty that the LUCAS point would represent that soil type. As a result, soil was removed as a layer for point selection.

During the subsequent field programme, when a sample was taken at any one point in the triplet the remaining pair were discarded. Detailed instructions relating to the exact positioning of the soil sample were also given to surveyors (e.g. to avoid field margins, tracks, etc.).

Restrictions in access (e.g. not possible at any of the triplet points) and weather conditions subsequently reduced the number of actual samples collected to just under 20,000.

A further 2,000 samples were collected for Bulgaria and Romania in 2012, using the same methodology to define sample locations.

For the soil survey of 2015, 26,000 points were initially targeted, slightly less than the 10% targeting. The increase in number compared to the 2009/2012 survey reflected the addition of Malta, Cyprus and Croatia, the need to include sites above 1000 m in elevation and a 3% increase in overall points in all MS. All points visited during the 2009 and 2012 surveys were revisited while the additional sites were selected by the procedure used in 2009. No triplets were used in the 2015 (or 2018) survey. In addition, the JRC arranged the bilateral collection of samples from five Western Balkan countries¹⁴.

Agroscope, the Swiss Institute for Sustainability Sciences also took part in the 2015 survey to assess the precision of the soil sampling protocol used by LUCAS compared to that used in the Swiss National survey. Two sets of samples were collected using a spade and an auger, then both sets were analysed by the main LUCAS laboratory in Hungary). The outcomes, described in Fernandez-Ugalde et al. 2019, showed that for the single depth 0-20 cm, the spade and gouge auger methods produced similar results for all properties (Lin's concordance correlation coefficient ≥ 0.73), with a better relation for arable land than other land cover classes and concluded that – as long as only one depth class is sampled – the LUCAS Sampling Protocol was an accurate method for topsoil sampling at the continental scale.

The sampling locations used in the 2018 survey were to all intents the same as 2015¹⁵. In 2018, the Austrian Agency for Health and Food Safety (AGES) received a duplicate sample to carry out laboratory analysis on parameters not measured under LUCAS SOIL (e.g. available nutrients, additional cations, different analytical methodologies – results are due mid-2020).

84% and 74% of the target points were accessible for sampling in 2015 and 2018, respectively.

In summary:

- 2009: 23 MS were sampled (Romania and Bulgaria were excluded, as were Cyprus and Malta although informally, the JRC collected samples from the latter pair),
- 2012: only Bulgaria and Romania were sampled (the JRC also received samples from Iceland),
- 2015: all EU MS were sampled. Switzerland contributed voluntarily while the JRC supported the collection of samples from Western Balkan Candidate Countries)
- 2018: all EU Member States were sampled.

2. What has been measured?

The current evolution of LUCAS Soil has led to sub-modules, which are continuously under refinement based on a) stakeholder needs (EU COM, statistics, reporting, impact assessment), b) involvement of countries, and c) research needs (which partially helps to improve the monitoring, and address stakeholder needs, e.g. through modelling). These are summarised in Table 1.

Table 1: Breakdown of LUCAS Soil measurements and policy context.

Sub-module	Sampling & analysis	Measurement parameters	Indicator	Context
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¹⁴ Albania, Bosnia and Herzegovina, Montenegro, North Macedonia and Serbia,

¹⁵ <https://onlinelibrary.wiley.com/doi/full/10.1111/ejss.12862>

Soil chemistry				
Soil carbon	routine	C _{org} concentration N _{total} (C-N dynamics) Bulk density Stones Depth of litter layer Depth of peat	SOC stock change (SOC sequestration potential)	7 th and 8 th EAP UNCCD LDN EU-SDG OECD CAP impact LULUCF MRV GSP/ESP Research
Soil nutrients	routine	Micro-nutrients (see also heavy metals) Macro-nutrients	Need to be defined	CAP Research Farm2Fork
Soil Pollution	a) routine	Heavy metals	Need to be defined	Zero pollution strategy
	b) exploratory	Organic (persistent) pollutants Plastics Antibiotics	Need to be defined	Research
Soil biology				
Soil biology	exploratory	Functional genes (DNA)	Need to be defined	MAES 7 th and 8 th EAP Research
Soil physics				
<i>Basic physical parameters</i>	<i>routine</i>	<i>Particle size (texture class)</i> <i>Bulk density</i> <i>Stone content</i> <i>Electric conductivity</i>		<i>(no repetition foreseen)</i>
Erosion	exploratory	Modelling using SOC, texture class Observed features	Loss of soil from rill erosion	7 th and 8 th EAP UNCCD LDN
Compaction	exploratory	Bulk density	Need to be defined	UNCCD LDN Feedback to soil biodiversity

Each module has its own characteristics:

- maturity in sampling and analysis (routine operation, pilot phase to explore feasibility, demonstration and exploration)
- temporal scale: return intervals
- spatial scale: point density and point selection
- statistics: trend detection, error, subsamples and rolling inventory

Each parameter and module requires an evaluation scheme: thresholds.

In order to harmonize the development and reporting of indicators, all of these methodical aspects related to inventory design and detectability of trend, require constant development, updating, and dialogue with experts and countries.

In the future additional details on the site condition (e.g. soil type, humus type, peat type, parent material, relief, ground water (depth and quality), and land use) will be added.

The initial surveys (2009/2012 and 2015) targeted physical and chemical properties, such as particle size distribution (texture), pH, organic carbon concentrations, nutrient concentrations (N, P, K, S), metal content (only 2009/2012), salinity (only 2015 onwards) and cation exchange capacity. In addition, visible and near-infrared spectra data were collected on both the 2009/2012¹⁶ and 2015 samples (see Castaldi et al 2018 for application of LUCAS Soil spectral data for airborne imaging spectrometry assessment of soil carbon levels).

In the 2018 survey, bulk density, specific measurements for organic-rich soil and soil erosion assessments were carried out in the field while the core laboratory analysis was expanded to measure metal content, genetic composition (DNA), residues of plant protection products and antibiotics, and the presence of antimicrobial resistance genes.

To reduce unknown systematic errors and inter-laboratory bias between countries, a decision was taken to only use a single laboratory for all soil analysis for the LUCAS 2009 samples. A similar approach was also adopted by the German Agricultural Soil Inventory for the same reasons (Bach et al, 2011).

3. Sampling depth

Mineral topsoils

Initially, LUCAS SOIL advised surveyors to collect a composite sample from a 'spade depth' – around 20 cm. Primarily, this instruction aimed to capture soil characteristics for the most reactive part of the soil to management activities. It should be noted that in some cases (e.g. pesticide residues), even 20 cm is considered too deep as the focus is needed only on the uppermost 5 cm!

A pilot exercise was carried out in Portugal in 2018 (at the invitation of PT) to increase the sampling depth to 30 cm in mineral soils¹⁷. There is minimal impact on the time required the standard sample (other than to check that the required depth had been reached). However, to accommodate the additional time required to take the additional bulk density sample (i.e. 20-30 cm), the number of replicate samples was reduced from five to three.

Organic topsoils

For organic soils in wetlands (including wetlands under forest, grassland and shrubs), the default depth of 20 cm can present problems. The organic horizon in these soils can be significantly deeper than 20 cm, and any natural or anthropogenic disturbance (e.g. drainage) can cause variations in organic carbon content on the overall organic horizon in a very short-term. Fenner & Freeman (2011) observed that wetland soils already lose OC after few months of a drought period. Bader et al. (2018) found that, on average, managed organic topsoils could lose 5-10 % of their OC in one year. Ideally, the depth of peat is sampled. Due to the large amounts of degraded peat, and the specific samplings requirements (e.g. bulk density of organic soils, some countries (e.g. Finland, Ireland) have devoted a great deal of research and development into sapling protocols for peatland. These need to be analysed and evaluated for LUCAS Soil in order to minimize the systematic errors under the current sampling.

¹⁶

¹⁷ Soil with organic carbon content below 12%. Traditionally, soils with organic carbon content of 12-20% are referred to as organic rich, while above 20% as organic soils (also referred to as peat).

As a first step to improve the quality of the sampling of wet organic soils, in the 2018 Survey, all samples deemed to be organic soils from the previous two surveys, together with all LUCAS Wetlands sites (Land cover class H), were assessed to see whether they satisfied the criteria for Histosol soil type (i.e. peat) that requires the presence of a histic horizon (e.g. have at least 12% organic carbon or 20% organic matter if the mineral fraction has no clay)

- Of 10 cm thickness or more from the soil surface to a bedrock contact, or
- Of 40 cm thickness or more from the soil surface.

4. Field Sampling protocol

A key goal of the LUCAS SOIL approach is the standardised collection of soil samples. The initial LUCAS Soil field sampling protocol was adapted from standard FAO Guideline for Soil Profile Description and the 2006 BIOSOIL sampling manual. Guidelines for sample collection were amended slightly to provide further clarification in subsequent surveys based on the feedback from surveyors.

Samples of around 0.5-1.0 kg are collected from designated locations by a process of composite sampling that represent the area characterised by the LUCAS point. In addition to the sample at the LUCAS point, four additional samples are taken at each site, two meters distant from the central point in the shape of a cross, preferably along cardinal compass points. The five samples are mixed together to create a composite sample that is representative for the heterogeneous local site conditions. A subsample of it is taken for laboratory analysis.

Surveyors were asked to remove vegetation residues and litter from the surface and to collect only the mineral topsoil (a mineral topsoil may still contain fine roots, their parts and brownish homogeneous organic materials).

Proposals for the 2022 LUCAS Soil module

1. Technical considerations for the 2022 LUCAS survey

The following sections presents a response to the main issues raised by Commission services during the various thematic and stakeholder workshops held during 2019.

In essence, they address:

- Issues of statistical representativity (with a focus on monitoring soil organic carbon stock), possibly with a greater focus on managed lands
- Changes to the sampling depth, to reflect IPCC requirements
- Changes to the sample collection protocol
- Proposals for laboratory analysis, to include pollutants and emerging substances of concern
- Coordination with MS activities and roadmap towards an integrated EU Soil Monitoring System and collaboration with Member States

In addition, there are consideration in the future from DG SANTE for pesticide residue data in soil to support indicator development.

2. Optimum sampling framework

The current design of the LUCAS SOIL module is, in simple terms, a stratified random selection of points selected for LUCAS 2009 field visits. This has been increased over time to reflect the increasing geographical focus of the survey. As a result of discussions within the ISSG laboratory, the JRC has undertaken the following analysis to ascertain the necessary sample population to assess soil organic carbon stocks for a range of reporting units, at defined levels of confidence.

LANDMARK evaluation

As part of the LANDMARK H2020 Project¹⁸, the JRC collaborated with researchers from the University of Wageningen to determine the number of sites required for a representative soil monitoring system for the EU to assess soil functions (i.e. biomass production, carbon sequestration, nutrient cycling, water quality and quantity regulation, provision of habitat).

For this exercise, the following covariate layers were used:

- Bioclimatic regions of Europe, as defined by Metzger et al. (2005).
- Land-cover, as defined by CORINE land-cover map, with the same broad classes as identified for the development of 2009 LUCAS Soil
- Soil Diagnostic Map of Europe (paper under peer review), created in the LANDMARK project utilising the 1:1 million European Soil Database (Panagos et al., 2016).

The Soil Diagnostic Map of Europe was based on the physical and chemical characteristics of Soil Typological Units (STU), which represent a number of soil types within a landscape element known as a Soil Mapping Unit (SMU). STUs are not visualised but reflect areal percentage of an SMU. For each STU, a pedological diagnostic feature was defined according to the definitions and rules of the World Reference Base for Soils (WRB, 2014). Analysis of the results highlighted major limitations in the approach. Specifically, the following intermediate conclusions were apparent:

- *the scale of the 1:1 million pan-European soil dataset was too restrictive to predict diagnostic criteria of sites at field level. This constraint had been identified in the original sampling design in LUCAS 2009.*
- *As a result, soil characteristics were not considered as a covariate for the representativity exercise and the reporting areas were defined as combinations of land use classes and climatic zones at national levels.*

To assess the possible sample designs for LUCAS 2022, the Wageningen team used a pure nugget model-based approach to predict the variance of the estimated mean of various reporting units within a simple random

¹⁸ <http://landmark2020.eu/>

sampling survey (i.e. assuming that the data are independent). On this basis, the sample variances are model-unbiased estimates of population variances (spatial variances) within reporting units. These variances can then be used to compute the required sample sizes for simple random sampling given a requirement on the precision of the estimated populations mean of reporting units. Given the broad policy interest, a specific assessment was made of the sample numbers required to be representative of soil organic carbon for Member State in any given Climate Zone x Land-cover reporting unit with a probability of 90%, while the error should not be larger than 10% of the mean. A further consideration was that all reporting units should contain at least 20 sampling locations.

The results of this analysis (90% probability/10% error), in terms of optimised sampling design for climatic zones and land cover reporting units for soil carbon, are summarised below. We could regard these totals as the optimum sample size for LUCAS Soil:

- Cropland: 38,731 (LUCAS 2018 = 10,140 – an under sampling of 28,591)
- Grassland: 6,385 (LUCAS 2018 = 5,460 – an under sampling of 925)
- Woodland: 9,163 (LUCAS 2018 = 8,320 – an under sampling of 843)
- Others: 2,509

Total: 56,788

The conclusions of the LANDMARK study shows that at a NUTSO level, the current LUCAS Soil sampling design for soil organic carbon is under representative of croplands but broadly in line for the numbers required for grasslands and woodland

JRC evaluation of fix grid approach

Independently of the LANDMARK study, the JRC assessed the merits of adopting **a regular grid for agricultural soils** (as defined by CORINE 2018 LC), following the approach adopted by the German Agricultural Soil Survey. The application of an 8 km x 8 km grid for the entire EU resulted in just over 31,000 points falling on agricultural land. This corresponds to around 17,000 points for arable land, 1,800 points for permanent crops, 6,000 points for pastures and a further 6,000 points for heterogeneous agriculture (land parcels with in which annual and permanent crops or crops and other vegetation types are mixed).

As a comparison, we calculated around 3,300 points for Germany, which is comparable in number to their exercise. Differences probably reflect changes in agricultural areas between 2010 (when the German stratification was done) and 2018 CORINE dataset.

Given the primary scope of the LUCAS Survey is to generate data aggregations at MS or Regional level, an exercise was carried out to determine the optimum sample size for all land cover types in MS and at NUTS 2 level (i.e. no consideration of climate zones or farm types) which could function as a minimum expanded baseline for 2022. The Raosoft calculator¹⁹ was used to determine the recommended sample size for a given level of precision (i.e. confidence level and margin of error).

Table 2. The number of samples for various representative scenarios²⁰

Class	NUTSO	Targeted NUTSO	NUTS2 x Cropland	Standard Survey	Repeat only points
Cropland	10,200	12,800	26,000	10,200	8,280
Grassland	5,400	6,000	6000	5,460	3,780
Woodland	8,100	8,100	8,100	8,320	4,860
Wetland	2,100	2,100	1,000	1,000	540

¹⁹ <http://www.raosoft.com/samplesize.html>

²⁰ Level of precision: MS (crop, grass, wood): confidence 90%, margin error 5%
NUTS 2 (only crop): confidence 90%, margin error 10%

Shrubland	2,100	500		1,020	270
Bareland	2,100	500		0	270
Total	30,000	30,000	32,000 / 41,000	26,000	18,000

In summary, the results (rounded for simplicity) suggest that approximately 30,000 samples would be statistically representative for soil organic carbon assessments of the main target land cover classes at NUTS0 level (an increase of 4,000 points over the 'standard' survey planning) while 26,000 points in cropland alone would be needed to be representative at NUTS2 level.

In the former calculation (for NUTS0), this would involve an increase of around 1,000 points each for shrub lands, wetlands and bare areas, which are currently underrepresented.

Alternatively, the soil component could focus only on cropland, grassland, woodland and wetlands, in which case the number of points for these classes would be increased to reflect broader policy interests but at the expense of other categories (shrubs and bare).

In conclusion:

- statistical representativity at NUTS0 for cropland, grassland and woodland can be achieved with relatively little additional effort and cost (i.e. 30,000 locations) if we take the 2018 survey as a baseline (which was planned to collect 26,000 points);
- Increased focus on agricultural land can be achieved with the same number of points but at the expense of other land cover types;
- The survey could target exclusively cropland (representative at NUTS2) and grassland (representative at NUTS0) with around 32,000 points – rising to 41,000 to include woodland and wetlands.

Regarding the geographic **distribution of points**, we can make the following observations:

- **Maintain the repeated core points from the past three surveys** (c. 18,000 points).
- **Reallocate the remainder** of the eventual total on the basis of stratified random allocations to land cover classes that are under represented on the basis of latest statistical data (e.g. FSS 2016).
- In the event that access to a specific location is not possible, a **set of backup sampling sites will be generated to ensure sample size** and representativity.
- **Sample all MS** to ensure consistency of results between all countries.

As a possible consideration, the JRC has developed a spatial dataset of estimated soil carbon sequestration capacity for Europe²¹, based on the integration of LUCAS 2009 points and Century biogeochemical modelling. This capacity, expressed as the ratio between the actual SOC stock and the potential (equilibrium) SOC stock could be considered as a factor in the selection of new points.

3. Representativity of the current LUCAS sampling to assess the effects of management practices on soil quality under CAP

An exercise was carried out by the JRC (Units D3 and D5) to assess the degree to which CAP payments influence management practices. To facilitate this test, the geographic coordinates of the centroids of parcels (i.e. agricultural plots) that have received payments since 2010 were made available from the Land Parcel Identification System.

²¹ <https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity>

It should be stressed that a) not all countries reported payment locations for all years, and b) digital boundaries of plots are being assembled since 2019 and are not currently available for this exercise.

The distance between 2015 LUCAS points and each centroid for each year was calculated and a section made for cropland and grassland points that are within 200 m of a LPIS centroid (see table). The assumption is that given typical European field sizes, a LUCAS point within 200 m of a LPIS centroid was likely to be located within the same plot).

We can postulate that 79% of all LUCAS SOIL croplands points from 2015 are affected by the CAP, while 77% of grassland site are affected. It should be noted that the situation varies from country to country, and by year to year. This would indicate that the **current sample size is highly representative of soils that are managed under the CAP**, but there is scope for greater representativity through the allocation of additional points.

Table 3. Cropland LUCAS SOIL Points under CAP

NUTS_0	total_points	points_2010	points_2011	points_2012	points_2013	points_2014	points_2015	points_2016	points_2017	points_2018
AT	117	NA	NA	116	116	116	90	85	94	94
BE	88	50	68	54	68	70	70	65	66	67
BG	221	3	83	89	81	90	92	90	90	94
CY	34	NA	NA	33	33	33	34	34	34	34
CZ	218	1	3	4	1	145	145	144	143	148
DE	821	101	646	644	634	635	655	611	613	614
DK	163	114	116	108	111	104	112	117	125	120
EE	49	30	30	32	32	32	32	32	32	33
EL	281	258	260	256	256	244	244	242	244	240
ES	1908	134	1751	1791	1764	1771	1786	1790	1793	1793
FI	170	166	165	165	164	164	164	163	163	163
FR	1575	76	NA	71	1302	1295	1297	1300	1294	1294
HR	12	NA	NA	9	10	9	11	11	11	11
HU	261	NA	77	77	77	80	84	88	91	90
IE	14	NA	10	8	10	8	9	12	12	12
IT	791	26	749	741	744	725	713	760	770	743
LT	173	47	50	132	125	118	104	88	84	82
LU	5	5	5	5	5	5	5	5	5	5
LV	80	NA	33	29	28	31	28	30	43	50
MT	2	2	2	2	2	2	2	2	2	2
NL	84	59	61	60	56	57	56	57	56	54
PL	680	NA	610	603	608	601	611	612	613	610
PT	109	95	93	89	82	81	82	84	83	86
RO	442	16	172	22	172	177	194	195	176	177
SE	145	5	116	117	118	112	119	126	123	123
SI	12	2	12	12	12	11	11	11	11	11
SK	96	30	23	23	23	26	24	25	23	24
UK	270	18	69	233	232	235	238	233	228	230
	8821	1238	5204	5525	6866	6977	7012	7012	7022	7004

Table 4. Grassland LUCAS SOIL Points under CAP

NUTS_0	total_points	points_2010	points_2011	points_2012	points_2013	points_2014	points_2015	points_2016	points_2017	points_2018
AT	166	NA	NA	148	148	148	133	129	128	149
BE	25	12	18	14	18	19	20	18	18	18
BG	118	NA	49	51	51	59	56	64	63	65
CY	14	NA	NA	12	12	12	14	13	13	11
CZ	109	NA	1	2	2	83	85	84	83	85
DE	403	47	349	345	345	340	344	345	346	345
DK	28	21	22	22	21	19	21	22	23	23
EE	38	22	23	24	27	27	28	28	28	27
EL	119	84	103	93	93	90	90	83	89	87
ES	605	27	481	507	498	500	522	523	522	523
FI	51	42	38	38	37	37	37	36	36	36
FR	785	33	NA	45	650	646	649	647	643	644
HR	27	NA	NA	19	19	18	20	19	19	19
HU	74	NA	20	18	24	24	27	30	28	28
IE	147	NA	123	126	124	118	126	130	134	134
IT	362	5	317	311	312	302	301	321	327	298
LT	93	24	37	79	75	58	53	55	53	50
LU	3	3	3	3	3	3	3	3	3	3
LV	102	NA	62	52	56	56	59	65	62	64
NL	58	45	46	48	44	47	47	49	49	48
PL	323	NA	285	278	282	284	285	283	289	290
PT	96	80	72	66	58	57	57	61	58	58
RO	437	19	182	21	193	206	234	232	210	209
SE	109	4	76	74	77	72	76	75	75	77
SI	33	NA	31	31	31	31	31	31	31	31
SK	47	27	31	31	20	22	20	22	20	23
UK	348	82	148	277	281	282	292	283	286	296
	4720	577	2517	2735	3501	3560	3630	3651	3636	3641

This link between LUCAS Soil and LPIS now offers the possibility to understand land use changes in the years between LUCAS Surveys. This research can help to:

- Derive spatially explicit land use data from IACS for LUCAS soil points (or groups of points)
- To develop methodologies to spatially evaluate LUCAS Soil and ancillary data, to provide soil data to farmers

This information will be used to supplement LUCAS microdata, currently under development.

For these reasons, discussion has taken place with DG AGRI on possibilities of a soil health pilot under the IACS data sharing initiative (to include LPIS and GSAA). This pilot will aim to identify the feature types in IACS that could contain information on land management practices that are not collected under LUCAS (e.g. crop rotation, pesticide application). This will be developed further during 2020.

It is worth reflecting that croplands account for around 28% of the EU land area or 66% of UAA.

