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BOOK OF ABSTRACTS

Block B

B3 Indicators for soil ecosystem services

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B3 Indicators for soil ecosystem services

Session Description

Involved projects: SERENA, MINOTAUR, WP6

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European soil policy is developing towards a regular assessment of soil health on the basis of monitoring by the Member States of the chemical, physical and biological condition of soils and their actual capability to contribute to the provision of ecosystem services (ES). This call invites contributions on indicators for soil health, including specific references and target values associated to healthy soils, and approaches for monitoring, defining sampling scheme, modelling and mapping of indicators and their linkage to ES. Methodological approaches aimed to the characterization of bundles of soil ES and soil threats are particularly welcome.

What is the consequence of the definition of soil ecosystem services, soil threats, and indicators used to map them, on bundles mapping at EU scale?

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Keywords: Soil ecosystem services, soil threats, bundles, European scale

Soils are diverse ecosystems consisting in living and non-living components that interact in various ways, and from such interactions is that we derive the supply of a wide range of ecosystem services. Despite their significant role, soil ecosystem services (SESs), soil health and soil security are increasingly endangered by soil threats (STs). While there is an increasing amount of information accessible regarding individual STs and SESs, further studies are needed to understand the interactions of multiple SESs and STs at the same time, also known as bundles. One potential approach to define these bundles would be through the critical analysis of STs and SESs indicators used in existing exercises assessing individual STs and SESs. Through a systematic literature search we reviewed the indicators used for the different STs and SESs mapping at the EU level. We found 32 and 17 mapping studies for ST and SES, respectively. The considered STs are soil organic carbon loss, erosion, and

compaction, while SESs includes climate regulation and carbon sequestration, hydrological control, biomass production, and erosion control. For the considered STs/SESs, various indicators exist in the literature, with an average of seven indicators per ST/SES. For many SESs/STs a consensus on the indicator used seems not to exist, as each study defines its own indicator. Five distinct reasons explained this lack of consensus: i) the indicators targeted specific but different sub-services or sub-threats, ii)different parts of the ecosystem are considered when assessing SESs or STs, iii) the STs and SESs are assessed at different steps iv)the ST is expressed as a process or as the state of the soil resulting from this process (or not), v)the potential or the current ST/SES is assessed. Due to the differences in SES/ST conceptions and indicators used to estimate them, we expect very different maps for a given SES/ST at the EU scale. Consequently, it is important to consider the varying significance and spatial patterns of the existing maps for each individual ST/SES when reusing and combining them to create bundles or other products. It is crucial to carefully assess the relevance of the resulting products, as certain combinations are particularly meaningless. Combining various sub-threats, such as different types of erosion, to assess total soil loss or multiple sub-services like nutrient and water provision for plants to evaluate biomass provisioning, is a highly efficient method for assessing complex ST and SES.

Recommended indicators to assess soil health: proposal from EJP SOIL

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More than ever, the important role that soil plays in sustaining life is recognized. This is, amongst others, expressed in high level objectives at EU scale and in the UN Sustainable Development Goals (SDGs). Achieving these targets and goals is in large part reliant on sustainable land and soil management. As discussed by EEA (2023), soil quality is often described using soil indicators. These are observed and evaluated soil properties, which can indicate the degree to which soils fulfil expected functions as needed for the wellbeing of crops, livestock, and consequently, human society. To be able to use indicators for evaluation purposes, reference values, thresholds and target values are also needed. It is, however, not straightforward to set reference values, thresholds and target values, nor

to select appropriate indicators, because such values, and even indicators, likely should vary depending on e.g. land use, soil type, climate, degradation type, soil management status.

Several past (e.g. EU soil research projects) and recent initiatives have proposed and published soil indicators and reference, thresholds or target values, including EEA (2023), the Soil Monitoring Law proposal (SML, EC 2023) and the EU soil dashboard (JRC 2023). Considering those documents and also existing literature, a large group of soil scientists from EJP SOIL reviewed information on indicators and threshold setting, dealing with a range of indicators that can, on the one hand inform on soil degradation, and on the other about soil fertility also. Adding their expertise and knowledge they provided recommendations for the selection of soil indicators to be used for accounting soil fertility and degradation changes. Topics like selection of indicators, determining the costs of soil monitoring by using field/laboratory methods as well as Remote Sensing (RS)/Proximal Sensing (PS) methods, scale effects, and modelling were also included. Depending on the indicators to be measured best periods and methods to sample as well as sampling frequency were also discussed.