4. Field sampling protocol – depth

Soil profiles

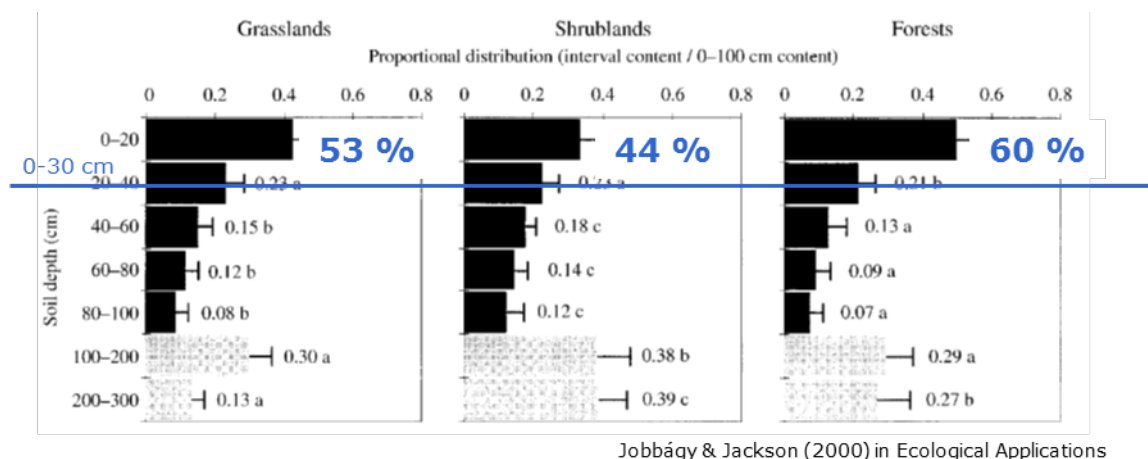
Where existing, national soil monitoring programmes investigate deeper soil horizons (e.g. Germany, 0-10, 10-30, 30-50, 50-70 & 70-100 cm). The reasons is that some change in the topsoil may be simple re-allocation down the soil profile, rather than loss into the groundwater, or uptake by plants and soil animals, or lateral translocation processes (sedimentation). There are different ways to investigate deeper soil layers, such as machine or manual augers, or soil pits. Such sampling requires experts to carry out site preparation, excavation and the collection of sub-samples, thus there is an impact on capacity and time. In the case of the German survey²², the fieldwork for 2,631 final locations lasted seven years. Additionally, the total number of samples analysed is approximately 120,000 compared to around 30,000 for LUCAS.

For this reason, we would propose not to excavate soil profiles under the umbrella of LUCAS but instead invite the EJP Soils to develop a research programme on how to assign subsoil properties to LUCAS Topsoil data.

²² https://www.thuenen.de/media/institute/ak/Allgemein/news/Thuenen_Report_64_final.pdf

Extended topsoil sampling

As explained previously, the current LUCAS sampling protocol collects a sample from a depth of 20 cm. The IPCC guidelines recommend using a default 0-30 cm depth for national greenhouse gas inventories (Eggleston et al., 2006). This is because most of the SOC dynamics related to land use change occur in soil zone most densely rooted, i.e. the top 30 cm (Conant et al., 2001; Luo et al., 2010). Related to the total SOC stock down to one metre, Jobbágy & Jackson (2000) estimated that OC in the top 30 cm contain 53 % to 60% of the total amount, in cropland and woodland, respectively. Balesdent et al. (2018) found that the subsoil (30-100 cm) accounted for around 19% of the OC that has been incorporated to the soil in the past 50 years.



Based on this scientific evidence and experiences presented above, together with surveyor feedback on the pilot exercise carried out in Portugal in 2018 (at the invitation of PT), we **propose to increase the sampling depth in the 2022 soil survey to 30 cm**²³.

It is proposed that the majority of samples would be collected as a single sample to a depth of 30cm. For the 4,000 bulk density samples), which would act as a control set, two samples would be collected, corresponding to 0-20 cm depth and 20-30 cm, to allow comparison with data collected from previous surveys. Further design options can be scientifically developed and tested at national level through the EJP SOIL,

5. Field sampling protocol – collection of sample

Sampling quality – systematic errors

Analysis of changes between the 2009 and 2015 datasets by the JRC show that the LUCAS sampling protocol is working well in mineral soils under cropland, grassland and most woodlands (JRC 2020a, b). However, the high level of variance in samples collected from organic and organic-rich woodlands, particularly in Scandinavia, suggests that there are some inconsistencies in how the sampling protocol is being applied. It is believed that in some cases the organic soil horizon (which should be included) is being removed completely and the sample being taken from the underlying mineral material (causing systematic bias, which cannot be treated in the statistics unless documented at each point).

To this extent, we **propose to refine the sampling protocol and surveyor training for woodlands** and saturated organic soils to ensure that there is a consistent approach to sampling in these environments. Correspondence will be sought with the ICP Forest manual on methods on how to sample the litter layer, and increasing the depth of organic soils to 40 cm.

Seasonality of sampling

Together with Eurostat, the JRC will investigate whether the collection of soil samples can be scheduled for spring and autumn, thus avoiding full crop development and in the Mediterranean region, hard, dry soils during

²³ Soil with organic carbon content below 12%. Traditionally, soils with organic carbon content of 12-20% are referred to as organic rich, while above 20% as organic soils (also referred to as peat).

the summer months. It is interesting to note that the FAO suggest that a soil sampling campaign should take no longer than 60 days within the same season.

We propose that the 2022 field component should assess the presence of gully erosion in all points.

6. Laboratory Analysis

Some inherent soil parameters (such as particle size distribution, cation exchange capacity, base saturation), are vital for subsequent analysis and modelling but in principle, do not change over the course of a few years. In practice, these parameters will only be measured for new soil points.

For the 2022 survey, the following options are proposed (dependant on budget availability):

Revisited points:

- **Subset of core analysis**
 - Organic Carbon & total nitrogen
 - P, K, S and pH, only in cropland and managed grassland (possibility to also consider Ca, Na, Mg, Na, Mg, H)
 - Electrical conductivity (EC) only in regions with salinity problems (predominantly southern EU MS, but also regions with irrigation, where likely saline aquifers are concerned, as well as coastal agricultural plots)
 - Particle size and coarse fragments for 600 points (quality control with previous surveys on 3% of sample)
- **Bulk density**
 - 2000 new points to complete the 9000 points planned in 2018
 - Repeat measurements in soils where 2018 data suggest compaction problems (BD > 1.6 g/cm³)
- **Biodiversity and genetic assessments** (for the same 1,000 points of LUCAS 2018)
 - Repeat DNA analyses for biodiversity index
 - Identification of key genes for a functional assessment of biodiversity (e.g. ecosystem services, such as nitrogen cycle, decomposition, etc.)
 - Presence of antibiotics resistance genes
- **Soil pollution module²⁴** (budgetary restrictions allowing, at least same 3,000 locations from 2018, to understand better temporal change dynamics)
 - Metals
 - Antibiotics (more substances?)
 - PPP²⁵ (more samples?)
 - Plastic (to be decided following ongoing pilots)
 - Industrial chemicals (e.g. POPs, PFAS, PAHs, dioxins and furans, PCBs,...?)

New points

- Standard core analysis (to be compatible with past surveys)
- 2000 locations will be selected for bulk density (in cultivated or grassland soils.)

²⁴ Dependent on policy priorities and budget availability

²⁵ i.e. the c. 90 active ingredients sampled in 2018

- 1,000 additional points will be selected for biodiversity - attention to locations with high pressures on biodiversity (reflecting agricultural intensity, low OC, compaction, erosion, contamination) to understand better temporal change dynamics.
- Subset for pollution (as above) – PPP and metals in all new points

Table 5. The policy relevance and proposed indicators for LUCAS laboratory analysis.

Policy Area	Indicator	Existing LUCAS until 2018	New LUCAS 2022
AGRI	Soil nutrient status Soil fertility	N, P, K, CEC, BS, pH, OC, CO ₃	Ca, Na, Mg,
	Erosion (water, wind, harvest)	Particle size distribution, Coarse fragments, OC	
	Compaction	OC, Bulk density, Clay content	Texture, Bulk Density
AGRI/CLIMA	Soil organic C content Soil organic C stocks	OC, CaCO ₃ , Bulk Density, Particle size distribution	More points in cropland and grassland
	C-Sequestration Pot	OC, Particle size distribution	
	N-Cycle, C:N ratio	N, OC, Particle size distribution	
	Salinity/Sodicity	EC	Na
Biodiversity	Species richness/diversity	DNA/metagenomics	Rna, meso and macrofauna analysis?, microbial respiration?
	Pressures	N, P, K, metals, pH, salts	
	Peatlands	OC, depth,	Classification
Ecosystem Service	Biomass, Climate Regulation, Nutrient Cycling, Habitat, Water Regulation	OC, particle sis	Models/pedo-transfer functions
Soil sealing			Loss of point
Zero Pollution	Acidity Critical loads exceedance	pH, S, N,	H ⁺
	Metal	12 elements	Measure new points and above national thresholds

	Pesticides	90 active ingredients and metabolites, Cu & S	Increase sample size
	Industrial/Organics		POPs, PFAS, PAHs, dioxins, furans, PCBs
	Veterinary	2 antibiotics	More compounds
Contaminated sites	Metals and industrial pollutants	Not assessed	Need reallocation of points
Land degradation		All data	

Outlook: soil analysis with spectrometers

The JRC is aware that new spectral methods for measuring SOC concentration and stocks are increasingly becoming available for field assessments. Market assessments show a range of costs for instrumentation with varying accuracies, mostly due to hardware constraints or moisture and surface roughness of the soil. We propose that **EJP-SOIL demonstrate operational robustness of using spectral systems** to determine accurately soil properties and compatibility with ISO standards – with possible adoption for future (e.g. 2026) LUCAS Survey.

Future surveys after 2022

Determining **sampling frequency** is an important element of soil monitoring programme. It is well recognised that some soil parameters, such as nutrients applied as fertilizers (and pollutants via composts and sludges), can respond relatively rapidly (i.e. in a few years) to changes in drivers, while others, such as SOC stock changes are generally much slower and also reflect inherent variation in their measurement. As an indication, the '4 per 1000' initiative²⁶ targets an increase of 0.4% per year in organic carbon stocks of agricultural topsoil, which would amount to 4% change over a decade. This is comparable to the findings of Post et al (1991) who noted that rates of change in temperate climates are typically less than 0.5 Mg C ha⁻¹ year, compared to stock levels around 100 Mg C ha⁻¹. The Commission's Mapping and Assessment of Ecosystems and their Services (MAES) has set a threshold of 5% change over a 10 year period to be statistically significant.

Specifically for soil organic carbon, the analysis of changes between the LUCAS 2009 and 2015 survey seem to confirm that the use of short intervals (e.g. every LUCAS Survey) for detecting the relatively low levels of changes in soil properties at the same location is challenging and that changes can only be reliably measured over a period of years or even decades (Post et al 1991). In fact, there is high level of interest in the 2018 results as these will provide almost a 10 year interval to assess changes in soil organic carbon stocks, which is in line with the recommendations by Smith et al (2019), for decadal field investigations to support MRV requirements.

However, there are positive effects of more frequent sampling, for example, the assessment of systematic error, and the reliability and consistency of trends and thus precision of results. However, for such intermediate surveys, a smaller sampling density may be sufficient. In this respect, the 2009 and 2015 sample could be regarded as a more precise baseline against which 2022 levels can be assessed.

In addition, the repeated nature of LUCAS allows us to explore other soil parameters beyond the core set selected in 2009. In this respect, one could foresee a proposal where soil organic carbon is only measured at the same location every two or three surveys (depending on the eventual interval). Intermediate surveys could focus on other issues (e.g. pollution, biodiversity, etc.) and soil organic carbon samples from other locations.

Also the different EU policies required different reference years, and this has influenced the frequency of the sampling in the past.

However, by the time of the 2026 (or subsequent) LUCAS Survey, one could envisage that the outcomes of discussions for the integration with MS programmes (as outlined in Section 7 of this document) will have borne fruit and the mechanisms for data integration between LUCAS and national activities will be in place. In this sense, one could foresee the development of a **paired-survey concept** whereby the 'standard' LUCAS survey (at date n, n+2, n+4, ...), is complemented the intermediate surveys (i.e. n+1, n+3, n+5, ...).

The second survey would undertake a full analysis of an alternative set of points from the previous survey, which are selected in consultation with MS. These points could also be considered as 'Tier 2 sites' that would provide more detailed representativity for key parameters such as soil organic carbon (in respect to administrative area or specific land use categories). The intermediate survey would also contain a subset of core points from the previous survey that would focus on soil biodiversity, peatlands and pollution issues. Due to technical limitations imposed as a result of teleworking, no attempts have been made to quantify the number of samples at this point in time. However, this will be addressed the Soil Monitoring Task Force.

In conclusion, the following proposals are made:

2022 (N): Given the number of policy baselines associated with the next LUCAS Survey (CAP/Farm2Fork, LULUCF, Zero Pollution, Biodiversity, etc.), a full soil module should be considered. This would involve the extended core analysis and erosion on all points (according to reporting unit) plus biodiversity and pollutants (to be defined) on subset.

N+1 (e.g. 2026): Extended core analysis on Tier 2 locations not sampled in 2022 (to be defined in conjunction with MS) plus pollutants, biodiversity and peatlands on subset of 2022 sites.

N+2: All 2022 sites - soil organic carbon, biodiversity and pollutants

N+3: Soil carbon from 2026 sites, extra focus on pollutants, biodiversity and peatlands.

N + 4: Focus on soil carbon (2030 sites - all land cover types, alternatively only on agricultural land)

²⁶ <https://www.4p1000.org/>

NB. Core analysis will be performed on all new points in any survey

NB. Soil erosion questions to be retained on field form for all surveys

Table 6.. Proposal for post-2022 Soil Module

	2022 (N)	N+1	N+2	N+3	N+4
<i>Extended core analysis on enlarged core population – particle size only on new points</i>					
<i>Extended analysis on Tier 2 sites selected with MS</i>					
<i>Limited bulk density</i>					
<i>Biodiversity / Genetics subset</i>					
<i>Organic pollutants (inc. PFA)</i>					
<i>Plastics</i>					
<i>Metal pollution</i>					
<i>Peatlands</i>					
<i>Erosion</i>					

A final consideration is that the JRC is increasingly looking at possibilities offered by remote sensing to integrate and complement the point measurements framework of LUCAS (e.g. estimation of soil carbon through remote sensing based techniques could be a cost effective approach). One aspect is the increasing applications of machine-learning tools to spatial predictions LUCAS data are used to train soil carbon predictions associated with primary productivity data from COPERNICUS). In this respect, the availability of multiple soil datasets, linked to land usage and primary productivity indicators, are showing high potential in soil carbon predictions. JRC is already developing a prototype machine-learning based EU-scale soil carbon model in collaboration with Colorado State University and INRA. A further promising area is to build on the results of the work carried out by JRC.D5 on the use of LUCAS data to train AI routines to classify Sentinel-1 data to generate information on crop types for LUCAS points in the interval between surveys.

That said, it should be noted that a combination of remote and in situ or point data will still be necessary to derive high resolution and accurate SOC maps, with known uncertainties. Earth observation systems are also problematic for deriving soil properties. These include:

- reliance on proxies of reflected energy (no actual measurements of soil characteristics),
- limited penetration depth - first micrometer for visible/NIR sensing systems, potentially a few centimetres for microwave data)
- visibility of bare soil –difficult due to increasing use of reduced tillage, cover crops or crop residue being left on the ground

In this respect, it should be noted that LUCAS Soil data are viewed as key in situ reference data by the European Space Agency's World Soils current call for proposals to develop a global Earth Observation-Soil Monitoring System (EO-SMS).

Annex 2: List of ESDAC datasets

— Soil Point Data	page 43
<ul style="list-style-type: none">• LUCAS 2015 TOPSOIL data• LUCAS 2009 TOPSOIL data• LUCAS 2015 Topsoil data of Switzerland• Soil profile analytical database 14 (SPADE 14)• Soil Profile Analytical Database 2• SPADE/M	
— Soil Properties & European Soil Database	page 49
<ul style="list-style-type: none">• European Soil Database European Soil Database v2.0 (vector and attribute data)• European Soil Database v2 Raster Library 1kmx1km• SINFO: ESDB Data adapted for the MARS Crop Yield Forecasting System• European Soil Database Derived data• Topsoil physical properties for Europe (based on LUCAS topsoil data)• Maps of Soil Chemical properties at European scale based on LUCAS 2009/2012 topsoil data• WRB Data for the Soil Atlas of the Northern Circumpolar Region• Soil Atlas of Africa and its associated Soil Map (data)	
— Soil threats datasets	page 62

Soil Erosion

- Soil Loss by Water Erosion in Europe
- Net erosion and sediment transport using WaTEM/SEDEM (for EU)
- Soil Erodibility (K- Factor) High Resolution dataset for Europe
- Rainfall Erosivity in the EU and Switzerland (R-factor)
- Cover Management factor (C-factor) for the EU
- Support Practices factor (P-factor) for the EU
- LS-factor (Slope Length and Steepness factor) for the EU
- Global Soil Erosion
- Global Rainfall Erosivity
- Global soil erosion by water in 2070
- Global phosphorus losses due to soil erosion
- Pan European Soil Erosion Risk Assessment - PESERA
- Soil Erosion Risk Assessment in Europe data (MESALES model)
- Soil erosion by wind
- Soil erosion in forestland in Europe (using RUSLE2015)

- Soil loss due to crop harvesting in the European Union
- G2 soil erosion model data

Soil Organic Carbon

- Topsoil Soil Organic Carbon (LUCAS) for EU25
- Pan-European SOC stock of agricultural soils
- Carbon budget in the EU agricultural soils
- Soil Organic Matter (SOM) fractions for 186 LUCAS 2009 soil samples (grassland, forest)
- OCTOP: Topsoil Organic Carbon Content for Europe
- Global Soil Organic Carbon Estimates

Soil Biodiversity

- Potential threats to soil biodiversity in Europe
- Global Soil Biodiversity Atlas Maps
- Biodiversity factor in soil erosion

Landslides

- European Landslide Susceptibility Map version 2 (ELSUSv2)

Salinization

- Saline and Sodic Soils in European Union

Compaction

- Natural susceptibility to soil compaction in Europe


Soil Pollution/contamination

- Copper distribution in topsoils in the European Union
- Maps of heavy metals in the soils of the EU, based on LUCAS 2009 HM data
- Caesium-137 and Plutonium-239+240 in European topsoils

- Soil Organic Carbon - Saturation Capacity in Europe
- Maps of indicators of soil hydraulic properties for Europe
- Maps of the Storing and Filtering Capacity of Soils in Europe
- Maps of preservation capacity of cultural artefacts and buried materials in soils in the EU
- European map of soil suitability to provide a platform for most human activities (EU28)
- Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)
- Soil GHG fluxes using LUCAS soil-DayCent (for EU)
- N2O emissions from agricultural soils in Europe

1 LUCAS 2015 TOPSOIL data

Short Description

	<p>Data from the 2015 LUCAS campaign soil component containing soil properties data (clay, silt and sand content, coarse fragments, pH (CaCl₂ and H₂O), organic carbon content, CaCO₃, nitrogen, phosphorous, potassium, EC (Electrical conductivity) and multispectral reflectance data for 21,859 samples. These primary data are supplemented by reference ancillary data describing a range of environmental conditions for the LUCAS Soil locations.</p>
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Detailed Description

This package contains the LUCAS Topsoil data of the 2015 LUCAS soil survey. It contains a CSV and Excel file with soil data, and an ESRI shapefile that shows the LUCAS Master Grid sampling points and an associated attribute table that holds the soil data. LUCAS Soil provides harmonised data for the entire territory of the European Union (EU), addressing all major land cover types simultaneously, in a single sampling period (April – October 2015), using a standard sampling protocol and a single laboratory for analysis. Data are presented for 21,859 locations across all EU Member States and cover 90% of the locations where soil samples were taken in 2009 and 2012 (only Romania and Bulgaria). The remaining 10% were substituted by new locations in each country, new territories, and points above 1,000 m elevation. In addition to the parameters analysed in 2009 and 2012, electrical conductivity has been added to measure salt content in soils.

Metadata

- Coverage: European Union (EU-27) plus UK. Data from Switzerland are also available. Data from Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia will be available soon.
- Resolution: Point data. 21,859 data points. 4,246 are at new locations when compared with the 2009/2012.
- Format: CSV files; To facilitate use of the data, .XLS and ESRI shapefile formats are also available;
- Date released: 2015

Data Access


<https://esdac.jrc.ec.europa.eu/content/lucas2015-topsoil-data>

References:

- Jones, A, Fernandez-Ugalde, O., Scarpa, S. LUCAS 2015 Topsoil Survey. Presentation of dataset and results, EUR 30332 EN, Publications Office of the European Union: Luxembourg. 2020, ISBN 978-92-76-21080-1, doi:10.2760/616084
- Fernández-Ugalde, O., Ballabio, C., Lugato, E., Scarpa, S., Jones, A., Assessment of changes in topsoil properties in LUCAS samples between 2009/2012 and 2015 surveys, EUR 30147 EN, Publications Office of the European Union: Luxembourg 2020, ISBN 978-92-76-17430-1, doi:10.2760/5503, JRC120138.

2 LUCAS 2009 TOPSOIL data

Short Description

	<p>Data from the 2009 LUCAS campaign soil component containing soil properties data (clay, silt and sand content, coarse fragments, pH, organic carbon content, CaCO₃, nitrogen, phosphorous, potassium, cation exchange capacity) and multispectral absorbance data.</p>
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Detailed Description

Through this page you will be able to download the LUCAS_TOPSOIL data (soil properties data; multispectral reflectance data).

There are three download files.

- **LUCAS_TOPSOIL_v1**: an Excel file that contains the geographical coordinates of the location where the data were sampled and for each location the values for a number of properties.
- **LUCAS_Romania_Bulgaria_2012.zip**: 2 Excel files containing data for Romania and Bulgaria, from the LUCAS 2012 campaign; (27/09/2019, important note: the values for nitrogen N are in mg/100g)
- **LUCAS_TOPSOIL_v1_spectral** consists of a file that contains the multispectral absorbance data (formats available: RDATA and .csv)

Metadata

- Coverage: EU-27 (Croatia non included)
- Resolution: 22,000 location points
- Format: Excel (+Spectra)
- Date released: 2009

Data Access

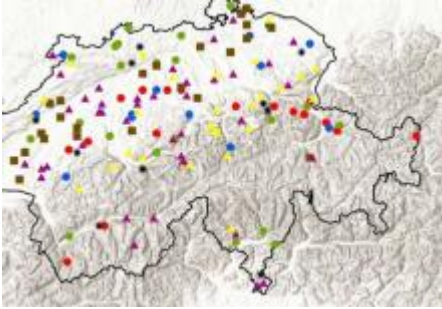
<https://esdac.jrc.ec.europa.eu/content/lucas-2009-topsoil-data>

References:

- Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A., Fernández-Ugalde, O. 2018. [LUCAS Soil, the largest expandable soil dataset for Europe: A review](#). *European Journal of Soil Science*, 69(1): 140-153, DOI: 10.1111/ejss.12499
- Tóth, G., Jones, A., Montanarella, L. (eds.) 2013. [LUCAS Topsoil Survey. Methodology, data and results](#). JRC Technical Reports. Luxembourg. Publications Office of the European Union, EUR26102 – Scientific and Technical Research series – ISSN 1831-9424 (online); ISBN 978-92-79-32542-7; doi: 10.2788/97922
- Toth G., Jones A., Montanarella L. (2013) [The LUCAS topsoil database and derived information on the regional variability of cropland topsoil properties in the European Union](#). *Environmental Monitoring and Assessment*, 185 (9), pp. 7409-7425.

3 LUCAS 2015 Topsoil data of Switzerland

Short Description:

	<p>The dataset contains the data of physical and chemical properties analysed in samples taken in Switzerland within the context of LUCAS 2015 survey. These data have been used in the study “Comparison of sampling with a spade and gouge auger for topsoil monitoring at the continental scale”. The dataset format is an Excel file.</p>
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Detailed Description

The dataset contains the data of physical and chemical properties analysed in samples taken in Switzerland within the context of LUCAS 2015 survey. These data have been used in the study “Comparison of sampling with a spade and gouge auger for topsoil monitoring at the continental scale”, published in the European Journal of Soil Science: <https://onlinelibrary.wiley.com/doi/abs/10.1111/ejss.12862>. The LUCAS 2015 survey had 150 sampling locations distributed in arable, grassland, and woodland land cover classes in mineral soils in Switzerland. At each sampling location, topsoil samples (0–20 cm) were taken with the LUCAS spade and the gouge auger sampling methods. Altogether, 300 samples were taken at the 150 locations: 150 samples with spade and 150 with gouge auger. The samples were analysed for clay, silt and sand contents, organic carbon, nitrogen, potassium, phosphorus, calcium carbonate, pH and electrical conductivity.

The dataset has two sets of data. The first set (columns C to N in the Excel file) contains the data of physical and chemical properties analysed in samples taken with the LUCAS spade method. The second set (columns O to Z in the Excel file) contains the data of the physical and chemical properties in samples taken with the gouge auger method. Every sample is identified with its Soil ID. The first two columns of the dataset are common to the two sets of data and contain the sampling location and its land cover class.

Metadata

Coverage: Switzerland

Resolution: 150 location points

Format: Excel

Date released: 2015

Data Access


<https://esdac.jrc.ec.europa.eu/content/lucas-2015-topsoil-data-switzerland>

References:

Fernández-Ugalde, O., Jones, A. and Meuli, R.G., 2020. Comparison of sampling with a spade and gouge auger for topsoil monitoring at the continental scale. *European Journal of Soil Science*, 71(2), pp.137–150.

4 Soil Profile Analytical Database 2

Short Description

	Soil Profile Analytical Database for Europe (2009) (separate from the European Soil Database SPADE-1) aiming to provide sufficient soil property data to support higher tier modeling of pesticide fate at the European level. Joint venture between JRC, ECPA and the ESNB.
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Detailed Description

The original Soil Profile Analytical Database included in the European Soil Database (ESDB), known as SPADE-1 database, has limitations when applying models in a Pan-European context. SPADE-2 was developed to derive appropriate characterisation of soil profile data for Soil Typological Units (STUs) in the Soil Geographical Database of the ESDB (Hollis et al., 2006). SPADE 2 aims to provide sufficient soil property data to support higher tier modeling of pesticide fate at the European level.

Data supplied by each country were based on the national data archives and, for some parameters, particularly particle-size distribution, the analytical techniques used varied slightly from country to country. The raw data supplied by national data providers has thus been harmonised and validated to provide a single data file (SPADE_2.dbf) that can be easily used in conjunction with the SGDBE.

Harmonisation of particle-size data was carried out using a monotonic cubic spline interpolation procedure. Validation analyses have been carried out to ensure that any problems related to the harmonisation procedure were identified and corrected and that the range and population distributions of all parameters were consistent with expected patterns and ranges. Unusual outliers within parameter data sets were identified and, if necessary, corrected. As a result of the limitations of the SPADE-1 profile data for use in modelling at the European level, the European Crop Protection Association (ECPA), supported by the European Soil Bureau of the European Commission Joint Research Centre have sponsored the collation of a second profile database (SPADE-2) for use with the SGDBE. The overall objective was to provide sufficient soil property data to support higher tier modelling of pesticide fate at the European level.

Data Access


<https://esdac.jrc.ec.europa.eu/content/soil-profile-analytical-database-2>

References:

- [SPADE-2: Soil Profile Analytical Database for Europe Version 2.0 Beta Version](#) March 2009, Jacqueline A. Hannam, John M. Hollis, Robert J.A. Jones, Pat H. Bellamy, Sue E. Hayes, Ann Holden, Marc H. Van Liedekerke and Luca Montanarella.
- [SPADE-2: The Soil Profile Analytical Database for Europe \(version 1.0\)](#), John M. Hollis, Robert J.A. Jones, Charles J. Marshall, Ann Holden, Jan Renger van de Veen and Luca Montanarella (2006). EUR 22127 EN .

5 SPADE/M (Measured soil profiles)

Short Description

	Database (2004) developed from the measured profiles; present in the Soil Profile Analytical Database of Europe of the European Soil Database v2. It counts 560 profiles within the EU.
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Detailed Description

The Soil Profile Analytical Database of Europe of Measured parameters (SPADE/M) is part of the distribution package of the Soil Geographic Database of Eurasia (SGDBE). It was created to provide a common structure for storing standardized information on typical soil profile properties of major European soils. The criterion applied to include a profile in the database was to adequately cover the range of European soils rather than to sample profiles for a statistical representation of soil properties at European scale. The typical combinations of profile parameters and morphological characteristics of the sample site were intended to support the definition of generalized rules for estimating pedological and hydrological properties of the pedo-transfer rule (PTR) database of the SGDBE. Compared to the spatial database the information on measured profiles has received relatively little attention.

Metadata

Time Reference: 2004

Format: 64 Data Profiles could be recovered in form of hard-copies. All recovered former profile data were for plots located in England and Wales. As a result the number of PLOT data has been increased from 496 to 560 and the number of Horizons from 2366 to 265.

Data Access


<https://esdac.jrc.ec.europa.eu/content/spadem>

References:

Hiederer, R., R.J.A. Jones and J. Daroussin (2006). Soil Profile Analytical Database for Europe (SPADE): Reconstruction and Validation of the Measured Data (SPADE/M). *Geografisk Tidsskrift, Danish Journal of Geography* 106(1). p. 71-85.

6 Soil profile analytical database 14 (SPADE 14)

Short Description

	Soil Profile Analytical Database 14 (SPADE 14) is based on the concept used in previous versions of SPADE (SPADE 1 and 8). It includes 1078 soil profile data from 28 countries.
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Detailed Description

The existing Soil Profile Analytical Database (SPADE), a component of the Eurasian Soil Database (ESDB), has been updated to include estimated analytical data for the dominant soil units (STUs) of the 1:1.000.000 Soil Geographical database of Europe (i.e. not including Belarus, Russia and the Ukraine). This task was contracted out by the Joint Research Centre to the University of Copenhagen, Denmark (Prof. Henrik Breuning-Madsen, Prof. Thomas Balstrøm and M.Sc. Jeppe Aagaard Kristensen), in cooperation with stakeholders of various countries.

The results of this contract (a report and the corresponding data) are made available here. The data are presented as delivered by the contractors and do not carry any official status. Questions about the report and the data should be addressed to Mr. Arwyn Jones (arwyn.jones@ec.europa.eu).

Among other attributes, the SPADE14 includes the following parameters: Depth, Horizon names, Bulk density, Carbon-to-Nitrogen ratio, Total carbonate, Gypsum, Cation exchange capacity, Electric conductivity, Exchangeable calcium, potassium, magnesium and sodium, Exchangeable sodium percentage, Texture, Organic matter content, pH, Porosity, Structure, Water retention.

Metadata

Title: SPADE14

Description: 1078 soil profile data from 28 countries. 571 Soil profiles originate from SPADE8, 349 soil profiles from other countries and 158 profiles are new.

Resolution: not applicable; the data are tabular and linked to Soil Typological Units of the ESDB

Time Reference: 2014

Format: Excel tables organized per country. Estimated Profile and Horizon data (with attributes) linked to STUs from the SGDBE

Data Access


<https://esdac.jrc.ec.europa.eu/content/spade-14>

References:

Kristensen, J.A., Balstrøm, T., Jones, R.J., Jones, A., Montanarella, L., Panagos, P. and Breuning-Madsen, H., 2019. Development of a harmonised soil profile analytical database for Europe: a resource for supporting regional soil management. *Soil*, 5(2), pp.289-301.

7 European Soil Database European Soil Database v2.0 (vector and attribute data)

Short Description

	<p>This database is the only harmonized soil database for Europe, extending also to Eurasia. It contains a soil geographical database SGDBE (polygons) to which a number of essential soil attributes are attached, and an associate database PTRDB, with attributes which values have been derived through pedotransfer rules. Also part of the database is the Soil Profile Analytical Database, that contains measured and estimated soil profiles for Europe.</p>
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Detailed Description

The Soil Geographical Database of Eurasia at scale 1:1,000,000 is part of the European Soil Information System (EUSIS). It is the resulting product of a collaborative project involving all the European Union and neighbouring countries. It is a simplified representation of the diversity and spatial variability of the soil coverage. The methodology used to differentiate and name the main soil types is based on the terminology of the F.A.O. legend for the Soil Map of the World at scale 1:5,000,000. This terminology has been refined and adapted to take account of the specificities of the landscapes in Europa. It is itself founded on the distinction of the main pedogenetic processes leading to soil differentiation: brunification, lessivage, podzolisation, hydromorphy, etc.

The database contains a list of Soil Typological Units (STU). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example the texture, the water regime, the stoniness, etc. The geographical representation was chosen at a scale corresponding to the 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMU) to form soil associations and to illustrate the functioning of pedological systems within the landscapes. Each SMU corresponds to a part of the mapped territory and as such is represented by one or more polygons in a geometrical dataset.

Main attributes include: Soil texture, soil classification, Parent material, dominant land use, WRB classification, etc

In the dataset, users can find:

- the Soil Geographical Database of Eurasia at scale 1:1,000,000 (SGDBE)
- the Pedotransfer Rules Database (PTRDB)
- the Soil Profile Analytical Database of Europa (SPADBE)
- the Database of Hydraulic Properties of European Soils (HYPRES)

Metadata

Coverage: Eurasia

Resolution: 1: 1,000,000

Format: Shape files

Date released: 2001

Data Access


<https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data>

References:

Panagos P., Van Liedekerke M., Jones A., Montanarella L., 2012. [European Soil Data Centre: Response to European policy support and public data requirements](#). Land Use Policy, 29 (2), 329-338.

8 European Soil Database v2 Raster Library 1kmx1km

Short Description

	<p>This database (2006) is a set of raster data sets that have been derived from the European soil Database v2, for most attributes. The values for the attributes are categorized (non-continuous). These rasters are an interpretation of the data that are contained in the ESDB v2.0</p>
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Detailed Description

This library contains raster (or grid) data files (in native ESRI GRID format) for most attributes (73 in total) of the SGDBE and PTRDB databases, which are components of the ESDB v2.0; cell sizes are 1km x 1km and the grid is aligned with the reference grid recommended during the 1st Workshop on European Reference Grids in the context of the INSPIRE (Infrastructure for Spatial Information in Europe) initiative. The grids are in the ETRS89 Lambert Azimuthal Equal Area (ETRS_LAEA) co-ordinate system, also documented in the workshop proceedings.

The grid origin is defined 4.321.000,0 m west of the projection centre point (52N, 10 E), and 3.210.000,0 m south of projection centre point (52N 10 E). The grid extent is such that it covers all EU25 countries. Width: 7.500.000,0 m ; Height : 5.500.00,0 m ; 7500 columns, 5500 rows.

Raster values have been derived using the "features to raster" tool in the Spatial Analyst extension of ArcGIS, the feature layer being a shapefile created from the SGDBE geometrical database to which attributes from SGDBE and PTRDB have been linked according to the "dominant value" principle for the "dominant value" rasters and the "dominant STU" principle for the "dominant STU" rasters (see here for an introduction of soil map visualization).

The 1km x 1km raster attributes correspond to the attributes represented in the maps of the European Soil Data Base Map Archive (published on Soil Portal) as "a collection of maps which represent all attributes which are present in the in the Soil Geographical Database of Eurasia at scale 1:1,000,000 (version 4 beta) and the PedoTransfer Rules Data Base(version 2.0). Type of Document: PDF, Format: A3",.

Main attributes include: Soil texture, soil classification, Parent material, dominant land use, WRB classification, etc

Metadata

Coverage: Eurasia

Resolution: 1km x 1 km

Format: Raster files

Date released: 2001

Data Access


<https://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km>

References:

Panagos P., Van Liedekerke M., Jones A., Montanarella L., 2012. [European Soil Data Centre: Response to European policy support and public data requirements](#). Land Use Policy, 29 (2), 329-338.

9 SINFO: ESDB Data adapted for the MARS Crop Yield Forecasting System

Short Description

	A database (2007) that is the result of adapting the European Soil Database for the provision of new and specific soil information for the CGMS (Crop Growth Monitoring System) for use in the MARS Crop Yield Forecast Sing System
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Detailed Description

The objective of the SINFO project is to describe the existing system and to propose a new method evolution for the MARS Crop Yield Forecast Sing System (MCYFS). The work consisting in:

- Rewriting the Pedo Transfer Rules (PTR) according to the new nomenclature;
- Redefinition of new Soil Physical Groups and their parameters;
- Redefinition of new Rooting Depth classes;
- Re-evaluation of CGMS Suitability Criteria;
- New evaluation of Soil Suitability Criteria;
- Generation of soil parameters with FAO (Food and Agriculture Organisation) soil map.

The soil data are used to determine soil input variables to the agrometeorological model giving information about the soil types geographical location and the soil properties which are needed to simulate the crop growth during the year. The main soil properties are soil depth aiming at defining the potential rooting depth, and water retention properties giving through soil physical groups. Each STU has one soil physical group defining the available water capacity (AWC). The AWC is a static soil characteristic and gives the amount of water between field capacity (wet soil) and wilting point (no water available for plants anymore) per unit length rooting depth. Multiplication of AWC and rooting depth gives the maximum available water which a soil can supply to a plant.

It should be noted that the rain fed crop yields of the CGMS are more sensitive to the rooting depth than to the soil physical group (van der Goot, 1998). The CGMS stores these data in the tables ROOTING_DEPTH and SOIL_PHYSICAL_GROUP. Further, the soil map is used as a 'land use probability map' to define which crops have to be included in the simulation for a given soil unit. Ideally, this decision would be taken on the basis of actual land-use information, but a European wide detailed classification of land cover is not available. Hence within the CGMS the decision is simply based on the soil suitability of the different crops: if at least part of the soil mapping unit (one or more STU's) is deemed appropriate then the simulation will be performed. The result of this strategy is that the yield figures produced by the CGMS are assessed for suitable soils only.

Suitable soils are determined per crop group on the basis of crop growth limiting properties of these soils. The limiting soil properties are for instance slope, texture, agriculture limiting phase, rooting depth, drainage, salinity and alkalinity. The slope, texture and phase data can be obtained directly from the soil database, while others like rooting depth, drainage conditions, salinity and alkalinity have to be derived from basic soil properties using pedotransfer rules.

The suitable STUs and the percentage of the suitable area of SMUs and NUTS regions are available in the tables SUITABILITY, SMU_SUITABILITY and NUTS_SUITABILITY. Because a SMU and a NUTS region can consist of more than one STU the percentage suitable area must be calculatedc

Metadata

Coverage: Eurasia

Resolution: 1km x 1 km

Format:

Date released: 2007

Data Access

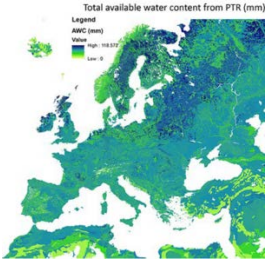
<https://esdac.jrc.ec.europa.eu/content/sinfo-esdb-data-adapted-mars-crop-yield-forecasting-system>

References:

European Commission, 2006. New soil information for the MARS Crop Yield Forecasting System. Luxembourg: Office for Official Publications of the European Communities. ISBN 92-79-03376-X, ISSN 1018-5593, 22499 EN

10 European Soil Database Derived data

Short Description

	his dataset includes Additional Spatial layers derived from the European Soil Database
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Detailed Description

A number of layers for soil properties have been created based on data from the European Soil Database in combination with data from the Harmonized World Soil Database (HWSD) and Soil-Terrain Database (SOTER). The available layers include: Total available water content, Depth available to roots, Clay content, Silt content, Sand content, Organic carbon, Bulk Density, Coarse fragments. The layers of soil properties of Soil Typological Units (STUs) are only intended to facilitate modelling purposes. The final result of the modelling activity should be aggregated to SMUs or another larger mapping unit. The derived data have mainly the following features (compared to the past - European Soil Database):

- Represent a soil property from all STUs pertaining to an SMU in a single raster layer was made by mapping the STUs to geographic positions
- The attribute data are in part based on the STU table of the ESDB and other data sources : Harmonized World Soil Database (HWSD), Soil and Terrain Database (SOTER)
- The range of parameters is broadened by using Pedo-Transfer Rules (PTRs) to derive estimates of additional parameter

Metadata

Coverage: Eurasia

Resolution: 1km x 1 km

Format: Idrisi raster format

Date released: 2013

Data Access

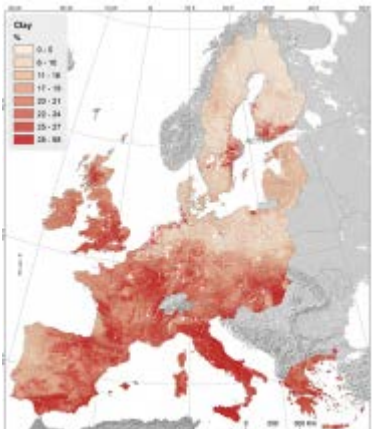
<https://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data>

References:

- Hiederer, R. 2013. [Mapping Soil Properties for Europe - Spatial Representation of Soil Database Attributes](#). Luxembourg: Publications Office of the European Union – 2013 – 47pp. – EUR26082EN Scientific and Technical Research series, ISSN 1831-9424, doi:10.2788/94128
- Hiederer, R. 2013. [Mapping Soil Typologies - Spatial Decision Support Applied to European Soil Database](#). Luxembourg: Publications Office of the European Union – 2013 – 147pp. – EUR25932EN Scientific and Technical Research series, ISSN 1831-9424, doi:10.2788/87286

11 Topsoil physical properties for Europe (based on LUCAS topsoil data)

Short Description

	<p>This dataset (GIS maps)(2016) contains 7 soil property maps that have been derived using soil point data from the LUCAS 2009 soil survey (around 20,000 points) for EU-25, using hybrid approaches like regression kriging. Properties:</p> <ul style="list-style-type: none"> • clay, silt sand content; • coarse fragments; • bulk density; • USDA soil textural class; • available water capacity. <p>Resolution 500m</p>
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Detailed Description

Data are available for the following **Physical properties**:

- Clay content (%) in topsoil (0-20cm) modelled by Multivariate Additive Regression Splines
- Silt content (%) in topsoil modelled by Multivariate Additive Regression Splines
- Sand content (%) in topsoil modelled by Multivariate Additive Regression Splines
- Coarse fragments (%) content in topsoil modelled by Multivariate Additive Regression Splines
- Bulk density derived from soil texture datasets (obtained from the packing density and themapped clay content following the equation of Jones et al. 2003)
- USDA soil textural classes derived from clay, silt and sand maps
- Available Water Capacity (AWC) for the topsoil fine earth fraction

These data are based on the LUCAS topsoil data for ca 20,000 samples across EU.

The Land Use and Cover Area frame Statistical survey (LUCAS) aimed at the collecting harmonised data about the state of land use/cover over the extent of European Union (EU). Among these 2 · 10⁵ land use/cover observations selected for validation, a topsoil survey was conducted at about 10% of these sites. Topsoil sampling locations were selected as to be representative of European landscape using a Latin hypercube stratified random sampling, taking into account CORINE land cover 2000, the Shuttle Radar Topography Mission (SRTM) DEM and its derived slope, aspect and curvature.

The LUCAS topsoil database was used to map soil properties at continental scale over the geographical extent of Europe. Several soil properties were predicted using hybrid approaches like regression kriging. For those datasets, we predicted topsoil texture and related derived physical properties. Regression models were fitted using, along other variables, remotely sensed data coming from the MODIS sensor. The high temporal resolution of MODIS allowed detecting changes in the vegetative response due to soil properties, which can then be used to map soil features distribution. We will also discuss the prediction of intrinsically collinear variables like soil texture which required the use of models capable of dealing with multivariate constrained dependent variables like Multivariate Adaptive Regression Splines (MARS). Cross validation of the fitted models proved that the LUCAS dataset constitutes a good sample for mapping purposes leading to cross-validation R² between 0.47 and 0.50 for soil texture and normalized errors between 4 and 10%.

Metadata

Coverage: European Union

Resolution: 500m

Input data: LUCAS 2009 Topsoil 20,000 sample point data

Model: Multivariate Additive Regression Splines (MARS)

Data Access

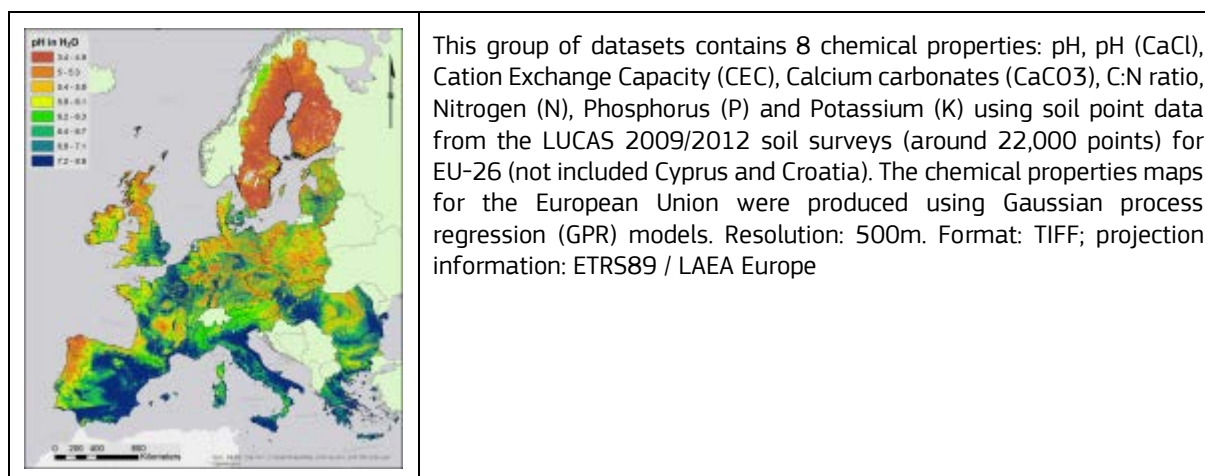
<https://esdac.jrc.ec.europa.eu/content/topsoil-physical-properties-europe-based-lucas-topsoil-data>

References:

Ballabio C., Panagos P., Montanarella L. 2016. [Mapping topsoil physical properties at European scale using the LUCAS database](#) Geoderma, 261, pp. 110-123

12 Maps of Soil Chemical properties at European scale based on LUCAS 2009/2012 topsoil data

Short Description



Detailed Description:

Data are available for the following **Chemical properties**:

- pH (measured in H₂O)
- pH (n CaCl₂ 0.01 M solution)
- Cation Exchange Capacity (CEC)
- Calcium carbonates (CaCO₃)
- C:N ratio
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

The Physical property maps (clay, silt and salt content; coarse fragments; bulk density; USDA soil textural class; available water capacity) are available in ESDAC from September 2015. In September 2019, we concluded the development of the LUCAS Chemical parameters [pH, pH CaCl, Cation Exchange Capacity (CEC), Calcium carbonates (CaCO₃), C:N ratio, Nitrogen (N), Phosphorus (P) and Potassium (K)] and we made them available for download together with the scientific publications.