A reasonable agreement was found between the main recommendations and the indicators proposed by the Soil Monitoring Law, the EUSO soil dashboard and EEA (2023), except for certain indicators (e.g. biodiversity, soil sealing, Available Water Content) and for threshold values that should be discussed and adapted to local conditions.

Keywords: soil indicators; soil sampling; soil threats; soil fertility

Comparing soil fauna parameters and ecological indices to evaluate agronomic tillage and fertiliser management in European long-term experiments

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Soil fauna actively contribute to the maintenance of various soil functions and ecosystem services, and agricultural management practices have a varying degree of influence on soil fauna biodiversity. Therefore, several groups of organisms should be considered simultaneously for a comprehensive assessment. The evaluation of the effect of farming practices on soil fauna is commonly carried out using several types of indices: (i) abundance indices, indicating the quantity of animals; (ii) taxonomical indices, evaluating taxa diversity; and (iii) functional indices, measuring the roles of taxa in ecosystems. Still, the complexity of factors involved in the agricultural management and sustainable use of soil resources, as well as the composition and diversity of the soil organisms in the different soils, do not allow to have clear evidence on the priority indices suitable for the precise and accurate monitoring detection of changes in the soil status.

This work will compare the three categories of indices mentioned, within the EJP-MINOTAUR project. The aim is to determine which type of indices are most sensitive in detecting differences in soil fauna communities when organic or mineral fertilisation practices and standard, reduced or no tillage management are applied.

The impacts of farming practices on soil fauna abundance and diversity were evaluated in nine European Long Term Agricultural Experiments (LTEs) across a gradient of pedoclimatic conditions, employing different tillage systems and fertilisation practices. In autumn 2022, these LTEs were sampled to assess soil health, also on the basis of fauna diversity indices. Specifically, nematodes, microarthropods, and earthworms were selected as representative of micro-, meso-, and macrofauna biodiversity, respectively.

Overall data variability resulted very high, notably that of abundances (coefficient of variation >83% in all cases) probably due to different pedoclimatic conditions. However, it is noteworthy that the abundance data for all micro-, meso-, and macrofauna showed greater overall variation than that showed by both diversity indices and ecological indices, probably due to the aggregate distribution of edaphon. Generalized linear mixed models was applied setting (i) tillage and fertilisation and (ii) LTE sites as fixed and random effect, respectively. Comparison of treatments was complicated by crossing effects, that necessarily reduce the number of direct relations. Both no tillage and reduced tillage showed a greater micro- and mesofauna abundance than in standard tillage. Likewise, the QBS-ar ecological index concerning mesofauna was significantly higher in no tillage than in standard tillage.

Our results suggest that the development and application of appropriate ecological indices not only will facilitate a more accurate and comprehensive evaluation of soil fauna biodiversity, but it will even contribute to the formulation of targeted conservation and to foster sustainable management strategies aimed at promoting long-term soil health.

Keywords: nematode; microarthropod; earthworm; soil health; alpha biodiversity

Comparing soil properties between LUCAS Soil and National Soil Information Monitoring System (N-SIMS): major differences and implications for future policies to evaluate soil quality

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Soil is crucial for life as it provides us food and fibre, regulates water and climate, and hosts thousands of organisms. A recent assessment states that 60-70% of soils in Europe can be considered as unhealthy due to different soil degradation processes. To protect this non-renewable resource at human scale, we first need to acquire knowledge about it and implement soil monitoring to determine the current soil properties, assess the soil status and detect soil changes over time.

In Europe, two types of monitoring networks currently exist in parallel. Many EU Member states (MS) developed their own soil information monitoring system (N-SIMS), some of them in place for decades. Since 2009, a European topsoil monitoring programs has been established by the European Commission based on the Land Use/Land Cover Area Frame Survey (LUCAS) led by EUROSTAT. This survey was repeated several times since 2009 and offers a consistent spatial database. Nevertheless, N-SIMS and LUCAS Soil were established for different purposes with diverging monitoring strategies.

To evaluate soil quality and support European policies, there is a clear need to establish reference values to assess soil health, based on reliable soil data. Consequently, a question remains whether the soil properties obtained by both monitoring programs (N-SIMS and LUCAS Soil) are comparable, and what could be the limitations of using either one dataset or the other.