With 22,000 sampled locations the LUCAS soil database is unique in Europe for the number of available observations, its spatial coverage and its temporal resolution. While LUCAS point data are available upon request from the European Soil Data Centre (ESDAC), the interpolated maps of chemical properties offer a better overview of the distribution of soil chemical properties in the EU to the scientific community and to policy makers. The derived maps will establish baselines that will help monitor soil quality and provide guidance to agro-environmental research and policy developments in the European Union. The chemical properties datasets, together with the physical properties, contribute to one of the main objectives of the GlobalSoilMap project.

The modelling is based on Gaussian Process Regression technique that allows the estimation of prediction uncertainty. The best performing prediction was obtained for the C:N ratio (R²=0.91), followed by phosphorus and potassium (R²=0.75). The performance prediction of the rest of chemical properties in terms of R² is higher than 0.60 with the exception of CEC (R²= 0.35).

Topsoil pH is influenced by soil parent material, erosional effects, climate and vegetation. The calcium carbonate content is highly correlated with pH, having similar influencing factors. Soil nitrogen distribution is dependent on soil organic carbon, vegetation and climate and soil texture. The land use appears to be the main driver for phosphorus content in soils, as agricultural areas have higher concentrations due to fertilizer application. CEC is influenced by the clay distribution in soils, topography and parent material.

Metadata

Resolution: 500m; **Format:** geo TIFF; **projection information:** ETRS89 / LAEA Europe

Geographical Coverage: European Union (EU-26 excluding Cyprus and Croatia)

Input data: LUCAS 2009 Topsoil 22,000 sample point data

Model: Gaussian process regression (GPR)

Data Access

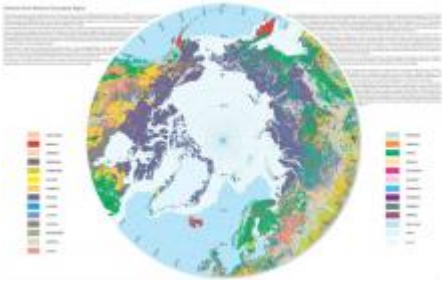
<https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data>

References:

Ballabio, C., Lugato, E., Fernández-Ugalde, O., Orgiazzi, A., Jones, A., Borrelli, P., Montanarella, L. and Panagos, P., 2019. [Mapping LUCAS topsoil chemical properties at European scale using Gaussian process regression](#). *Geoderma*, **355**: 113912

13 WRB Data for the Soil Atlas of the Northern Circumpolar Region

Short Description

	<p>This dataset includes maps from the Northern Circumpolar Region.</p> <p>Content: https://esdac.jrc.ec.europa.eu/content/soil-atlas-northern-circumpolar-region</p>
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Detailed Description

The 144 pages atlas is the result of a three-year collaborative project with partners from northern EU countries, as well as Norway, Iceland, Greenland, Canada, the USA and Russia and gives a detailed overview of circumpolar soil resources relevant also to agriculture, forest management, water management, land use planning, infrastructure and housing and energy transport networks. In a clear style, the atlas describes the origin and major characteristics of the different soil types that can be found in this environment. The atlas is a visually stunning publication using striking maps, informative texts and dramatic photographs to explain and illustrate the great diversity of soils in northern landscapes.

Metadata

Coverage: Northern Circumpolar Region.

Resolution: 1km x 1 km

Date released: 2008

Data Access

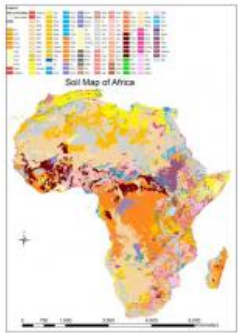
<https://esdac.jrc.ec.europa.eu/content/wrb-data-soil-atlas-northern-circumpolar-region>

References:

Jones, A., V. Stolbovoy, C. Tarnocai, G. Broll, O. Spaargaren and L. Montanarella (eds.), 2009, Soil Atlas of the Northern Circumpolar Region. European Commission, Office for Official Publications of the European Communities, Luxembourg. 142 pp.

14 Soil Atlas of Africa and its associated Soil Map (data)

Short Description

	<p>This GIS map (2013), present in the Soil Atlas of Africa, contains the dominant WRB Reference Soil Group and associated qualifiers (shapefile).</p>
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Detailed Description

At the African Union and European Union Commission College meeting in Addis Abeba, Ethiopia (April 25-26, 2013) the Atlas was introduced by EU Commissioner Hedegaard (Climate Action) on behalf of the European Commission President José Manuel Barroso. The WRB classification data are available.

Metadata

Coverage: Africa.

Resolution: 1km x 1 km

Date released: 2013

Data Access

<https://esdac.jrc.ec.europa.eu/content/soil-map-soil-atlas-africa>

References:

Dewitte, O., Jones, A., Spaargaren, O., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Thiombiano, L., Van Ranst, E., Yemefack, M., Zougmore, R., 2013. [Harmonisation of the soil map of Africa at the continental scale](#). Geoderma, 211-212, 138-153

15 Soil Loss by Water Erosion in Europe

Short Description

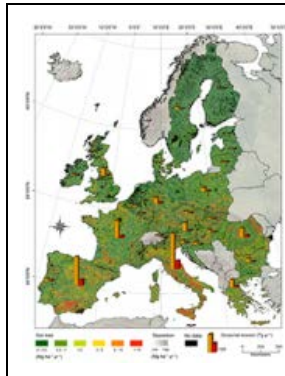


References:

- Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, .C. 2015. [The new assessment of soil loss by water erosion in Europe](#). *Environmental Science & Policy*. **54**: 438-447.
- Panagos, P., Borrelli, P., Robinson, D.A. [Common Agricultural Policy: Tackling soil loss across Europe](#). *Nature* **526**,
- Panagos, P., Imeson, A., Meusburger, K., Borrelli, P., Poesen, J., Alewell, C. 2016. [Soil Conservation in Europe: Wish or Reality?](#) *Land Degradation and Development*, **27 (6)**: 1547-1551

16 Net erosion and sediment transport using WaTEM/SEDEM (for EU)

Short Description



Dataset (GIS map) (218) that shows the net soil erosion and deposition in European Union as a result of an application WaTEM/SEDEM model; resolution 100m; EU28. Data are also available at 25m resolution.

Detailed Description

The estimated sediment yield totals 0.164 ± 0.013 Pg yr⁻¹ (which corresponds to 4.62 ± 0.37 Mg ha⁻¹ yr⁻¹ in the erosion area). The greatest amount of gross on-site erosion as well as soil loss to rivers occurs in the agricultural land (93.5%). The Sediment Delivery Ratio (SDR) i.e., the ratio between sediment yield (SY) and gross erosion, indicates that the sediment routed down the hillslopes to the riverine system accounts for 15.3% of the total eroded soil.

Metadata

Title: Sediment transport using WaTEM/SEDEM

Description: JRC in collaboration with University of Basel and Universite Cathilique de Louvain quantify the potential spatial displacement and transport of soil sediments due to water erosion at European scale. We computed long-term averages of annual soil loss and deposition rates by means of the extensively tested spatially distributed WaTEM/SEDEM model. Our findings indicate that soil loss from Europe in the riverine systems is about 15% of the estimated gross on-site erosion.

Spatial Coverage: European Union 28 Member States

Resolution: 100m - Available also at 25m per country

Time Reference: 2010

Format: Raster (Grid)

Projection: ETRS89 Lambert Azimuthal Equal Area

Input data: RUSLE2015 soil erosion estimates, Digital Elevation Model (DEM) at 25m.

More Information: [Sediment transport using WaTEM/SEDEM](#)

Release Date: 15/2/2018

Data Access

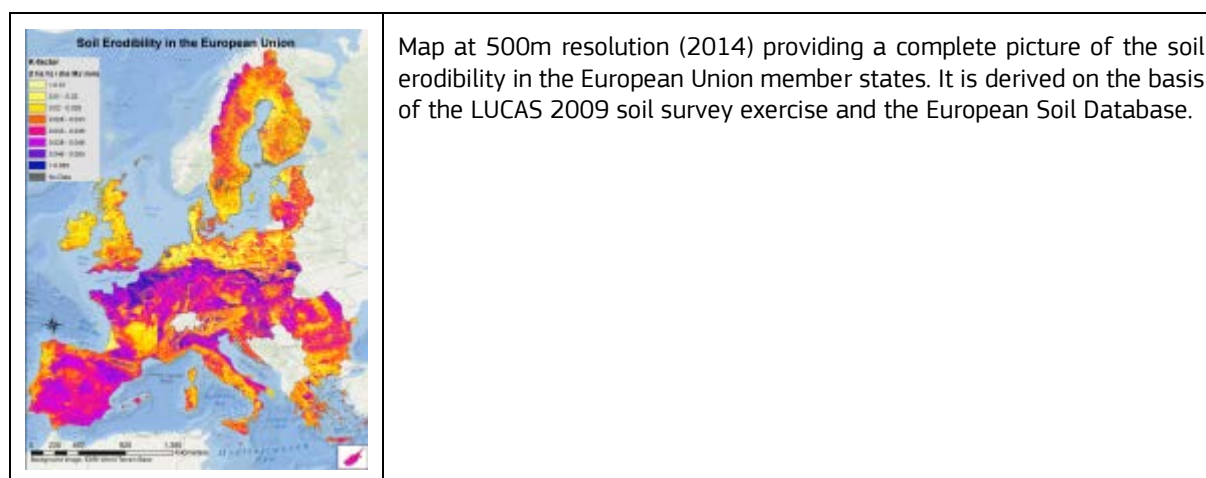
<https://esdac.jrc.ec.europa.eu/content/estimate-net-erosion-and-sediment-transport-using-watemsedem-european-union>

References:

Borrelli, P., Van Oost, K., Meusburger, K., Alewell, C., Lugato, E., Panagos, P. 2018. [A step towards a holistic assessment of soil degradation in Europe: Coupling on-site erosion with sediment transfer and carbon fluxes](#). *Environmental Research*, **161**: 291-298.

17 Soil Erodibility (K- Factor) High Resolution dataset for Europe

Short Description



Detailed Description

The soil erodibility dataset overcomes the problems of limited data availability for K-factor assessment and presents a high quality resource for modellers who aim at soil erosion estimation on local/regional, national or European scale. The new proposed dataset has also been verified against local/regional/national studies with very good results. Soil erosion modellers (and not only) may use it for their applications at any scale. The aim of this study is the generation of a harmonised high-resolution soil erodibility map (with a grid cell size of 500 m) for the 25 EU Member States and then for the 28 Member States. Soil erodibility was calculated for the LUCAS survey points using the nomograph of Wischmeier and Smith (1978). A Cubist regression model was applied to correlate spatial data such as latitude, longitude, remotely sensed and terrain features in order to develop a high-resolution soil erodibility map. The mean K-factor for Europe was estimated at 0.032 t ha h ha⁻¹ MJ⁻¹ mm⁻¹ with a standard deviation of 0.009 t ha h ha⁻¹ MJ⁻¹ mm⁻¹. The yielded soil erodibility dataset compared well with the published local and regional soil erodibility data. However, the incorporation of the protective effect of surface stone cover, which is usually not considered for the soil erodibility calculations, resulted in an average 15% decrease of the K-factor. The exclusion of this effect in K-factor calculations is likely to result in an overestimation of soil erosion, particularly for the Mediterranean countries, where highest percentages of surface stone cover were observed.

Metadata

Title: Soil Erodibility in Europe High Resolution dataset (500m)

Description: This map provides a complete picture of the soil erodibility in the European Union member states. It is derived from the LUCAS 2009 point survey exercise and the European Soil Database.

Spatial coverage: All Member States of the European Union where data available. Due to a number of requests from non-EU users, we also make available the Extrapolated datasets covering also Norway, Switzerland, Balkan states, Moldova and Ukraine.

Pixel size: 500m

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 2014

Input data source: LUCAS point data, European Soil Database

Data Access

<https://esdac.jrc.ec.europa.eu/content/soil-erodibility-k-factor-high-resolution-dataset-europe>

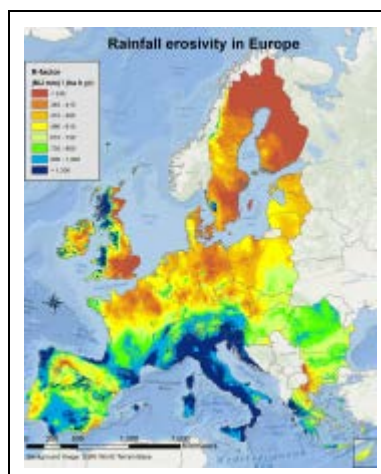
References:

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C. Soil erodibility in Europe: A high-resolution dataset based on LUCAS, Science of Total Environment, 479-480 (2014) pp. 189-200

Panagos, P., Meusbürger, K., Alewell, C., Montanarella, L. Soil erodibility estimation using LUCAS point survey data of Europe, *Environmental Modelling & Software*, Volume 30, April 2012, Pages 143-145

18 Rainfall Erosivity in the EU and Switzerland (R-factor)

Short Description



Dataset (GIS map) (2015) and associated products for the "Rainfall erosivity" (R-factor), one of the input layers when calculating the Universal Soil Loss Equation (USLE) model, which is the most frequently used model for soil erosion risk estimation; for EU28+Switzerland; R-factor map at resolutions of 500m.

Detailed Description

The purpose of this study is to assess rainfall erosivity in Europe in the form of the RUSLE R-factor, based on the best available datasets in Europe. We used the Rainfall Erosivity Database on the European Scale (REDES) which contains 1,675 precipitation stations in all European Union (EU) Member States and Switzerland, with temporal resolutions of 5 to 60 minutes. The R-factor values calculated from precipitation data of different temporal resolutions were normalised to R-factor values with temporal resolutions of 30 minutes using linear regression functions. Precipitation time series ranged from a minimum of 5 years to maximum of 40 years. The average time series per precipitation station is around 17.1 years, the most datasets including the first decade of the 21st century. Gaussian Process Regression (GPR) has been used to interpolate the R-factor station values to a European rainfall erosivity map at 1 km resolution. The covariates used for the R-factor interpolation were climatic data (total precipitation, seasonal precipitation, precipitation of driest/wettest months, average temperature), elevation and latitude/longitude. The mean R-factor for the EU plus Switzerland is 722 MJ mm ha⁻¹ h⁻¹ yr⁻¹, with the highest values (>1,000 MJ mm ha⁻¹ h⁻¹ yr⁻¹) in the Mediterranean and alpine regions and the lowest (Less than 500 MJ mm ha⁻¹ h⁻¹ yr⁻¹) in the Nordic countries. The erosivity density (erosivity normalised to annual precipitation amounts) was also highest in Mediterranean regions which implies high risk for erosive events and floods.

The current package include a series of datasets on Rainfall erosivity:

- a) Rainfall erosivity in Europe (R-factor);
- b) Erosivity Density;
- c) The standard error of the estimates;
- d) Monthly rainfall erosivity in Europe;
- e) Projections of Rainfall Erosivity in 2050 (Future R-factor)
- f) Seasonal erosivity in Europe;
- g) Indicators of rainfall erosivity;
- h) Past Erosivity and trend detection (1961-2018)
- j) Monthly R-factor maps of Greece and seasonal Erosivity Density;
- i) The R-factor in Switzerland (as calculated in 2012) and the code for calculating R-factor;
- k) The Rainfall Erosivity Database at European Scale (REDES) 1,675 stations with R-factor data.

The Rainfall Erosivity and the other climatic data is in Raster format. REDES is provided as a shape (and excel) file.

Metadata

Title: Rainfall erosivity in Europe

Description: This map provides a complete rainfall erosivity dataset for European Union (28 member States) and Switzerland based on REDES database with high temporal resolution rainfall measurements of 26,394 years. Gaussian Process Regression(GPR) model was used to interpolate the rainfall erosivity values of single stations and to generate the R-factor map.

REDES is provided as a point database including R-factor for each of the 1,675 stations (see below).

Monthly R-factor maps are also available (see below)

R-factor detailed assessments for Greece and Switzerland are available (see below).

Future projections (2050) of R-factor are available (see below).

Spatial coverage: European Union (28 Countries) & Switzerland

Pixel size: 500m

Measurement Unit: MJ mm ha⁻¹ h⁻¹ yr⁻¹

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 40 years - Predominant in the last decade: 2000 – 2010

Data Access

<https://esdac.jrc.ec.europa.eu/content/rainfall-erosivity-european-union-and-switzerland>

References:

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva, S., Tadic, M.P., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewicz, A., Dumitrescu, A., Begueria, S., Alewell, C. 2015. [Rainfall erosivity in Europe](#). *Sci Total Environ.* **511**: 801-814. DOI: 10.1016/j.scitotenv.2015.01.008.

Ballabio, C., Borrelli, P., Spinoni, J., Meusburger, K., Michaelides, S., Begueria, S., Klik, A., Petan, S., Janecek, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewicz, A., Dumitrescu, A., Tadić, M.P., Nazzareno, D., Kostalova, J., Rousseva, S., Banasik, K., L., Alewell, C., Panagos, P. 2017. [Mapping monthly rainfall erosivity in Europe](#). *Sci Total Environ.* **579**: 1298-1315. DOI: 10.1016/j.scitotenv.2016.11.123

Panagos, P., Ballabio, C., Meusburger, K., Spinoni, J., Alewell, C., Borrelli, P. 2017. [Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets](#). *Journal of Hydrology*, **548**: 251-262.

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K. 2016. [Spatio-temporal analysis of rainfall erosivity and erosivity density in Greece](#). *Catena*, **137**, 2603, pp. 161-172

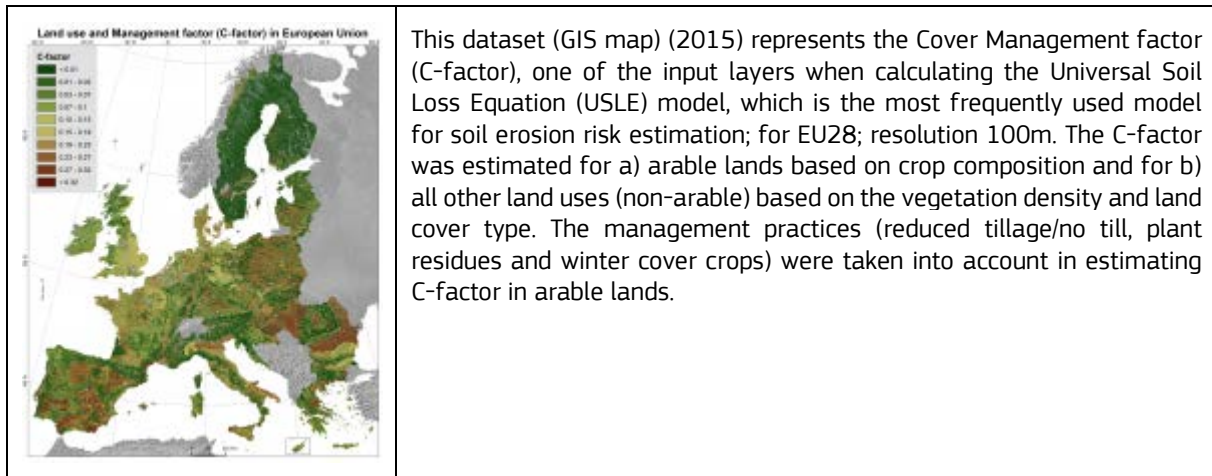
Panagos, P., Borrelli, P., Spinoni, J., Ballabio, C., Meusburger, K., Beguería, S., Klik, A., Michaelides, S., Petan, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewicz, A., Dumitrescu, A., Tadic, M.P., Diodato, N., Kostalova, J., Rousseva, S., Banasik, K., Alewell, C. 2016. [Monthly rainfall erosivity: conversion factors for different time resolutions and regional assessments](#). *Water*, **8(4)**, No 11

Bezák, N., Ballabio, C., Mikoš, M., Petan, S., Borrelli, P., Panagos, P. 2020. Reconstruction of past rainfall erosivity and trend detection based on the REDES database and reanalysis rainfall. *Journal of Hydrology*. Article number 125372

Panagos, P., Meusburger K., Ballabio C., Borrelli P., Begueria S., Klik A., Rymaszewicz A., Michaelides, S., Olsen, P., Tadic, M.P., P., Aalto, J., Lakatos, M., Dumitrescu, Rousseva, S., Montanarella, L., Alewell C. 2015. Reply to the comment on "Rainfall erosivity in Europe" by Auerswald et al. *Science of the Total Environment*, **532**, pp. 853-857. Download the Article: [10.1016/j.scitotenv.2015.05.020](https://doi.org/10.1016/j.scitotenv.2015.05.020).

19 Cover Management factor (C-factor) for the EU

Short Description



Detailed Description:

Land use and management influence the magnitude of soil loss. Among the different soil erosion risk factors, the cover-management factor (C-factor) is the one that policy makers and farmers can most readily influence in order to help reduce soil loss rates. The present study proposes a methodology for estimating the C-factor in the European Union (EU), using pan-European datasets (such as CORINE Land Cover), biophysical attributes derived from remote sensing, and statistical data on agricultural crops and practices. In arable lands, the C-factor was estimated using crop statistics (% of land per crop) and data on management practices such as conservation tillage, plant residues and winter crop cover. The C-factor in non-arable lands was estimated by weighting the range of literature values found according to fractional vegetation cover, which was estimated based on the remote sensing dataset Fcover. The mean C-factor in the EU is estimated to be 0.1043, with an extremely high variability; forests have the lowest mean C-factor (0.00116), and arable lands and sparsely vegetated areas the highest (0.233 and 0.2651 respectively). Conservation management practices (reduced/no tillage, use of cover crops and plant residues) reduce the C-factor by on average 19.1% in arable lands. The methodology is designed to be a tool for policy makers to assess the effect of future land use and crop rotation scenarios on soil erosion by water. The impact of land use changes (deforestation, arable land expansion) and the effect of policies (such as the Common Agricultural Policy and the push to grow more renewable energy crops) can potentially be quantified with the proposed model. The C-factor data per land use and country can be found in the publication while the C-factor maps (at 100m pixel resolution) are available for download here. The C-factor dataset is in Raster format. The user can download 2 datasets:

1. Cover management factor (C-factor) in the European Union at **100m resolution**
2. A shapefile where the user can map the:
 - Cover-Management factor (C-factor) in arable lands at regional (NUTS2) level in the European Union
 - Influence of Tillage practices on C-factor reduction
 - Influence of plant residues on C-factor reduction
 - Influence of cover crops on C-factor reduction

Metadata

Title: Cover Management(C-factor) factor of soil erosion by water at European Scale.

Description: The C-factor (Cover and Management) is presented at 100m resolution. This C-factor was estimated for a) arable lands based on crop composition and for b) all other land uses (non-arable) based on the vegetation density and land cover type. The management practices (reduced tillage/no till, plant residues and winter cover crops) were taken into account in estimating C-factor in arable lands.

Spatial coverage: European Union (28 Countries)

Pixel size: 100 m

Measurement Unit: Dimensionless

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 2010

Data Access

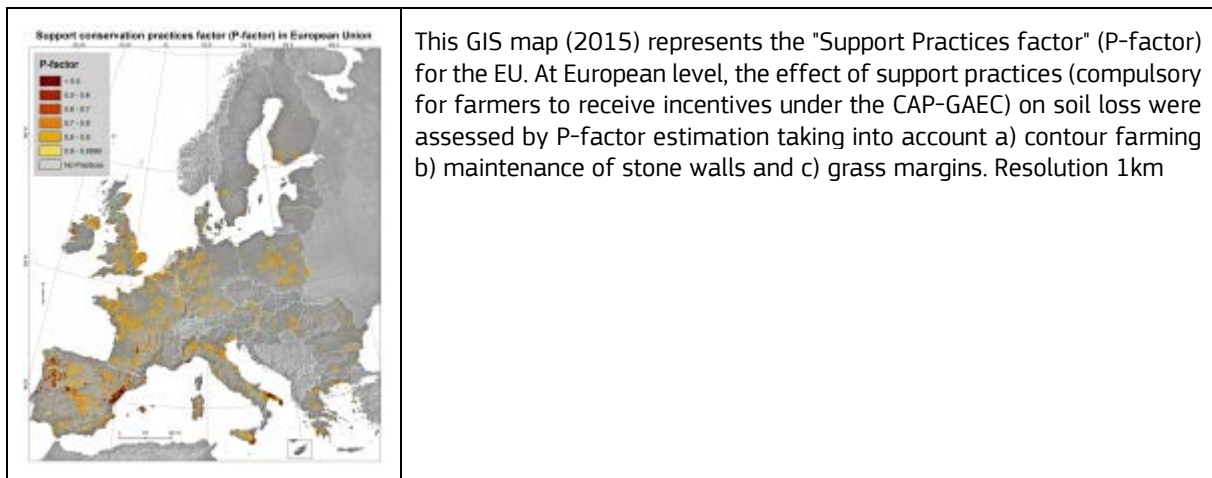
<https://esdac.jrc.ec.europa.eu/content/cover-management-factor-c-factor-eu>

References:

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E., Montanarella, L., 2015. [Estimating the soil erosion cover-management factor at European scale](#). Land Use policy journal. 48C, 38-50

20 Support Practices factor (P-factor) for the EU

Short Description



Detailed Description

The mean P-factor considering contour farming, stone walls and grass margins in the European Union is estimated at 0.9702. The support practices accounted for in the P-factor reduce the risk of soil erosion by 3%, with grass margins having the largest impact (57% of the total erosion risk reduction) followed by stone walls (38%). Contour farming contributes very little to the P-factor given its limited application; it is only used as a support practice in eight countries and only on very steep slopes. Support practices have the highest impact in Malta, Portugal, Spain, Italy, Greece, Belgium, Netherlands and United Kingdom where they reduce soil erosion risk by at least 5%. The P-factor modelling tool can potentially be used by policy makers to run soil-erosion risk scenarios for a wider application of contour farming in areas with slope gradients less than 10%, maintaining stone walls and increasing the number of grass margins under the reform of the Common Agricultural Policy. The P-factor dataset is in Raster format. The public user can download 2 datasets :

- Support practice factor (P-factor) in the European Union at 1km resolution
- Mean P-factor at regional (NUTS2) level in the European Union

Metadata

Title: Support practices (P-factor) factor on the reduction of soil erosion by water at European Scale.

Description: At European level, the effect of support practices (compulsory for farmers to receive incentives under the CAP-GAEC) on soil loss were assessed by P-factor estimation taking into account a) contour farming b) maintenance of stone walls and c) grass margins.

Spatial coverage: European Union (28 Countries)

Pixel size: 1 Km

Measurement Unit: Dimensionless

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 2010

Data Access

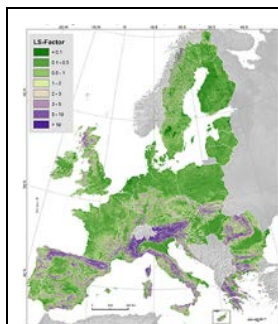
<https://esdac.jrc.ec.europa.eu/content/support-practices-factor-p-factor-eu>

References:

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J., Alewell, C. 2015. [Modelling the effect of support practices \(P-factor\) on the reduction of soil erosion by water at European Scale](#). *Environmental Science & Policy*, **51**: 23-34

21 LS-factor (Slope Length and Steepness factor) for the EU

Short Description



his dataset (GIS maps) (2015) represents the "Slope Length and Steepness factor" (LS-factor), one of the six input layers when calculating the Universal Soil Loss Equation (USLE) model, which is the most frequently used model for soil erosion risk estimation; for EU28; maps at resolutions of 25m (per country) and 100m (Europe-wide).

Detailed Description

The Universal Soil Loss Equation (USLE) model is the most frequently used model for soil erosion risk estimation. Among the six input layers, the combined slope length and slope angle (LS-factor) has the greatest influence on soil loss at the European scale. The S-factor measures the effect of slope steepness, and the L-factor defines the impact of slope length. The combined LS-factor describes the effect of topography on soil erosion. The European Soil Data Centre (ESDAC) developed a new pan-European high-resolution soil erosion assessment to achieve a better understanding of the spatial and temporal patterns of soil erosion in Europe. The LS-calculation was performed using the original equation proposed by Desmet and Govers (1996) and implemented using the System for Automated Geoscientific Analyses (SAGA), which incorporates a multiple flow algorithm and contributes to a precise estimation of flow accumulation. The LS-factor dataset was calculated using a high-resolution (25 m) Digital Elevation Model (DEM) for the whole European Union, resulting in an improved delineation of areas at risk of soil erosion as compared to lower-resolution datasets. This combined approach of using GIS software tools with high-resolution DEMs has been successfully applied in regional assessments in the past, and is now being applied for first time at the European scale.

Metadata

Title: Slope Length and Steepness factor (LS-factor)

Description: The LS-calculation was performed using the original equation proposed by Desmet and Govers (1996) and implemented using the System for Automated Geoscientific Analyses (SAGA), which incorporates a multiple flow algorithm and contributes to a precise estimation of flow accumulation.

Spatial coverage: European Union (28 Countries)

Pixel size: 25m and 100m

Measurement Unit: Dimensionless

Projection: ETRS89 Lambert Azimuthal Equal Area

Data Access

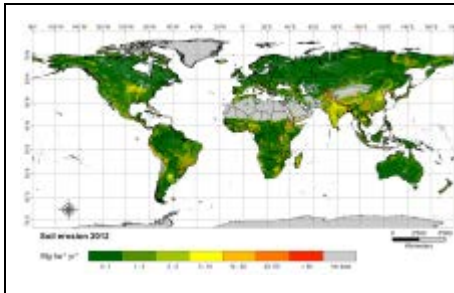
<https://esdac.jrc.ec.europa.eu/content/ls-factor-slope-length-and-steepness-factor-eu>

References:

Panagos, P., Borrelli, P., Meusburger, K. (2015) [A New European Slope Length and Steepness Factor \(LS-Factor\) for Modeling Soil Erosion by Water](#). *Geosciences*, **5**: 117-126

22 Global Soil Erosion

Short Description



Global Soil Erosion is a re-sampled dataset (25km) of the original Global Soil Erosion map. Both the 2012 and 2001 datasets are provided. The data package includes also the input layers (K, LS, R, C) at 25km resolution and a sample area (in Amazon rainforest) at the original resolution of 250m

Detailed Description:

The Global Soil Erosion map (GeoTIFF format) at 25km resolution is available for free download in the European Soil Data Centre (ESDAC). This is based on the Verion 1.1 of the JRC/ Uni-Basel "RUSLE-based Global Soil Erosion Modelling platform (GloSEM)". The native resolution is ca. 250m and we provide an example of those data (at the equator marked with a rectangle).

Shared files are resampled to ca. 25km.

We provide two RUSLE outputs:

- RUSLE Soil loss in 2012 (25km resolution)
- RUSLE Soil loss in 2001 (25km resolution)

Note: For Research purposes, we start uploading some country datasets at the original resolution of 250m (available: Vietnam).

In addition, we provide the 25km resolution resampled input datasets:

- * R-factor (the original one at 1km can be downloaded from <https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity>)
- * K-factor
- * C-factor
- * LS-factor

Metadata

Title: Global Soil Erosion Modelling platform (GloSEM)

Description: This map provides an assessment of global soil erosion for 2012 and 2001. We used the 250m original data to re-sample at 25km. In this study 202 countries are included with more than 125 million Km². The total soil loss has been estimated to 35 Pg yr⁻¹ of soil eroded in 2001. The estimates are lower compared to past studies in 2012, 35.9 Pg yr⁻¹ - Increase of 2.5% in soil erosion globally (due to land use change).

Spatial coverage: World (125 million Km² - c.a 84% of the earth surface)

Pixel size: 25km (on request the 250m).

Measurement Unit: t ha⁻¹ yr⁻¹

Projection: GCS_WGS_1984

Temporal coverage: 2012 and 2001

More information: [Global Soil Erosion](#)

Data Access

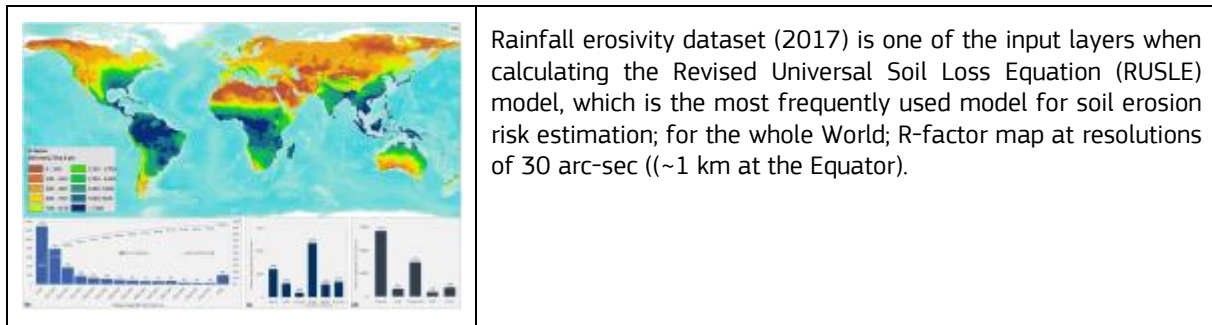
<https://esdac.jrc.ec.europa.eu/content/global-soil-erosion>

References:

Borrelli P., Robinson D.A., Fleischer L.R., Lugato E., Ballabio C., Alewell C., Meusburger K., Modugno S., Schutt B., Ferro V., Bagarello V., Van Oost K., Montanarella L., Panagos P. 2017. [An assessment of the global impact of 21st century land use change on soil erosion](#). *Nature Communications*, **8** (1): art. no. 2013

23 Global Rainfall Erosivity

Short Description



Detailed Description

The purpose of this study is to assess rainfall erosivity in the World in the form of the RUSLE R-factor, based on the best available datasets in the Globe. We used the Global Rainfall Erosivity Database (GloREDa) which contains 3,625 precipitation stations from 63 countries in the Globe with temporal resolutions of 1 to 60 minutes. The R-factor values calculated from precipitation data of different temporal resolutions were normalised to R-factor values with temporal resolutions of 30 minutes using linear regression functions. Precipitation time series ranged from a minimum of 5 years to maximum of 52 years. The average time series per precipitation station is around 16.8 years, the most datasets including the first decade of the 21st century. Gaussian Process Regression (GPR) has been used to interpolate the R-factor station values to a European rainfall erosivity map at 30 arc-seconds (~ 1 km at the Equator).

Globally, the mean rainfall erosivity is estimated to be 2,190 MJ mm ha⁻¹ h⁻¹ yr⁻¹ and broadly reflects climatic patterns, with the highest values, (which are 3 three times higher greater than the mean) are found in South America (especially around the Amazon Basin) and the Caribbean countries, Central and parts of east Western Africa and South East Asia. The lowest values are mainly found in mid and high latitude regions such as Canada, the Russian Federation, Northern Europe, Northern Africa, the and Middle East and southern Australia. It should be noted that high rainfall erosivity does not necessarily mean high erosion as factors such as soil characteristics, vegetative cover and land use are also important factors. The new global erosivity map is a critical input to global and continental assessments of soil erosion by water, flood risk and natural hazard prevention. Current global estimates of soil erosion by water are very uncertain, ranging over one order of magnitude (from around 20 to over 200 Pg per year). More accurate global predictions of rill and interrill soil erosion rates can only be achieved when the rainfall erosivity factor is thoroughly computed.

The global erosivity map is publicly available and can be used by other research groups to perform national, continental and global soil erosion modelling. At global scale, this is the first time ever that an erosivity database of such dimension is compiled. The Global Rainfall Erosivity Database, named hereafter as GloREDa, contains erosivity values estimated as R-factors (refer to the method section) from 3,625 stations distributed in 63 countries worldwide. This is the result of an extensive data collection of high temporal resolution rainfall data from the maximum possible number of countries in order to have a representative sample across different climatic and geographic gradients. GloREDa has three components, which are described in the relevant publication:

The Rainfall Erosivity database at European Scale (REDES) plus 1,865 stations from 23 countries outside Europe (Australia, New Zealand, South Korea, Japan, China, India, Malaysia, Iran, Kuwait, Israel, Turkey, Russian Federation, United States of America, Mexico, Costa Rica, Jamaica, Colombia, Suriname, Chile, Brazil, Algeria, South Africa, Mauritius).

The number of GloREDa stations varied greatly among continents. Europe had the largest contribution to the dataset, with 1,725 stations (48% of total), while South America had the lowest number of stations (141 stations or $\sim 4\%$ of total). Africa has very low density of GloREDa stations (5% of the total). In North America and the Caribbean, we collected erosivity values from 146 stations located in 6 countries (United States, Canada, Mexico, Cuba, Jamaica and Costa Rica). Finally, Asia and the Middle East were well represented in GloREDa, with 1,220 stations (34% of the total) distributed in 10 countries including the Siberian part of the Russian Federation, China, India, Japan.

Metadata

Title: Rainfall Erosivity in the World

Description: This map provides a complete rainfall erosivity dataset for the whole World based on 3625 precipitation stations and around 60,000 years of rainfall records at high temporal resolution (1 to 60 minutes). Gaussian Process Regression(GPR) model was used to interpolate the rainfall erosivity values of single stations and to generate the R-factor map.

Spatial coverage: World

Pixel size: 30 arc-seconds (~1 km at the Equator).

Measurement Unit: MJ mm ha⁻¹ h⁻¹ yr⁻¹

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 30-40 years - Predominant in the last decade: 2000 - 2010

Data Access

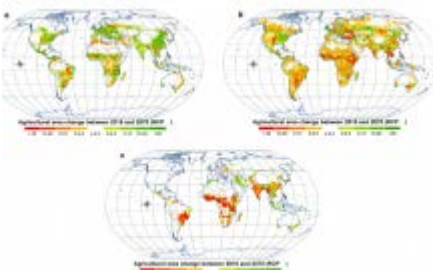
<https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity>

References:

Panagos P., Borrelli P., Meusburger K., Yu B., Klik A., Lim K.J., Yang J.E, Ni J., Miao C., Chattopadhyay N., Sadeghi S.H., Hazbavi Z., Zabihi M., Larionov G.A., Krasnov S.F., Garobets A., Levi Y., Erpul G., Birkel C., Hoyos N., Naipal V., Oliveira P.T.S., Bonilla C.A., Meddi M., Nel W., Dashti H., Boni M., Diodato N., Van Oost K., Nearing M.A., Ballabio C., 2017. [Global rainfall erosivity assessment based on high-temporal resolution rainfall records](#). *Scientific Reports* **7**: 4175. DOI: 10.1038/s41598-017-04282-8.

24 Global soil erosion by water in 2070

Short Description

	<p>Land use and climate change impacts on global soil erosion by water (2015-2070). This dataset includes the baseline scenario (2015) and the future projections (2070) of soil erosion based on land use changes and climate change effects.</p>
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Detailed Description

We use the latest projections of climate and land use change to assess potential global soil erosion rates by water to address policy questions; working towards the goals of the United Nations working groups under the Inter-Governmental Technical Panel on Soils of the Global Soil Partnership. This effort will enable policy makers to explore erosion extent, identify possible hotspots, and work with stakeholders to mitigate potential impacts. In addition, we also provide insight into the potential mitigating effects attributable to conservation agriculture and the need for more effective policy instruments for soil protection. Scientifically, the modeling framework presented adopts a series of methodological advances and standardized data to communicate with adjacent disciplines and move towards robust, reproducible and open data science.

Metadata

- Modelled area: 143 million Km² which is about ~95.5% of Earth's land
- Resolution: 25Km² x 25Km²
- Global Coverage: 202 countries included in the study
- Three alternative (2.6, 4.5 & 8.5) Shared Socioeconomic Pathway and Representative Concentration Pathway (SSP-RCP) scenarios
- 14 General Climate Circulation Models (GCMs) used to assess future rainfall erosivity scenarios
- The baseline model (2015) predicts global potential soil erosion rates of 43 (-7, +9.2) Pg yr⁻¹
- Climate projections indicate an overall trend moving towards a more vigorous hydrological cycle, which could increase global water erosion up to more than +60% (SSP5-RCP8.5)

Data Access

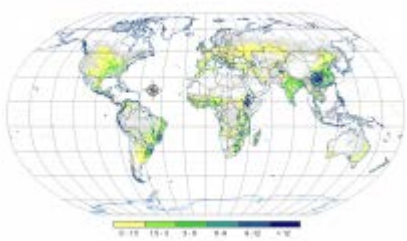
<https://esdac.jrc.ec.europa.eu/content/global-soil-erosion-water-2070>

References:

Borrelli P., Robinson D.A., Panagos P., Lugato E., Yang J.E., Alewell C., Wuepper D., Montanarella L., Ballabio C. 2020. [Land use and climate change impacts on global soil erosion by water \(2015-2070\)](#). *Proceedings of the National Academy of Sciences (PNAS)*, 117(36), 21994–22001; doi: 10.1073/pnas.2001403117

25 Global phosphorus losses due to soil erosion

Short Description

	Global average phosphorus (P) losses due to soil erosion in kg ha ⁻¹ yr ⁻¹ . Thus we combine the most recent spatially distributed global soil erosion estimates with global P content of cropland soils (data also available for P content)
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Detailed Description

The world's food production depends directly on phosphorus. However, this plant nutrient is not unlimited, but comes from finite geological reserves. How soon these reserves might be exhausted is the subject of scholarly debate. An international research team led by the University of Basel [with the participation of the JRC, INRA (FR), UK Centre for Ecology & Hydrology and Kangwon National University (South Korea)] has investigated which continents and regions worldwide are suffering the greatest loss of phosphorus. The researchers combined high-resolution spatially discrete global data on the phosphorus content of soils with local erosion rates. Based on this, they calculated how much phosphorus is lost through erosion in different countries.

An important conclusion of the study is that more than 50% of global phosphorus loss in agriculture is attributable to soil erosion. Africa, Eastern Europe and South America register the greatest phosphorus losses – with limited options to mitigate the problem. P loss for arable soils, due to erosion by water, globally of approximately 5.9 kg ha⁻¹. In Europe those losses are much less (1.2 kg ha⁻¹) mainly due to higher input fertilizer and less erosion. The highest phosphorus losses are found in soils of Africa (9.7 kg ha⁻¹) as it is not possible to afford the high costs of chemical fertilizer and in South America (6.1 kg ha⁻¹).

Metadata

Study area: We cover 1.04 billion ha of global cropland with a resolution of 0.5°×0.5° based on the land-use harmonization data.

Main dataset: Global average phosphorus (P) losses due to soil erosion in kg P ha⁻¹ yr⁻¹.

Spatial coverage: World (1.04 billion ha - Arable lands)

Pixel size: 0.5° latitude x 0.5° longitude

Measurement Unit: kgP ha⁻¹ yr⁻¹.

Projection: regular

Temporal coverage: 2012

Data Access


<https://esdac.jrc.ec.europa.eu/content/global-phosphorus-losses-due-soil-erosion>

References:

Alewell, C., Rengeval, B., Ballabio, C., Robinson, D.A., Panagos, P., Borrelli, P. 2020. [Global phosphorus shortage will be aggravated by soil erosion](#). Nat Commun 11, 4546.

26 Pan European Soil Erosion Risk Assessment - PESERA

Short Description

	<p>A 2003 GIS map of Soil erosion estimates (t/ha/yr) by applying the PESERA GRID (physical) model at 1km, using the European Soil Database, CORINE land cover, climate data from the MARS Project and a Digital Elevation Model. The resulting estimates of sediment loss are from erosion by water.</p>
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Detailed Description

Pan European Soil Erosion Risk Assessment - PESERA : The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). Soil erosion estimates (t/ha/yr) by applying the PESERA GRID model at 1km, using the European Soil Database, CORINE land cover, climate data from the MARS Project and a Digital Elevation Model. The resulting estimates of sediment loss are from erosion by water. The PESERA model produces results that depend crucially on land cover as identified by CORINE and the accuracy of the interpolated meteorological data.

Metadata

Coverage: 23 EU Member states (Excluding Croatia, Sweden, Finland, Cyprus and Malta)
 Spatial Resolution: 1km
 Released: 2004

Data Access


<https://esdac.jrc.ec.europa.eu/content/pan-european-soil-erosion-risk-assessment-pesera>

References:

1. M. J. Kirkby, B. J. Irvine, R. J. A. Jones, G. Govers, and PESERA team, 2008. The PESERA coarse scale erosion model for Europe. Model rationale and implementation. European Journal of Soil Science 59 (6) , pp. 1293-1306.
2. Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. and Huting, J.(2004). European Soil Bureau Research Report No.16, EUR 21176, 18pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg

27 Soil Erosion Risk Assessment in Europe data (MESALES model)

Short Description

	<p>These Soil Erosion Risk Assessment in Europe data (2000) have been elaborated by INRA for JRC using the MESAES model and can be seen as an intermediate step towards a "state-of-the-art erosion modelling at the European scale", prior to the initiation of the PESERA project.</p>
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Detailed Description:

The goal of this work was to develop and apply a methodology based on present knowledge and available data for the assessment of soil erosion risk at the European scale. Factors influencing erosion have been graded for the diverse geographical situations existing in Europe and erosion mechanisms have been expressed with the help of experimental and expert-defined empirical rules.