In the context of workpackage 6 of EJP Soil, a comparison of statistical distribution of three soil properties (organic carbon, pH and clay content) has been conducted among 12 different EU countries including BE, DE, DK, EE, ES, FR, DE, HU, IT, NL, PL, SE and SK. In addition, a comparison of the results of two indicators including soil loss indicator OC/Clay and pH classes using N-SIMS and LUCAS Soil datasets has been conducted. The results underlined substantial differences in soil properties statistical distributions between N-SIMS and LUCAS Soil in many countries, particularly for woodland and grassland soils, affecting the evaluation of soil quality using indicators. Such differences that might be explained by both the monitoring strategy (spatial distribution of sites) and sampling protocols exposes the significance of selecting reliable data to support European and national policies. Those results advocate for a further effort of dialogue between national institutions conducting soil monitoring and LUCAS Soil to strengthen future soil monitoring and provide reliable data to reach the objectives of healthy soils.

High-resolution thematic soil mapping at EU level based on the combined use of LUCAS and national soil monitoring data in the framework of the EJP SOIL project

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The EJP SOIL project aims to provide the research and policy-making community with detailed and harmonised EU-wide thematic maps of agricultural soils, based on a common methodology, to improve the effectiveness of European agricultural and environmental policies, to contribute to European international reporting. Currently the national and the EU reporting are performed independently, which results in contrasting figures on soil status. Since national soil data sharing constraints are in place, a bottom-up approach is preferred to include as much relevant data as possible. However, this can in return, generate transboundary issues.

The specific objective of the EJP SOIL mapping exercise is to set-up a digital soil mapping procedure to: i) support participants in a bottom-up approach allowing countries to produce high-resolution thematic soil maps, ii) develop soil property maps based on the national databases (SIMS) and the LUCAS Topsoil database, iii) solve the problems of transboundary issues, iv) provide spatially explicit uncertainty estimates.

To achieve this, both top-down and bottom-up mapping approaches have been applied, using the same mapping algorithm (quantile random forest) but with different input data: i) EU-level mapping, using the most predictive EU-level auxiliary variables and LUCAS point data ii) country-driven mapping, using a) EU-level auxiliary variables, using national point data (SIMS), b) EU-level auxiliary variables, using both LUCAS and national point data (SIMS), c) the best covariates among EU-level and national covariates, using LUCAS point data, d) the best covariates among EU-level and national covariates, using national point data (SIMS), e) the best covariates among EU-level and national covariates, using both LUCAS and national point data (SIMS).

The spatial resolution chosen for the mapping exercise was a 100 m grid, which implied the production of an EU-wide covariate set at 100 m in INSPIRE-compatible projection by ISRIC. Soil properties commonly observed in both LUCAS and SIMS were selected for the maps, of which the methodologically most consistent pH was mapped first. In parallel, other activities aimed at comparing and developing transfer functions among LUCAS and SIMS are carried out in the EJP SOIL WP6.

Keywords: Digital Soil Mapping, EU-wide covariates, combined monitoring datasets

Harmonized soil biodiversity database to describe ecological status and soil health (MINOTAUR database)

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Existing differences in soil biodiversity data quality and geographic distribution seriously hamper effective use of available knowledge. The MINOTAUR project aims to optimize the data coupling, harmonization and analysis of soil biodiversity from various national and European data sources to support long-term harmonized European soil information and soil health monitoring. A standardized template for each data type was developed to collect soil biodiversity data. Soil biodiversity (macro fauna to microbes) data were collected 59 data sources (dataset, database, data warehouse) and 62 European projects. Collected biodiversity data along with meta-data were assessed and harmonized using standardized templates. The OpenADOM (Open source Application for Data Organization & Management), platform enables the creation of Information Systems (IS) quite rapidly and supports data sharing using FAIR principles. OpenADOM enables to describe the data model using a specific syntax with indentation to represent data structure and nesting. Data from different soil biological groups (macro, meso and micro fauna, bacteria and fungi) are linked to metadata (e.g. country, soil type, agricultural practices…). So far, macrofauna data were collected from over 9000 samples across 35 European countries. The use of OpenADOM platform allowed the rapid development of an IS for the MINOTAUR database, which otherwise would have been more time consuming considering the diverse set of data and meta-data types to be described and harmonized. The Minotaur database provides valuable information on harmonized soil biodiversity, supporting policy analysis and promoting soil biodiversity in global sustainability efforts.