Land cover and crust formation on cultivated soils were considered as key factors influencing runoff and erosion risk. A soil geographical database has been created for Europe, and a model of erosion risk has been developed using a Geographical Information System (GIS). The model uses empirical rules to combine data on land use (CORINE Land Cover database), soil crusting susceptibility, soil erodibility (determined by pedotransfer rules from the Soil Geographical Data Base of Europe at scale 1:1 Million), relief (USGS HYDRO1K digital elevation model), and meteorological data at a 1 x 1 km pixel size (Space Applications Institute, Ispra Joint Research Center). Spatial units for the presentation of results are defined using either administrative units or watershed catchment units.

Metadata

Title: Soil Erosion Risk Assessment in Europe data (MESALES model)

Description: These data have been prepared by INRA (France) under contract to the Joint Research Centre of the European Commission. It is one of the thematic applications based on the Soil Geographical Data Base of Europe at scale 1:1 Million.

Resolution: 1: 1,000,000

Published: 2000

More information: [MESALES Model](#)

Data Access

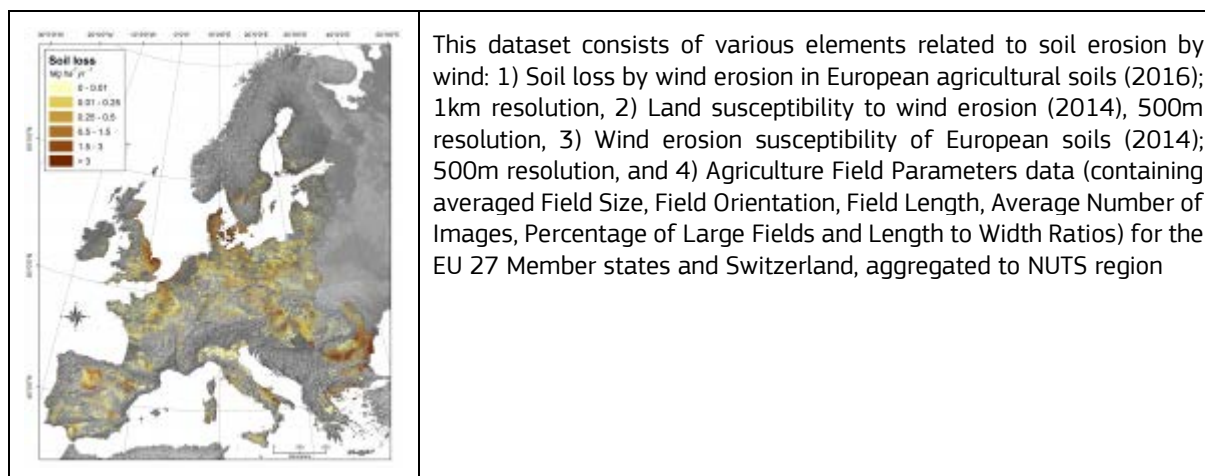
<https://esdac.jrc.ec.europa.eu/content/soil-erosion-risk-assessment-europe-data-mesales-model-dataset>

References:

Le Bissonnais Y., C. Montier, M. Jamagne, J. Daroussin, D. King (2002). Mapping erosion risk for cultivated soil in France. Catena, 46, 207-220

28 Soil erosion by wind

Short Description



Detailed Description

The European Commission – Joint Research Centre (JRC) provides access to results from a new series of studies on wind erosion at Pan-European scale:

- **Soil erosion by wind in European agricultural soils:** A GIS version of the Revised Wind Erosion Equation (RWEQ) was developed in JRC to model at large scale wind erosion. The model is designed to predict the daily soil loss potential by wind erosion at 1km spatial resolution.
- **Land susceptibility to wind erosion:** An Index of Land Susceptibility to Wind Erosion (ILSWE) was created by combining spatiotemporal variations of the most influential wind erosion factors (i.e. climatic erosivity, soil erodibility, vegetation cover and landscape roughness).
- **Wind erosion susceptibility of soils:** The wind-erodible fraction of soil (EF) is one of the key parameters for estimating the susceptibility of soil to wind erosion.
- **Former studies:** Agriculture Field Parameters on NUTS-3 regions.

Metadata

Title: Soil loss by wind erosion in European agricultural soils (Quantitative assessment)

Description: GIS-RWEQ is a simplified GIS-based application of the RWEQ model (ARS-USDA). It follows a spatially distributed approach based on a grid structure, running in R and Python scripts. The model scheme is designed to describe the daily soil loss potential at regional or larger scale. A complete description of the methodology and the application in Europe is described in the paper: Borrelli, P., Lugato, E., Montanarella, L., & Panagos, P. (2017). A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach. *Land Degradation & Development*, 28: 335–344, DOI: 10.1002/ldr.2588

Spatial coverage: 28 Member States of the European Union

Pixel size: c.a 1Km

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: from January 2001 to December 2010

Data Access

https://esdac.jrc.ec.europa.eu/content/Soil_erosion_by_wind

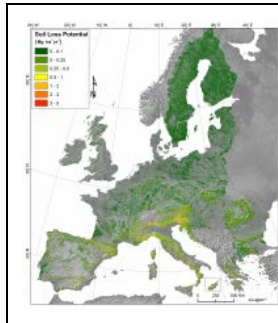
References:

1. Borrelli, P., Lugato, E., Montanarella, L., Panagos, P. (2016). [A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach](#). *Land Degradation & Development*, in Press, DOI: 10.1002/ldr.2588

2. Borrelli, P., Panagos, P., Ballabio, C., Lugato, E., Weynants, M. Montanarella, L 2016. Towards a pan-European assessment of land susceptibility to wind erosion. *Land Degradation & Development*, 27(4): 1093-1105, DOI: 10.1002/ldr.2318.
3. Borrelli, P., Panagos, P., Montanarella, L. 2015. New Insights into the Geography and Modelling of Wind Erosion in the European Agricultural Land. Application of a Spatially Explicit Indicator of Land Susceptibility to Wind Erosion. *Sustainability* 2015, 7(7), 8823-8836; doi:10.3390/su7078823
4. Borrelli, P., Ballabio, C., Panagos, P., Montanarella, L. (2014). Wind erosion susceptibility of European soils. *Geoderma*, 232, 471-478

29 Soil erosion in forestland in Europe (using RUSLE2015)

Short Description



Dataset (2 GIS-maps) (2016) related to soil erosion in Forestland in Europe. One map is the soil loss potential for EU28; the other map is the European Forest Cover Change for 36 European countries.

Detailed Description

This study provides a first pan-European analysis that delineates the spatial patterns of forest cover changes in 36 countries. The first dynamic assessment of the soil loss potential in the EU-28 forests is reported. The recently published High-resolution Global Forest Cover Loss map (2000–2012) was reprocessed and validated. Results show that the map is a powerful tool to spatiotemporally indicate the forest sectors that are exposed to cover change risks. The accuracy assessment performed by using a confusion matrix based on 2300 reference forest disturbances distributed across Europe shows values of 55.1% (producer accuracy) for the algorithm-derived forest cover change areas with a Kappa Index of Agreement (KIA) of 0.672.

Metadata

Title: Soil Erosion in forestland in Europe (Using Rusle2015)

Spatial coverage: European Union (28 Member States) for soil erosion in forestland 36 countries for the forest cover changes

Pixel size: 100m

Temporal coverage: 2010

Data Access


<https://esdac.jrc.ec.europa.eu/content/soil-erosion-forestland-europe-using-rusle2015>

References:

Borrelli, P., Panagos, P., Langhammer, J., Apostol, B., Schütt, B. 2016. [Assessment of the cover changes and the soil loss potential in European forestland: First approach to derive indicators to capture the ecological impacts on soil-related forest ecosystems](#). Ecological Indicators, 60, 1208–1220

30 Soil loss due to crop harvesting in the European Union

Short Description

	<p>Soil loss due to crop harvesting in the European Union. The regional estimates of total Soil Loss by Crop Harvesting (SLCH) are presented at country and regional level.</p>
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Detailed Description

Considerable amounts of soil can be removed from the field due to soil sticking to the harvested roots. **Soil Loss due to Crop Harvesting (SLCH)** is defined as the loss (or export) of top soil from arable land during harvesting of crops such as potato, sugar beet, carrot or chicory roots. We performed a research study to scale up the findings of past studies, carried out at plot, regional, and national level, in order to obtain some preliminary insights into the magnitude of soil loss from cropland due to **sugar beets** and **potatoes** harvesting in Europe. We address this issue at European Union (EU) scale taking into account longterm (1975–2016) crop statistics of sugar beet and potato aggregated at regional and country levels.

Four Shape files are available for download (corresponding to the 4 figures of the publication):

- Impact of soil texture, expressed by the textural index on Soil Loss by Crop Harvesting SLCH
- Aggregated data (at country level) on Soil Loss by Crop Harvesting (SLCH) for sugar beet and potato
- Soil Loss (1000 tons) by CropHarvesting (SLCH) crops at regional level (NUTS2) and contribution of crop harvesting (sugar beet and potato) to area-specific soil loss (t ha^{-1}) from all arable lands.
- Decrease (%) of Soil Loss due to Crop Harvesting (SLCH) during the 3 study periods (1975–1986, 1987–1999 and 2000–2016).

Metadata

Spatial Coverage: 28 Member States of European Union

Resolution: NUTS2

Time Reference: 3 periods 2000–2016, 1987–99, 1975–86

Format: Shape files and excel files

Projection: Lambert_Azimuthal_Equal_Area

Input data: Statistical data for crop harvesting in the European Union (Origin: Eurostat)

More Information: [Soil loss due to crop harvesting in the European Union](https://esdac.jrc.ec.europa.eu/content/soil-loss-due-crop-harvesting-european-union)

Data Access

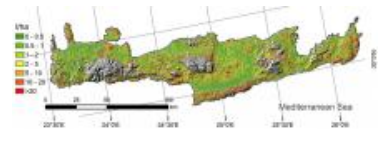
<https://esdac.jrc.ec.europa.eu/content/soil-loss-due-crop-harvesting-european-union>

References:

Panagos, P., Borrelli, P., Poesen, J., 2019. [Soil loss due to crop harvesting in the European Union: A first estimation of an underrated geomorphic process](#). *Science of The Total Environment*. **664**: 487–498.

31 G2 soil erosion model data

Short Description

	G2 generic model for soil erosion applied to 5 application areas (Crete island, Cyprus, Ishmi-Erzeni watershed, Korce, Strymonas/Struma); available layers: Soil erosion (Total & Monthly) plus Rainfall erosivity (Total & Monthly), vegetation retention (Total & Monthly), soil erodibility, topographic influence and slope intercept
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Detailed Description

G2 model is a new generic model for erosion, resulted from the cooperation of European Commission/Joint Research Centre and the Lab of Forest Management and Remote Sensing of the Aristotle University of Thessaloniki in the framework of geoland2 project. G2 estimates soil loss (in t/ha) from sheet and interrill erosion caused by splash and runoff, on a month-step basis and on a landscape scale.

Soil erosion layers (Total & Monthly) plus Rainfall erosivity (Total & Monthly), vegetation retention (Total & Monthly), soil erodibility, topographic influence and slope intercept are available for the three (5) application areas.

Metadata

- **Cyprus:** 9251 Km² - pixel size: 100m including sediment module
- **Crete island:** 8,336 Km² (Greece) - Pixel size: 300m, temporal coverage: 2011-2012.
- **Ishmi-Erzeni watershed :** 2,200 Km² (Albania) - Pixel size: 300m, temporal coverage: 2011-2012.
- **Korce Region:** 1690 Km² (Albania) - Pixel size: 30m
- **Strymonas/Struma** Catchment : 14,500 Km² (Greece / Bulgaria) - Pixel size: 300m, temporal coverage: 2003-2006.

Data Access


<https://esdac.jrc.ec.europa.eu/content/g2-soil-erosion>

References:

1. Karydas, C.G. and Panagos, P. 2018. [The G2 erosion model: An algorithm for month-time step assessments](#), *Environmental Research*, **161**: 256-267
2. Karydas, C.G., Panagos, P. 2016. [Modelling monthly soil losses and sediment yields in Cyprus](#). *International Journal of Digital Earth*, **9(8)**: 766-787
3. Zdruli, P, Karydas, CG, Dedaj, K, Salillari, I, Cela, F, Lushaj, S, Panagos, P (2016). [High resolution spatiotemporal analysis of erosion risk per land cover category in Korce region, Albania](#). *Earth Science Informatics*, **9(4)**: 481-495
4. Karydas, C.G., Zdruli, P., Koci, S., Sallaku, F. (2015a). [Monthly time-step erosion risk monitoring of Ishmi-Erzeni watershed, Albania using the G2 model](#). *Environmental Modeling & Assessment*, **20(6)**: 657-671
5. Panagos, P., Karydas, CG., Ballabio, C., Gitas, IZ., 2014. [Seasonal monitoring of soil erosion at regional scale: An application of the G2 model in Crete focusing on agricultural land uses](#). *International Journal of Applied Earth Observations and Geoinformation* **27PB**: 147-155
6. Panagos, P., Karydas, C.G., Gitas, I.Z., Montanarella, L. 2012. [Monthly soil erosion monitoring based on remotely sensed biophysical parameters: a case study in Strymonas river basin towards a functional pan-European service](#), *International Journal of Digital Earth* **5(6)**: 461-487

32 . Topsoil Soil Organic Carbon (LUCAS) for EU25

Short Description

	<p>This dataset (2015) provides maps for Topsoil Soil Organic Carbon in EU-25 that are based on LUCAS 2009 soil point data through a generalized additive model. Map of predicted topsoil organic carbon content (g C kg⁻¹) : The map of predicted topsoil organic carbon content (g C kg⁻¹) was produced by fitting a generalised additive model between organic carbon measurements from the LUCAS survey (dependent variable) and a set of selected environmental covariates; namely slope, land cover, annual accumulated temperature, net primary productivity, latitude and longitude. It also includes a Map of standard error of the OC model predictions (g C kg⁻¹)</p>
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Detailed Description:

There is an increasing demand for up-to-date soil organic carbon (OC) data for global environmental and climatic modelling. The aim of this study was to create a map of topsoil OC content at the European scale by applying digital soil mapping techniques to the first European harmonized geo-referenced topsoil (0–20cm) database, which arises from the Land use/Cover Area frame statistical Survey (LUCAS). A map of the associated uncertainty was also produced to support careful use of the predicted OC contents. A generalized additive model (GAM) was fitted on 85% of the dataset ($R^2 = 0.29$), using OC content as dependent variable; a backward stepwise approach selected slope, land cover, temperature, net primary productivity, latitude and longitude as suitable covariates. The validation of the model (performed on 15% of the data-set) gave an overall R^2 of 0.27 and an R^2 of 0.21 for mineral soils and 0.06 for organic soils. Organic C content in most organic soils was under-predicted, probably because of the imposed unimodal distribution of our model, whose mean is tilted towards the prevalent mineral soils. This was also confirmed by the poor prediction in Scandinavia (where organic soils are more frequent), which gave an R^2 of 0.09, whilst the prediction performance (R^2) in non-Scandinavian countries was 0.28. The map of predicted OC content had the smallest values in Mediterranean countries and in croplands across Europe, whereas largest OC contents were predicted in wetlands, woodlands and mountainous areas. The map of the predictions' standard error had large uncertainty in northern latitudes, wetlands, moors and heathlands, whereas small uncertainty was mostly found in croplands. The map produced gives the most updated general picture of topsoil OC content at the European Union scale. Two available datasets:

- **Map of predicted topsoil organic carbon content (g C kg⁻¹)** : The map was produced by fitting a generalised additive model between organic carbon measurements from the LUCAS survey (dependent variable) and a set of selected environmental covariates; namely slope, land cover, annual accumulated temperature, net primary productivity, latitude and longitude. (format GeoTIFF)
- **Map of standard error of the OC model predictions (g C kg⁻¹)**: This map presents the associated uncertainty to the organic carbon content predictions. The standard error, which shows the theoretical range of deviation in the prediction made by the generalized additive model, was calculated for every pixel of the Map of predicted topsoil organic carbon content, based on the posterior covariance matrix of the fitted parameters. (format GeoTIFF)

Metadata

Title: Topsoil Soil Organic Carbon (LUCAS)

Description: The map of predicted OC content had the smallest values in Mediterranean countries and in croplands across Europe, whereas largest OC contents were predicted in wetlands, woodlands and mountainous areas. The map of the predictions' standard error had large uncertainty in northern latitudes, wetlands, moors and heathlands, whereas small uncertainty was mostly found in croplands. The map produced gives the most updated general picture of topsoil OC content at the European Union scale.

Spatial coverage: 25 European Union Member States (excluded Romania, Bulgaria, Croatia)

Pixel size: 1Km

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 2014

Input data source: LUCAS point data

Data Access

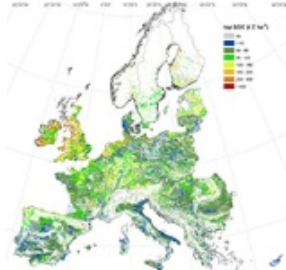
<https://esdac.jrc.ec.europa.eu/content/topsoil-soil-organic-carbon-lucas-eu25>

References:

D. de Brogniez, C. Ballabio, A. Stevens, R. J. A. Jones, L. Montanarella and B. van Wesemael (2014). A map of the topsoil organic carbon content of Europe generated by a generalized additive model. *European Journal of Soil Science*. 66(1): 121-134 . doi: 10.1111/ejss.12193

33 Pan-European SOC stock of agricultural soils

Short Description

	<p>Data (2014) related to Pan-European SOC stock of agricultural soils, containing GIS maps for a) Pan-European SOC stock of agricultural soils (shapefile), b) Potential carbon sequestration by modelling a comprehensive set of management practices (shapefile), c) Average Eroded SOC in agricultural soils (raster).</p>
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Detailed Description

The future EU policy in agriculture will utilize SOC as an indicator, both as a main parameter of soil quality and as a strategy to offset CO₂ emissions by C sequestration. However, a consistent picture of agricultural SOC stock is missing, as well as tools to orient future policymaker decisions. To fill this gap, the JRC developed a comprehensive modelling platform with comparable and harmonised European geographical and numerical datasets. We estimated a current top SOC stock of 17.63 Gt in EU agricultural soils, by an unprecedented model application running about 164,000 combinations of climate, soil and land use/management.

A comprehensive model platform was established at a pan-European scale (EU + Serbia, Bosnia and Herzegovina, Croatia, Montenegro, Albania, Former Yugoslav Republic of Macedonia and Norway) using the agro-ecosystem SOC model CENTURY. The model was implemented with the main management practices (e.g. irrigation, mineral and organic fertilization, tillage, etc.) derived from official statistics. The model results were tested against inventories from the European Environment and Observation Network (EIONET) and approximately 20,000 soil samples from the 2009 LUCAS survey, a monitoring project aiming at producing the first coherent, comprehensive and harmonized top-soil dataset of the EU based on harmonized sampling and analytical methods.

RC scientists found that making alternative uses of arable land could potentially help capture significant amounts of carbon from the atmosphere. They investigated the potential carbon sequestration of six of the most representative agricultural management practices on arable soils, and found that the conversion of arable land to grassland results in the highest potential soil organic carbon (SOC) sequestration rates, whereas the conversion of grassland to arable land has the effect of strongly increasing the amount of carbon losses to the atmosphere. The scientists have used a recently developed high resolution pan-European simulation platform to assess the potential impact of six management practices on SOC stock levels of arable soil under two IPCC climate change scenarios to 2100: arable to grassland conversion (and vice versa), straw incorporation, reduced tillage, straw incorporation with reduced tillage, ley cropping and cover crops. According to the results of three policy simulations carried out by the scientists, the allocation of just 12% of arable land to different combinations of agricultural management practices would produce significant mitigation effects, which would be sufficient to reach the EU's target of cutting its emissions to 20% below of the 1990 levels by 2020.

Metadata

Format: Polygon cover (shape file)

Fields: a) [**y2010**] = Soil organic stock (t C ha⁻¹) in the layer 0-30 cm at 2010, b) [**agr_ha**] = hectares under agricultural land use

Projection: ETRS_1989_LAEA_L52_M10

Coverage: pan-European scale (EU + Serbia, Bosnia and Herzegovina, Croatia, Montenegro, Albania, Former Yugoslav Republic of Macedonia and Norway)

Notes: values = 0 in the field[y2010] are units not simulated; the agricultural land use includes arable land, pasture and permanent croplands

Methodology - Metadata: Application of CENTURY model

Data Access

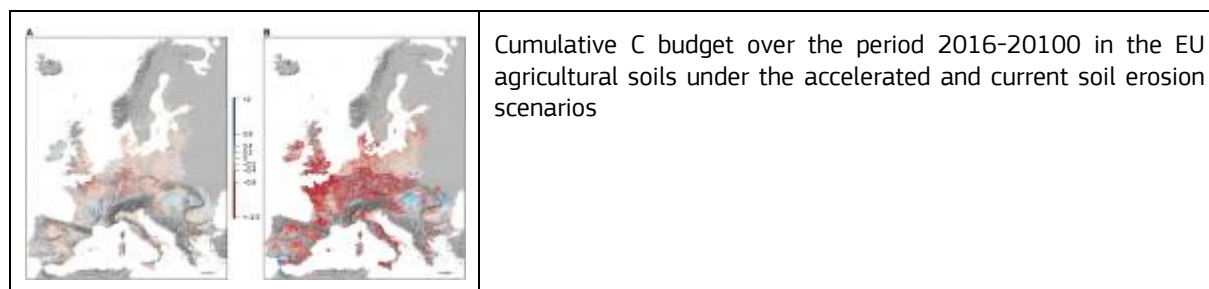
<https://esdac.jrc.ec.europa.eu/content/pan-european-soc-stock-agricultural-soils>

References:

- Lugato, E., Paustian, K., Panagos, P., Jones, A., Borrelli, P., 2016. [Quantifying the erosion effect on current carbon budget of European agricultural soils at high spatial resolution](#). *Global Change Biology* (2016), 22(5), 1976–1984, doi:<http://dx.doi.org/10.1111/gcb.13198>
- Lugato E., Panagos P., Bampa, F., Jones A., Montanarella L. (2014). [A new baseline of organic carbon stock in European agricultural soils using a modelling approach](#). *Global change biology*. 20 (1), pp. 313–326.
- Lugato E., Bampa F., Panagos P., Montanarella L. and Jones A. (2014). [Potential carbon sequestration of European arable soils estimated by modelling a comprehensive set of management practices](#). *Global Change Biology* (2014), 20, 3557–3567

34 Carbon budget in the EU agricultural soils

Short Description



Detailed Description

Soil play a significant environmental role in balancing the climate as it currently acts as a carbon sink, sequestering CO₂ from the atmosphere into soil organic carbon. Using a new biogeochemistry-erosion model to quantify the impact of future climate on the carbon cycle, the authors track the possible transformations of the organic carbon across the landscape. Taking into account all the additional feedbacks and C fluxes due to displacement by erosion, the authors of this study estimated a net source of 0.92 to 10.1 Tg C year⁻¹ from agricultural soils in the European Union to the atmosphere over the period 2016–2100. These ranges represented a weaker and stronger C source compared to a simulation without erosion (1.8 Tg C year⁻¹), respectively, and were dependent on the erosion-driven C loss parameterization, which is still very uncertain.

Metadata

Spatial Coverage: European Union EU-28

Resolution: 1km x 1km

Time Reference: 2016 - 2100

Format: raster format (GEOTIFF)

Projection: ETRS_1989_LAEA_L52_M10

Input data: Soil organic carbon stocks, Erosion factor, future Rainfall erosivity

More information: Soil erosion and carbon

Data Access


<https://esdac.jrc.ec.europa.eu/content/carbon-budget-eu-agricultural-soils>

References:

Lugato, E., Smith, P., Borrelli, P., Panagos, P., Ballabio, C., Orgiazzi, A., Fernandez-Ugalde, O., Montanarella, L., Jones, A. 2018. [Soil erosion is unlikely to drive a future carbon sink in Europe](#). *Science Advances*. **4**, eaau3523.

35 Soil Organic Matter (SOM) fractions for 186 LUCAS 2009 soil samples (grassland, forest)

Short Description

	This dataset contains the original measured Soil Organic Matter (SOM) fractions of a subset of the LUCAS 2009 topsoil dataset, for grassland and forest (186 samples)
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Detailed Description

Land management for C sequestration is most often informed by bulk soil C inventories, without considering the form in which C is stored, its capacity, persistency and N demand. Recent frameworks suggest that soil C accrual, its persistence and response to N availability can be better described if SOM is broadly divided into a Particulate Organic Matter (POM) and a Mineral Associated Organic Matter (MAOM) pool. POM, being predominantly of plant origin, contains many structural C-compounds with low N content and persists in soil through inherent biochemical recalcitrance, physical protection in aggregates and/or microbial inhibition. MAOM is largely made of microbial products richer in N, and persists in soil because of chemical bonding to minerals and physical protection in small aggregates.

In this study, we used the Land Use/Land Cover Area Frame Survey (LUCAS) database to determine topsoil C and N storage in European forests and grasslands on 9415 geo-referenced points and separate by size POM (2000–53 µm) and MAOM (<53 µm) in more than 180 subsamples.

Data Access

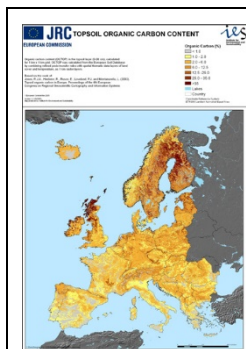
<https://esdac.jrc.ec.europa.eu/content/soil-organic-matter-som-fractions>

References:

Cotrufo, M.F., Ranalli, M.G., Haddix, M.L. et al. 2019. [Soil carbon storage informed by particulate and mineral-associated organic matter](#). Nat. Geosci. doi:10.1038/s41561-019-0484-6

36 OCTOP: Topsoil Organic Carbon Content for Europe

Short Description



2004 GIS map of Soil Organic Carbon (SOC) content (%) in the surface horizon of soils in Europe, associated to a JRC internal report.

Description

The estimation of soil carbon content is of pressing concern for soil protection and in mitigation strategies for global warming. This paper describes the methodology developed and the results obtained in a study aimed at estimating organic carbon contents (%) in topsoils across Europe. The information presented in map form provides policy-makers with estimates of current topsoil organic carbon contents for developing strategies for soil protection at regional level. Such baseline data are also of importance in global change modelling and may be used to estimate regional differences in soil organic carbon (SOC) stocks and projected changes therein, as required for example under the Kyoto Protocol to the United Nations Framework Convention on Climate Change, after having taken into account regional differences in bulk density.

The study uses a novel approach combining a rule-based system with detailed thematic spatial data layers to arrive at a much-improved result over either method, using advanced methods for spatial data processing. The rule-based system is provided by the pedo-transfer rules, which were developed for use with the European Soil Database. The strong effects of vegetation and land use on SOC have been taken into account in the calculations, and the influence of temperature on organic carbon contents has been considered in the form of a heuristic function. Processing of all thematic data was performed on harmonized spatial data layers in raster format with a 1 km × 1 km grid spacing.

Metadata:

Organic Carbon Content In Topsoils In Europe (OCTOP)

Description: ESDAC makes available the Maps of Organic carbon content (%) in the surface horizon of soils in Europe

Resolution: 1km

Published: 2004

Format: The data are in ESRI GRID format and are available as an ASCII raster file or in native ESRI GRID format.

The result is available as a map and an explaining booklet:

[The Map of Organic Carbon Content In Topsoils In Europe: Version 1.2 September - 2003 \(S.P.I.04.72\)](#).

Robert J.A. Jones, Roland Hiederer, Ezio Rusco, Peter J. Loveland and Luca Montanarella European Soil Bureau Research Report No.15, EUR 21209, 40pp. Office for Official Publications of the European Communities, Luxembourg.

Data Access

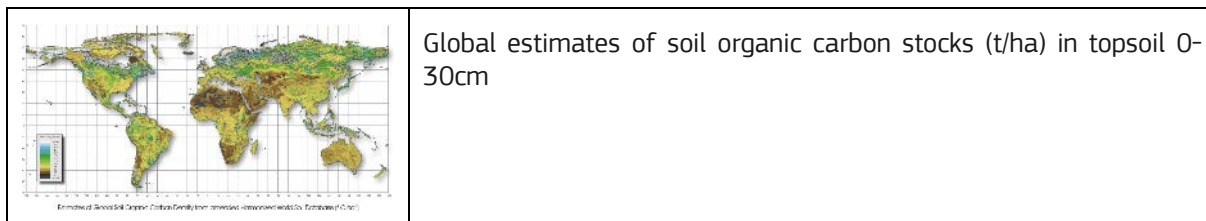
<https://esdac.jrc.ec.europa.eu/content/octop-topsoil-organic-carbon-content-europe>

References:

Jones, R.J.A, R. Hiederer, E. Rusco, P.J. Loveland and L. Montanarella (2005). Estimating organic carbon in the soils of Europe for policy support. European Journal of Soil Science, October 2005, 56, p.655-671.

37 Global Soil Organic Carbon Estimates

Short Description



Detailed Description

Global estimates of soil organic carbon stocks have been produced in the past to support the calculation of potential emissions of CO₂ from the soil under scenarios of change land use/cover and climatic conditions (IPCC, 2006), but very few global estimates are presented as spatial data. For global spatial layers on soil parameters, the most recent and complete dataset is available as the Harmonized World Soil Database (HWSD). The HWSD represents a step forward towards a spatially more detailed and thematically more refined set of global soil data.

Metadata

Description: Global estimates of soil organic carbon stocks (t/ha) in topsoil 0-30cm.

Data: Global Organic carbon density (t ha⁻¹) for the topsoil (0 – 30cm) and the subsoil layer (30 – 100cm) from the amended Harmonised World Soil Database.

Resolution: The Global Soil Organic Carbon estimates are available in 2 different grid resolutions (ZIP compression):

- Raster layer with resolution of 30 arc second (which corresponds to a grid size of approx. 1km x 1km at the Equator)
- Raster layer with resolution of 5 arc minute (which corresponds to a grid size of approx. 9km x 9km at the Equator)

Format: The data are in Idrisi format.

Last update: March 2012

Information about the data: [Global Soil Organic Carbon Estimates](#)

Data Access

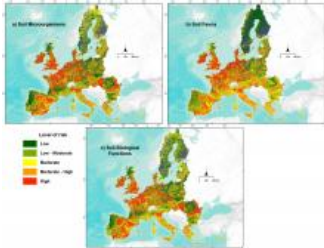
<https://esdac.jrc.ec.europa.eu/content/global-soil-organic-carbon-estimates>

References:

[Global Soil Organic Carbon Estimates and the Harmonized World Soil Database](#) R. Hiederer, M. Köchy 2012 – 79 pp. – EUR 25225 EN – EUR Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print), ISBN 978-92-79-23108-7

38 Potential threats to soil biodiversity in Europe

Short Description

	<p>Dataset that contains 3 GIS maps showing Potential threats to soil biodiversity in Europe (for soil microorganisms, for fauna,forbiological functions), along with 13 input layers (habitat fragmentation, climate change, soil erosion, etc.); resolution 500m.</p>
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Detailed Description

Because of the increasing pressures exerted on soil, below-ground life is under threat. Knowledge-based rankings of potential threats to different components of soil biodiversity were developed in order to assess the spatial distribution of threats on a European scale. A list of 13 potential threats to soil biodiversity was proposed to experts with different backgrounds in order to assess the potential for three major components of soil biodiversity: soil microorganisms, fauna, and biological functions. This approach allowed us to obtain knowledge-based rankings of threats. These classifications formed the basis for the development of indices through an additive aggregation model that, along with ad-hoc proxies for each pressure, allowed us to preliminarily assess the spatial patterns of potential threats. Intensive exploitation was identified as the highest pressure. In contrast, the use of genetically modified organisms in agriculture was considered as the threat with least potential. The potential impact of climate change showed the highest uncertainty. Fourteen out of the 27 considered countries have more than 40% of their soils with moderate-high to high potential risk for all three components of soil biodiversity. Arable soils are the most exposed to pressures. Soils within the boreal biogeographic region showed the lowest risk potential. The majority of soils at risk are outside the boundaries of protected areas. First maps of risks to three components of soil biodiversity based on the current scientific knowledge were developed. Despite the intrinsic limits of knowledge-based assessments, a remarkable potential risk to soil biodiversity was observed. Guidelines to preliminarily identify and circumscribe soils potentially at risk are provided. This approach may be used in future research to assess threat at both local and global scale and identify areas of possible risk and, subsequently, design appropriate strategies for monitoring and protection of soil biota.

Metadata

Title: Potential threats to soil biodiversity in Europe.

Description: Three major components of soil biodiversity are assessed: a) soil microorganisms, b) fauna, and c) biological functions. The maps were developed based on 13 potential threats to soil biodiversity which were proposed to experts with different backgrounds in order to assess biodiversity threat.

Spatial coverage: European Union (27 Countries - Croatia was not included)

Pixel size: 500 m

Measurement Unit: Dimensionless

Projection: ETRS89 Lambert Azimuthal Equal Area

Temporal coverage: 2015

Data Access


<https://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe>

References:

Orgiazzi, A., Panagos, P., Yigini, Y., Dunbar, M.B., Gardi, C., Montanarella, L., Ballabio, C. 2016. A [knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity](#). *Science of the Total Environment*, **545-546**: 11-20.

39 Global Soil Biodiversity Atlas Maps

Short Description

	<p>Dataset (2016) containing 2 GIS maps from the Global Soil Biodiversity Atlas: 1) the Soil Biodiversity map showing a simple index describing the potential level of diversity living in soils (with the use of two other datasets: distribution of microbial soil carbon used as a proxy for soil microbial diversity, and the distribution of the main groups of soil macrofauna used as a proxy for soil fauna diversity. 2) the Soil Biodiversity threats showing the potential rather than the actual level of threat to soil organisms. For the development of this map, a number of diverse threats and corresponding proxies were chosen.</p>
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Detailed Description:

This dataset contains 2 maps from the Global Soil Biodiversity Atlas

1. Soil Biodiversity map

This map is presented on pages 90-91 of the Global Soil Biodiversity Atlas. The map shows a simple index describing the potential level of diversity living in soils on our planet. In order to make this preliminary assessment, two sets of data were used:

distribution of microbial soil carbon developed by Serna-Chavez and colleagues (2013). This dataset was used as a proxy for soil microbial diversity:

distribution of the main groups of soil macrofauna developed by Mathieu (unpublished data). This dataset was used as a proxy for soil fauna diversity.

2. Soil Biodiversity threats map

This map is presented on pages 134-135 of the Global Soil Biodiversity Atlas. The map shows the potential rather than the actual level of threat to soil organisms. For the development of this map, the following threats and corresponding proxies were chosen:

- loss of aboveground biodiversity: map of plant species loss developed by the University of Maryland, Baltimore County (Ellis et al, 2012);
- pollution and nutrient overloading: map of the nitrogen fertiliser application developed by the NASA Socioeconomic Data and Applications Center (Potter et al., 2011);
- agricultural use: map of cropland percentage cover developed by the International Institute for Applied Systems Analysis - International Food Policy Research Institute (Fritz et al., 2015);
- overgrazing: map of cattle density developed by the International Livestock Research Institute (ILRI), the Food and Agriculture Organization of the United Nations (FAO) and the Free University of Brussels (Robinson et al., 2014);
- fire risk: map of fire density 1997-2010 developed by the United Nations Environment Programme Division of Early Warning and Assessment (UNEP – DEWA, 2015);
- soil erosion: map of Water and Wind Erosion Vulnerability Indices developed by the United States Department of Agriculture Natural Resources Conservation Service (USDA – NRCS, 2015);
- land degradation: map of Desertification Vulnerability Index developed by the United States Department of Agriculture Natural Resources Conservation Service (USDA – NRCS, 2015);
- climate change: map of Global Aridity Index developed by University of Leuven (UKL), with the support of the International Water Management Institute (IWMI) and the International Centre for Integrated Mountain Development (Zomer et al., 2008).

Data Access

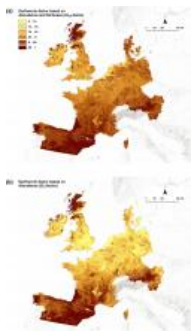
<https://esdac.jrc.ec.europa.eu/content/global-soil-biodiversity-maps-0>

References:

Orgiazzi, A., Bardgett, R.D., Barrios, E., Behan-Pelletier, V., Briones, M.J.I., Chotte, J-L., De Deyn, G.B., Eggleton, P., Fierer, N., Fraser, T., Hedlund, K., Jeffery, S., Johnson, N.C., Jones, A., Kandeler, E., Kaneko, N., Lavelle, P., Lemanceau, P., Miko, L., Montanarella, L., Moreira, F.M.S., Ramirez, K.S., Scheu, S., Singh, B.K., Six, J., van der Putten, W.H., Wall, D.H. (Eds.), 2016, Global Soil Biodiversity Atlas. European Commission, Publications Office of the European Union, Luxembourg. 176 pp.

40 Biodiversity factor in soil erosion

Short Description

	A biological factor to be included in soil erosion modelling. The available data for Earthworm diversity (richness and abundance) introduced a new "earthworm factor" to be incorporated in soil erosion modelling
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Detailed Description

New estimates of soil loss can be generated by including biological factors in soil erosion models. At the same time, the effects of soil loss on belowground diversity require further investigation. Available data and technologies make both processes possible. We think that it is time to commit to fostering the fundamental, although complex, relationship between soil biodiversity and erosion.

In this context, we identified three possible areas of research that, in our opinion, require advances in the coming years:

1. Comprehension and quantification of the interactions between soil biodiversity and erosion;
2. Development and integration of a "biodiversity factor" into the models used to assess soil erosion;
3. Assessment of the ecological impact of soil erosion on soil-living communities.

According to the current (limited) knowledge, earthworms can play a key role in reducing soil erosion, mainly due to their burrowing activity that increase soil porosity. Based available pan-European (11 countries) maps of earthworm richness and abundance, we developed an "Earthworm factor" (Et-factor) to be integrated into soil erodibility (K-factor) calculation. Due to uncertainty on the potential impact of earthworm communities on soil loss, two Et-factors were generated, one including richness and abundance (Et_{AR}-factor), the other only abundance data (Et_A-factor). Both factors were then included into K-factor to obtain revised soil erodibility values (K_{Et}-factor).

Metadata

Spatial Coverage: Pan-European, 11 countries: Belgium, Denmark, France, Germany, Hungary, Ireland, Luxembourg, Slovenia, Spain (partly), the Netherlands and the United Kingdom

Resolution: 500m

Time Reference: 2009

Format: Raster (tiff)

Projection: GRS_1980_IUGG_1980_Lambert_Azimuthal_Equal_Area

Input data: Soil erodibility (Panagos et al., 2014) and earthworm richness and abundance (Rutgers, Orgiazzi et al., 2016) in Europe

Data Access

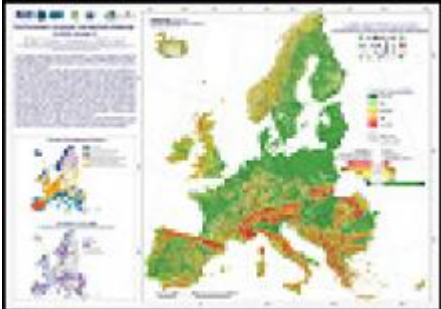
<https://esdac.jrc.ec.europa.eu/content/biodiversity-factor-soil-erosion>

References:

Orgiazzi, A., Panagos, P. 2018. [Soil biodiversity and soil erosion: It is time to get married: Adding an earthworm factor to soil erosion modelling](#). *Global Ecology and Biogeography*, **27**(10): 1155-1167.

41 European Landslide Susceptibility Map version 2 (ELSUSv2)

Short Description

	<p>The spatial dataset (GIS map) shows landslide susceptibility levels at European scale, derived from heuristic-statistical modelling of main landslide conditioning factors using also landslide location data. It covers all EU member states except Malta, in addition to Albania, Andorra, Bosnia and Herzegovina, Croatia, FYR Macedonia, Iceland, Kosovo, Liechtenstein, Montenegro, Norway, San Marino, Serbia, and Switzerland. This dataset is available together with ancillary spatial datasets</p>
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Detailed Description

ELSUS v2 shows levels of spatial probability of generic landslide occurrence at continental scale. It covers all European Union member states except Malta, and several neighbouring countries. The map has been produced by regionalizing the study area based on elevation and climatic conditions, followed by spatial multi-criteria evaluation modelling using pan-European slope angle, shallow sub-surface lithology, and land cover spatial datasets as the main landslide conditioning factors. In addition, the location of over 149,000 landslides across Europe, provided by various national organizations or collected by the authors, has been used for model calibration and map validation. Additional information is given in both the metadata and the references below.

Compared with the previous version ELSUS1000 v1, ELSUS v2 provides larger geographical coverage, higher spatial resolution and higher prediction model performance.

The map has been produced jointly by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, Hannover, Germany), Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI, Perugia, Italy), Institut de Physique du Globe de Strasbourg (CNRS-EOST, Strasbourg, France), and the Joint Research Centre (JRC, Ispra, Italy), as part of the collaborative work of the [European Landslide Expert Group](#) and the [European Centre on Geomorphological Hazards \(CERG\)](#) in support of the [EU Thematic Strategy for Soil Protection](#).

The landslide susceptibility map is available to download together with ancillary maps including confidence level of the classified landslide susceptibility, climate-physiographic regions, slope angle, lithology, and land cover. ELSUS v2 is to be viewed at scales up to 1:200,000 and should not be used to deduce local information on landslide susceptibility.

Metadata

Title: European Landslide Susceptibility Map version 2 (ELSUS v2)

Description: Landslide susceptibility levels at continental scale derived from heuristic-statistical modelling of main landslide conditioning factors using also landslide location data

Spatial coverage: All European Union member states except Malta, in addition to Albania, Andorra, Bosnia and Herzegovina, Croatia, FYR Macedonia, Iceland, Kosovo, Liechtenstein, Montenegro, Norway, San Marino, Serbia, and Switzerland

Cell size: 200 m

Format: Esri ASCII Grid

Map datum, projection: ETRS89, Lambert Azimuthal Equal Area

Landslide susceptibility coding: 0 = no data; 1 = very low; 2 = low; 3 = moderate; 4 = high; 5 = very high

Files: elsus_v2.asc and ancillary files

Ancillary datasets: Confidence Level Map of ELSUS v2, Climate-Physiographic regions, Slope Angle, Lithology, and Land Cover

Authoring organisations: BGR, CNR-IRPI, CNRS-EOST and EC-JRC.D

Data Access

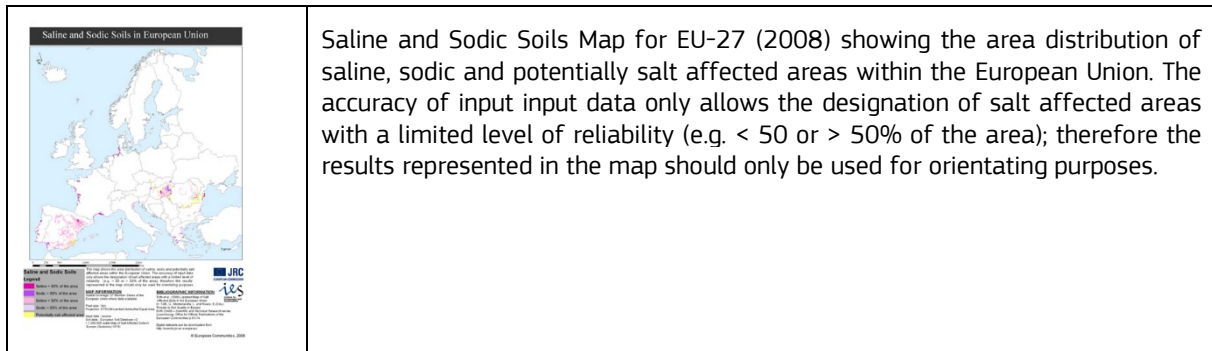
<https://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus-v2>

References:

- Wilde, M., Günther, A., Reichenbach, P., Malet, J.-P., Hervás, J., 2018. [Pan-European landslide susceptibility mapping: ELSUS Version 2](#). *Journal of Maps*, **14(2)**: 97-104 and supplemental map.
- Günther, A., Van Den Eeckhaut, M., Malet, J.-P., Reichenbach, P., Hervás, J., 2014. [Climate-physiographically differentiated Pan-European landslide susceptibility assessment using spatial multi-criteria evaluation and transnational landslide information](#). *Geomorphology*, **224**: 69-85

42 Saline and Sodic Soils in European Union

Short Description



Detailed Description

The **Saline and Sodic Soils Map** shows the area distribution of saline, sodic and potentially salt affected areas within the European Union. The accuracy of input data only allows the designation of salt affected areas with a limited level of reliability (e.g. < 50 or > 50% of the area); therefore the results represented in the map should only be used for orientating purposes. In total there are 5 categories:

- 1 - Saline > 50% of the area
- 2 - Sodic > 50% of the area
- 3 - Saline < 50% of the area
- 4 - Sodic < 50% of the area
- 5 - Potentially salt affected soils.

Metadata

Title: Saline and Sodic Soils in the European Union: Status and Potentials

Spatial coverage: 27 Member States of the European Union where data available.

Pixel size: 1km

Projection: ETRS89 Lambert Azimuthal Equal Area

Input data source: Soil data - European Soil Database v2, 1:1.000.000 scale Map of Salt Affected Soils in Europe (Szabolcs 1974)

Information: Tóth et al. (2008) Updated Map of Salt Affected Soils in the European Union. In: Tóth, G., Montanarella, L. and Rusco, E. (Eds.) Threats to Soil Quality in Europe. EUR23438 – Scientific and Technical Research series Luxembourg: Office for Official Publications of the European Communities p.61-74

Data Access


<https://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union>

References:

Toth G, Adhikari K, Varallyay Gy, Toth T, Bodis K, Stolbovoy V. Updated map of salt affected soils in the European Union. in: Toth, G., Montanarella, L. and Rusco, E. (eds.) Threats to Soil Quality in Europe EUR 23438 EN, Office for Official Publications of the European Communities; Luxembourg 2008, p 65-77

43 Natural susceptibility to soil compaction in Europe

Short Description

	Map (2008) showing the natural susceptibility of agricultural soils to compaction if they were to be exposed to compaction, based on the creation of logical connections between relevant parameters (using pedotransfer rules), taking as input parameters attributes of the European soil database (soil type, texture, etc.). For EU-27.
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Detailed Description

This map shows the natural susceptibility of agricultural soils to compaction if they were to be exposed to compaction. The evaluation of the soil's natural susceptibility is based on the creation of logical connections between relevant parameters (pedotransfer rules). The input parameters for these pedotransfer rules are taken from the attributes of the European soil database, e.g. soil properties: type, texture and water regime, depth to textural change and the limitation of the soil for agricultural use. Besides the main parameters auxiliary parameters have been used as impermeable layer, depth of an obstacle to roots, water management system, dominant and secondary land use. It was assumed that every soil, as a porous medium, could be compacted.