Keywords: soil biodiversity, harmonization soil information systems, soil health, soil health monitoring, harmonized metadata.

An approach for mapping Net Ecosystem Productivity (NEP) as a pragmatic indicator of soil ecosystem service greenhouse gas (GHG) regulation including carbon sequestration in EU Member States

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Modelling the spatio-temporal distribution of Soil Ecosystem Services (SESs) can provide insights to identify their drivers (e.g., land use, agricultural management), improving our understanding of SESs and their relationships, and the implementation of environmental policies. The SES regulation of greenhouse gas (GHG) fluxes from agricultural soils in EU, would especially benefit from such spatio temporal modelling.

Within SERENA project funded by EJP SOIL EU programme, to fill this gap, we are developing an approach to be included in a cookbook for the estimation of the net ecosystem productivity (NEP Gross primary production, GPP and Ecosystem respiration, R_{eco}) as pragmatic indicator of the GHG regulation selected in the first stage of the project. The selection was based on the ranking of different types of GHG indicators from a literature review. Based on different criteria (scientific soundness, data availability, and ability to convey information), we were not able to select an "ideal" indicator which provided complete information (such as the sum of all GHG fluxes) for this SES, but instead selected NEP as a "pragmatic" GHG indicator. At the next stage, we realized that methods to estimate NEP based on the analysis of light-use efficiency models were impractical to be implemented by project partners. It was also suggested not to use mechanistic models for assessing NEP since methods should be easily applicable, even without scripting knowledge. Thus, we focused on a newly developed

empirical model that could relate NEP to spatially exhaustive environmental covariates and be applicable with open GIS software. This was done by relating the well-known Fluxnet database of eddy covariance measures to spatially exhaustive covariates for agricultural areas (3600 8-day estimates of CO_2 fluxes). The approach for mapping NEP in EU member states includes three main stages:

1) GPP estimation from Fluxnet stations that grow/have grown wheat in the EU (and one US station) were related to the MODIS 8-days GPP values, monthly average temperature (WorldClim), and a recent high temporal resolution database of daily soil volumetric moisture.

2) R_{eco} estimates from the selected Fluxnet stations were fitted with a thermal performance model to monthly average temperature (WorldClim).

3) The NEP estimate is calculated as GPP-R_{eco}, and after the calculation, there is an additional last step where its finer spatial distribution is made explicit with the EU-2018 crop layer at 10-m resolution, published by JRC, for locations recorded as wheat.

Whereas the fitting quality for each independent component of NEP was relatively good, the overall fitting of the NEP indicator was not. Improvement could be obtained by applying other model fitting techniques (e.g. Gaussian Process Regression), using high-resolution environmental variables (with a weekly step), and trying to incorporate soil properties that have a much lower temporal variability (scales of several years) than the temporal scale of the main CO_2 flux data (weekly, seasonal and yearly). However, such improvements most certainly would come with a cost in terms of cookbook applicability.

Keywords: Soil ecosystem services, greenhouse gas and climate regulation, digital soil mapping, net ecosystem productivity, cookbook

Assessment of temporal dynamics of soil microbial biodiversity on chronosequences: preliminary results

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Soil ecosystems provide habitats for diverse groups of organisms. Monitoring soil biodiversity over the long-term is necessary to identify proper soil management practices and to preserve soil ecosystem services. Archived soil series offer promising opportunities to characterize microbial temporal dynamics. However, soil microbes are usually studied using cryopreserved fresh soils, while almost all archived soils are dried and stored at room temperature.

The aims of the present project are to assess the feasibility of using dried soil samples for the study of microbial biodiversity, to estimate the potential biases compared to frozen samples, and then to use such soils to study the temporal trends of microbial communities in response to environmental changes.

Soil samples were obtained from two long term experiments located in Italy (CREA) and in Slovenia (ULBF). These soils were subjected to different management practices, and were collected in 2011 (or 2012), stored both as frozen and dried (oven-dried or air-dried). Thereafter, the same soils were collected in 2022 and again stored frozen and dried, though for a shorter period of time (7-8 months). DNA was extracted from all these samples and used to quantify the abundance of bacterial functional genes, for sequencing of bacterial V3-V4 16S rDNA to assess the bacterial composition and will also be used for enzymatic analyses.