Metadata

Spatial coverage: 27 Member States of the European Union where data available.

Pixel size: 1km

Projection: ETRS89 Lambert Azimuthal Equal Area

Input data source: Soil data - European Soil Database v2, Land Use - CORINE Land Cover 2000

Explanation about the data:

The map of natural soil susceptibility to compaction was created from the evaluation of selected parameters from the ESDB. The soil susceptibility to compaction was divided into 4 categories. Two additional categories represent the data concerning places where this evaluation was either not relevant or could not be provided because of lack of information. In total there are 6 categories:

- 0 - no soil. This represents water bodies, glaciers and rock outcrops
- 1 - low susceptibility to compaction
- 2 - medium susceptibility to compaction
- 3 - high susceptibility to compaction
- 4 - very high susceptibility to compaction
- 9 - no evaluation possible. This was the case of towns including also soils, soils disturbed by man and marsh.

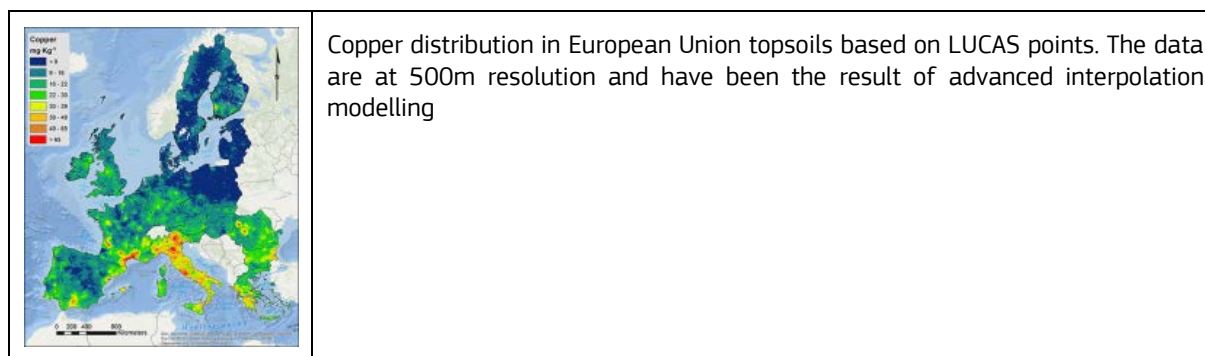
Data Access

<https://esdac.jrc.ec.europa.eu/content/natural-susceptibility-soil-compaction-europe>

References: -

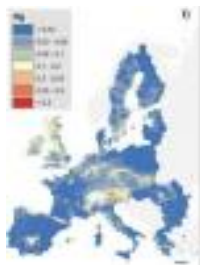
44 Copper distribution in topsoils in the European Union

Short Description



45 Maps of heavy metals in the soils of the EU, based on LUCAS 2009 HM data

Short Description

	Detailed maps of heavy metals in the EU27 (EU-28 except Croatia), based on topsoil HM data from LUCAS 2009
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Detailed Description:

Maps for As, Cd, Cr, Cu, Hg, Pb, Mn, Sb, Co and Ni concentrations in European topsoil.

Important note: the mentioned paper refers in some point to a "Zn" map; this is an error and should be read as "Mn".

For each of these maps: also a map of prediction error variance, as described in the article.

Metadata

Format: TIFF

Resolution: 1km

Spatial reference: ETRS89_LAEA_Europe

Geographical cover: EU27 (EU-28 except Croatia)

Data Access

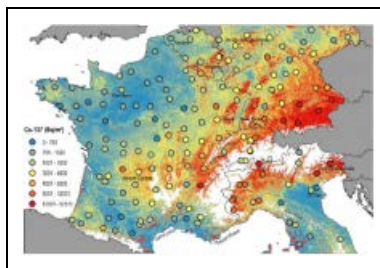
<https://esdac.jrc.ec.europa.eu/content/maps-heavy-metals-soils-eu-based-lucas-2009-hm-data-0>

References:

Gergely Tóth, Tamás Hermann, Gábor Szatmári and László Pásztor, 2016. Maps of heavy metals in the soils of the European Union and proposed priority areas for detailed assessment". Science of The Total Environment, Volume 565, 15 September 2016, Pages 1054-1062

46 Caesium-137 and Plutonium-239+240 in European topsoils

Short Description



Plutonium and Caesium inventories in European topsoils. Includes also the Chernobyl-derived ^{137}Cs and Global-derived ^{137}Cs

Detailed Description:

This study and maps are useful for establishing a reference base in the event of possible future fallout of radionuclides, but also for use in new studies, particularly in geomorphology. They will, for example, allow the reconstruction of soil erosion rates since the 1960s in areas of Europe where there have been major landscape changes. The two radionuclides (caesium, plutonium) were released during military nuclear tests, particularly in the 1960s, but cesium also during the Chernobyl accident in 1986.

The researchers used 160 samples from a European LUCAS topsoil database (2009). These samples were taken from soils under grassland, which have remained stable since the 1960s (absence of erosion and accumulation) and are representative of the variability of rainfall conditions observed in the countries covered by the study.

The radionuclides found in these samples, caesium and plutonium (^{137}Cs , ^{239}Pu , ^{240}Pu), left a specific footprint in European soils. Indeed, in the countries covered by the study, the plutonium came exclusively from the nuclear tests. As for caesium, it is the result of both nuclear tests, particularly in the 1960s, and the 1986 Chernobyl accident. The relationship between cesium and plutonium is therefore different depending on whether it comes from nuclear tests or from the Chernobyl accident. It is this relationship that has enabled researchers to trace the origin of these artificial radionuclides deposited on European soils.

Metadata

Resolution: 500m;

Format: geo TIFF;

projection information: ETRS89 / LAEA Europe

Geographical Coverage: European Union (France, Germany, Italy, Belgium, Luxembourg, Switzerland)

Input data: LUCAS 2009 Topsoil 160 sample point data

Model: Gaussian process regression (GPR)

Data Access


<https://esdac.jrc.ec.europa.eu/content/caesium-137-and-plutonium-239240-european-topsoils>

References:

Meusburger, K., Evrard, O., Alewell, C., Borrelli, P., Cinelli, G., Ketterer, M., Mabit, L., Panagos, P., van Oost, K., Ballabio, C. 2020. Plutonium aided reconstruction of caesium atmospheric fallout in European topsoils. Scientific Reports 10: 11858. <https://doi.org/10.1038/s41598-020-68736-2>

47 Soil Organic Carbon - Saturation Capacity in Europe

Short Description

	<p>This dataset (map) (2016) shows the Soil Organic Carbon (SOC) saturation capacity, expressed as the ratio between the actual and the potential SOC stock in each pixel. Values close to 0 indicate a great potential of soil to store more carbon.</p>
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Detailed Description

This dataset (map) shows the Soil Organic Carbon (SOC) saturation capacity, expressed as the ratio between the actual and the potential SOC stock in each pixel. Values close to 0 indicate a great potential of soil to store more carbon.

The actual SOC stock was derived from the Pan-European simulation using the biogeochemical CENTURY model (a detailed explanation can be found in the references below). The associated data can be found in ESDAC: "Pan-European SOC stock of agricultural soils"

The potential SOC stock was obtained simulating a grassland land use without nitrogen limitation, since it was considered a good scenario for SOC accumulation. The scenario set-up was analogous to that described in Lugato et al (2014b, see below) for the grassland land use, namely 'AR_GR_LUC'. However to obtain a potential SOC stock, the model was ran for 2000 years with repeated actual climate, in order to reach an equilibrium condition. The simulation involved only the agricultural soils, according to the Corine Land Cover. A value of 1 was arbitrary attributed to forest soils.

Metadata

ESRI Grid (250m resolution)

ETRS_LAEA_10_52 Coordinate System

Coverage: EU + Balkan + Norway

Data Access


<https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity>

References:

- [Lugato, E., Panagos, P., Bampa, F., Jones, A., Montanarella, L. A new baseline of organic carbon stock in European agricultural soils using a modelling approach \(2014a\) Global Change Biology, 20 \(1\), pp. 313-326.](#)
- [Lugato, E., Bampa, F., Panagos, P., Montanarella, L., Jones, A. Potential carbon sequestration of European arable soils estimated by modelling a comprehensive set of management practices \(2014b\) Global Change Biology, 20 \(11\), pp. 3557-3567.](#)

48 Maps of indicators of soil hydraulic properties for Europe

Short Description

	Plutonium and Caesium inventories in European topsoils. Includes also the Chernobyl-derived ^{137}Cs and Global-derived ^{137}Cs
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Detailed Description

Soil water information is an essential input for environmental, hydrological or land surface models. There is a need for reliable soil water information with European coverage. In the last decades, research institutes, universities and other research facilities have developed local prediction methods. Maps with a European coverage were produced with the limited information available at the end of the 1990's. Their unknown reliability hinders the accuracy estimation of models relying on soil information. An up-to-date map of soil hydraulic properties could improve the predictions of such models.

A reliable soil water map can serve multiple purposes, including scientific research and application of models on different geographical scales. It is also essential for the development and spatial implementation of a comprehensive soil quality (SQ) indicator planned by the Joint Research Centre of the European Commission.

New soil hydraulic pedotransfer functions (PTFs) were recently developed (**Toth et al., 2014**) and could support the computational basis of the new series of maps of soil hydraulic properties.

The purpose of the study that JRC undertook is to assist with the implementation of the research programme on soil quality indicators, namely to facilitate the completion of a new soil quality indicator by supplying reliable spatial data on soil hydraulic properties.

For this, the following map layers were developed:

- Water retention of topsoil
- saturated water content (cm^3/cm^3)
- water content at field capacity (cm^3/cm^3)
- water content at wilting point (cm^3/cm^3)
- Hydraulic conductivity of topsoil
- saturated hydraulic conductivity (cm/day)

Besides the true values in the units mentioned above, values scaled between 1 and 10 without measurement units were also calculated. Although the concepts of field capacity and permanent wilting point have been widely criticised, their use in modelling remains common. They are oversimplifying concepts that should not be static and should vary not only with soil, but also with vegetation and climatic conditions. Still they provide an easy measure to approach water-holding capacity in soils.

Metadata

The GeoTiff files are in the Coordinate System: ETRS_LAEA_10_52; pixels are aligned with other Rasters distributed in ESDAC.

Coverage: EU + Balkan + Norway

Switzerland)

Data Access


<https://esdac.jrc.ec.europa.eu/content/maps-indicators-soil-hydraulic-properties-europe>

References:

[h, B., Weynants, M., Nemes, A., Mako, A., Bilas, G., Toth, G., 2014. New generation of hydraulic pedotransfer functions for Europe. European Journal of Soil Science](#)

49 Maps of the Storing and Filtering Capacity of Soils in Europe

Short Description

	<p>This dataset (2016) contains 10 maps that relate to the soil's storing and filtering capacity in Europe (the EU only): cation storing capacity (STOR_CAPCA), cation filtering capacity (FILT_CAPCA), anion storing capacity (STOR_CAPAN), anion filtering capacity (FILT_CAPAN), solids and pathogenic microorganisms storing capacity (STOR_CAPSO), solids and pathogenic microorganisms filtering capacity (FILT_CAPSO), non-polar organic chemicals storing capacity (STOR_CAPNP), non-polar organic chemicals filtering capacity (FILT_CAPNP), nonaqueous Phase Liquids (NAPL) storing capacity (STOR_NAPL), nonaqueous Phase Liquids (NAPL), filtering capacity (FILT_NAPL). As input, variables from the European Soil Database have been used</p>
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Detailed Description

This dataset contains 10 maps that relate to the soil's storing and filtering capacity in Europe (the EU only):

- cation storing capacity (STOR_CAPCA)
- cation filtering capacity (FILT_CAPCA)
- anion storing capacity (STOR_CAPAN)
- anion filtering capacity (FILT_CAPAN)
- solids and pathogenic microorganisms storing capacity (STOR_CAPSO)
- solids and pathogenic microorganisms filtering capacity (FILT_CAPSO)
- non-polar organic chemicals storing capacity (STOR_CAPNP)
- non-polar organic chemicals filtering capacity (FILT_CAPNP)
- nonaqueous Phase Liquids (NAPL) storing capacity (STOR_NAPL)
- nonaqueous Phase Liquids (NAPL) filtering capacity (FILT_NAPL)

As input, variables from the European Soil Database have been used. The calculation is described in detail in the JRC technical report "Makó, A., Kocsis, M., Barna, GY., Tóth, G. 2017. **Mapping the storing and filtering capacity of European soils**; EUR 28392; doi:10.2788/49218; P54; Publications Office of the European Union, Luxembourg".

The calculated values were converted to a 10-point scale, where the code 1 represents the lowest and the code 10 the highest capacities. To transform the estimated values (continuous scale variables) into this limited number (10) of distinct categories the Visual Binning method was used (SPSS, Transform, Visual Binning, Equal Percentiles Based on Scanned Cases). This method generates binned categories with an equal number of cases in each bin using the aempirical (empirical distribution function with averaging) algorithm for percentiles.

The 10 maps come as 1 shapefile with an attribute table that contains 10 fields corresponding to the 10 parameters mentioned above.

The geometry of the shapefile is the one of the European Soil Database.

Metadata

Data Access


<https://esdac.jrc.ec.europa.eu/content/maps-storing-and-filtering-capacity-soils-europe>

References:

[Makó, A., Kocsis, M., Barna, GY., Tóth, G. 2017. Mapping the storing and filtering capacity of European soils; EUR 28392; doi:10.2788/49218; P54; Publications Office of the European Union, Luxembourg](#)

50 Maps of preservation capacity of cultural artefacts and buried materials in soils in the EU

Short Description

	Maps (2016) that indicate the preservation capacity of cultural artefacts and buried materials in soils in the EU, for bones, teeth and shells (<i>bones</i>), organic materials (<i>organics</i>), metals (Cu, bronze and Fe) (<i>metals</i>), stratigraphic evidence (<i>strati</i>).
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Detailed Description

The European Commission Joint Research Centre performed a **study** that identifies factors affecting the fate of buried objects in soil and develops a method for assessing where preservation of different materials and stratigraphic evidence is more or less likely in the landscape. The results inform the extent of the cultural service that soil supports by preserving artefacts from and information about past societies. They are also relevant to predicting the state of existing and planned buried infrastructure and the persistence of materials spread on land. Soils are variable and preserve different materials and stratigraphic evidence differently. This study identifies the material and soil properties that affect preservation and relates these to soil types; it assesses their preservation capacities for bones, teeth and shells, organic materials, metals (Au, Ag, Cu, Fe, Pb and bronze), ceramics, glass and stratigraphic evidence. Preservation of Au, Pb and ceramics, glass and phytoliths is good in most soils but degradation rates of other materials (e.g. Fe and organic materials) is strongly influenced by soil type. A method is proposed for using data on the distribution of soil types to map the variable preservation capacities of soil for different materials. This is applied at a continental scale across the EU for bones, teeth and shells, organic materials, metals (Cu, bronze and Fe) and stratigraphic evidence. The **maps** produced demonstrate how soil provides an extensive but variable preservation of buried objects.

The **results** of the study have been published: "Predicting the preservation of cultural artefacts and buried materials in soil", Mark Kibblewhite, Gergely Tóth, Tamás Hermann, Science of The Total Environment, Volume 529, 1 October 2015, Pages 249–263.

The 4 **maps** come as 1 shapefile with an attribute table that contains 4 fields corresponding to the 4 parameters mentioned above:

- bones, teeth and shells (*bones*)
- organic materials (*organics*)
- metals (Cu, bronze and Fe) (*metals*)
- stratigraphic evidence (*strati*)

Data Access


<https://esdac.jrc.ec.europa.eu/content/maps-related-predicting-preservation-cultural-artefacts-and-buried-materials-soils-eu-0>

References:

Kibblewhite M., Tóth G. and Hermann T. 2015 . "Maps of preservation capacity of cultural artefacts and buried materials in soils in the EU", dataset/maps downloaded from the European Soil Data Centre

51 European map of soil suitability to provide a platform for most human activities (EU28)

Short Description

	<p>This dataset (map)(2016) presents the suitability of soil as a platform for most human activities in the EU. Calculation of suitability was done using various properties of the European Soil database (soil type, soil water regime, limitation to agricultural use, depth to rock, land use) and slope of the terrain.</p>
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Detailed Description

Human activities on the earth's surface are linked to the various types of land uses. Most of the human activities are performed on artificial surfaces, such as urban and industrial areas or in areas of commercial, transport or sport facilities. Therefore the evaluation of the partial soil quality index for the soil function to provide platform for most human activities are considered with regards to the suitability for these artificial surfaces. Other main areas of human land use, such as agriculture and forestry are considered in other domains of the evaluation framework. Artificial surfaces means built environment, where the soils function is to support the construction. Although advanced construction technologies make development on all kind of soils possible, the costs may rise dramatically on less suitable lands and it can also cause environmental problems (contamination, flooding etc).

Suitability of a given soil is calculated on the basis of its structural stability. The strength of the soil is considered in terms of resistance against compaction and shearing stress. Our basic standpoint for the evaluation of soil strength is: the more stable the soil structure is, the higher its supporting ability for construction and other human activities. Most guidelines for construction purposes apply a kinematic approach for the suitability evaluation of soils of construction sites (Turner and Schuster 1996). Assessments also take the slope and underlying hydrological parameters into account.

Although soil susceptibility to compaction can be regarded as a good proxy of structural stability, from the viewpoint of construction suitability, mineral soils mostly show little differences.

Formulas for calculating soil strength based on effective stress and failure criterions were also found to be difficult to apply for our continental scale evaluation, mainly for two reasons. First, because of their scale dependency; second because of their heavy data requirements.

Metadata

Data Access


<https://esdac.jrc.ec.europa.eu/content/european-map-soil-suitability-provide-platform-most-human-activities-eu28>

References:

Tóth G. and Hermann T. 2015 . "European map of soil suitability to provide a platform for most human activities (EU28)", dataset/map downloaded from the European Soil Data Centre,

52 Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)

Short Description

	<p>This dataset (maps)(2016) indicates the availability of Raw Material (organic soil material and soil material for constructions) from soils in the European Union.</p>
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Detailed Description:

This dataset consists of 3 GIS maps that indicate the soil biomass productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27) and that corresponds to the figures 4, 5 and 6 from the publication "Continental-scale assessment of provisioning soil functions in Europe", Gergely Tóth, Ciro Gardi, Katalin Bódis, Éva Ivits, Ece Aksoy, Arwyn Jones, Simon Jeffrey, Thorum Petursdottir and Luca Montanarella, Ecological Processes 2013 2:32;.

Metadata

The GIS maps cover the EU27. The maps are Geotiff rasters with resolution of 1km. Coordinate system (ETRS_LAEA_10_52) and alignment of pixels are according to INSPIRE recommendation

Data Access

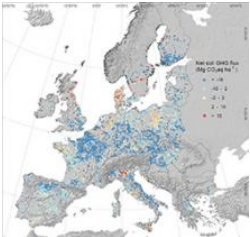
<https://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-croplands-and-forest-areas-european>

References:

"Continental-scale assessment of provisioning soil functions in Europe", Gergely Tóth, Ciro Gardi, Katalin Bódis, Éva Ivits, Ece Aksoy, Arwyn Jones, Simon Jeffrey, Thorum Petursdottir and Luca Montanarella, Ecological Processes 2013 2:32; DOI: 10.1186/2192-1709-2-32.

53 Soil GHG fluxes using LUCAS soil-DayCent (for EU)

Short Description

	Soil fluxes (CO ₂ and N ₂ O) under mitigation scenarios using the LUCAS soil-DayCent model integration framework.
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Detailed Description:

Here we run the state-of-the-art biogeochemistry model DayCent on approximately 8,000 soil sampling locations, classified as arable, from the most extensive harmonized land use and soil inventory network for the EU (LUCAS survey). The model was driven by measured soil characteristics and complemented with updated datasets, including a RPC4.5 climate change scenario. Our main idea was to quantify the net soil GHG fluxes, simulating two representative mitigating practice options starting in 2016, in comparison with a baseline of current agricultural practices. The first scenario was an integrated crop residue retention and lower soil disturbance management (IRS) while, the second saw the introduction of N fixing cover crops incorporated before the successive main crop (CC), generally referred to as 'green manure'.

Metadata

Spatial Coverage: European Union 28 Member States

Time Reference: 2015-2010

Format: dbf

Projection: ETRS89 Lambert Azimuthal Equal Area

Data Access


<https://esdac.jrc.ec.europa.eu/content/soil-ghg-fluxes-using-lucas-soil-daycent>

References:

Lugato, E., Leip, A., Jones, A. 2018. [Mitigation potential of soil carbon management overestimated by neglecting N₂O emissions](#). *Nature Climate Change* **8**:219–223

54 N₂O emissions from agricultural soils in Europe

Short Description

	<p>This dataset derives from the integration of the LUCAS soil survey with the biogeochemistry process-based model DayCent. The model was ran for more than 11,000 LUCAS sampling points under agricultural use, assessing also the model uncertainty. Meta-models based on model outcomes and the Random Forest algorithm were used to upscale the N₂O emissions at 1km resolution.</p>
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Detailed Description

It contains:

1) Average nitrous oxides emissions in soil LUCAS points

This dataset contains the average (2010-2014 time period) emissions of N₂O-N (kg ha⁻¹ yr⁻¹) simulated in soil LUCAS points.

The format is in dbf; the dataset can be joined with the LUCAS soil properties shapefile (available in ESDAC) by the 'sample_ID' field.

The average N₂O-N emissions and standard deviation were used to build Figs 3 and 4 of the cited paper.

2) Nitrous oxides emissions in agricultural soils of the EU

This dataset contains the N₂O-N emissions (kg N ha⁻¹ yr⁻¹) at 1 km² resolution in the EU, obtained by the meta-model MT1 (Fig 6) and MT2.

Format: geoTiff

Resolution: 1 km²

Projection: ETRS89 Lambert Azimuthal Equal Area

Metadata

Data Access

<https://esdac.jrc.ec.europa.eu/content/n2o-emissions-agricultural-soils>

References:

Lugato E, Paniagua L, Jones A, de Vries W, Leip A (2017) Complementing the topsoil information of the Land Use/Land Cover Area Frame Survey (LUCAS) with modelled N₂O emissions. PLoS ONE 12(4): e0176111. <https://doi.org/10.1371/journal.pone.0176111>

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of the European Union

doi: 10.2760/74273

ISBN 978-92-76-25322-8