For CREA samples, we observed no effect of storage conditions on bacterial communities, while the effects of tillage and sampling year were prominent. Conversely, for ULBF, different storage methods influenced the composition of the bacterial communities, while the effect of the different tillage practices resulted masked. It is possible that different physicochemical soil properties or the different soil drying procedure might determine a different preservation of bacterial DNA in dried soils.

Future perspectives include evaluating the effects of different drying procedures and studying the enzymatic activity of these soils, to better understand the potential use of archived dried soil samples for soil biodiversity monitoring.

Keywords: soil archive; soil microbiota; microbial DNA; biodiversity monitoring

The EJP SOIL ARTEMIS framework for on-farm monitoring of the impact of agroecological systems on soil quality and soil ecosystem services

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Agroecology represents an agricultural approach that focuses on sustaining productivity while optimizing local resources and mitigating negative environmental and socio-economic impacts. Understanding the efficacy of agroecological systems and promoting their adoption necessitates comprehensive monitoring, encompassing socio-economic and environmental factors, soil quality, and associated ecosystem services. Through approaches such as soil health assessment, ecosystem services assessment, and farmer participatory monitoring, we can evaluate the outcomes of agroecology and make informed decisions to support sustainable agricultural practices. Integrating these methodologies into on-farm assessments further enriches our comprehension and application of agroecology since it allows for the inclusion of a more diverse, and thus more realistic, set of employed agricultural practices.

Within ARTEMIS WP5, our objective is to devise a monitoring framework comprising direct and indirect indicators and tools tailored for on-farm monitoring of soil health and soil-related ecosystem services. This framework aims to ascertain whether implemented agroecological practices can sustain or enhance soil health and soil-related ecosystem services. Recognizing the vast array of ecosystem services offered by soil and the multitude of management options, we conducted an inventory of soil and management-related ecosystem services, categorized according to Paul et al. (2021), and solicited input from WP partners to rank their relevance to the scope of ARTEMIS. To refine and select indicators, we disseminated an inventory of potential soil and plant indicators, along with relevant properties for monitoring the impact of agroecological practices. These indicators were evaluated and ranked by WP partners to facilitate on-farm assessments.

The final goal of the monitoring framework task is to provide a catalogue of direct and indirect (e.g. remote sensing products, models, and tools) indicators for monitoring soil health, while also establishing correlations between these indicators and specific soil-related ecosystem services. Drawing from inventory rankings and consultations with farmers and agroecology experts, we have identified a list of direct indicators and significant ESS for inclusion in ARTEMIS. These indicators serve as a foundation for ongoing monitoring efforts in selected farms, fostering a basis for a long-term assessment and monitoring farm network.

Keywords: Ecosystem services; soil health, agroecology, indicators

Scientific indicators and stakeholders’ perceptions on soil threats in France: how do they compare?

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Soils are under multiple threats on a global scale, with varying levels of intensity and nature in different regions. Therefore, it is crucial to assess soil threats at a local level using specific indicators. Scientific indicators have been developed to accurately assess soil health, yet they can be challenging to implement at a local scale. As some stakeholders have a good knowledge of soil condition, the objective of this paper is to determine whether stakeholders' perception of soil threats can be used as a complementary indicator. The study focuses on five soil threats: erosion, artificialisation, compaction, soil organic carbon (SOC) loss, and contamination. It is based on 1,951 responses from a participatory stakeholder consultation conducted in France in 2021. We explored stakeholders’ prioritization of soil threats and elaborated perception maps at the departmental scale. We then compared stakeholders’ perception maps with scientific indicator maps per soil threats at the departmental scale. Our findings indicate that stakeholders consider artificialisation to be the most important threat in France. The spatial distribution of soil threats based on stakeholders’ perceptions and scientific indicators matches in 43% of the departments for SOC loss, and in over half of the departments for erosion (50%), artificialisation (63%), compaction (57%), and contamination (74%). However, disparities remain in certain departments and depending on the threat. These disparities can be explained by biases in the used indicators (scientific or stakeholders’ perception) or in the comparison. It can be concluded that, when these biases are taking into consideration, stakeholders’ perception can be used as an indicator for soil threats and can supplement existing scientific indicators.

Keywords: Multi-actor consultation; Soil challenge; Soil degradation; Soil health; Stakeholder perspective

SoilManageR – An R package to derive soil management indicators

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Sustainable agricultural soil management is essential for restoring, maintaining, and enhancing soil health. Many studies investigating soil management focus on comparison of single management factors (e.g., no-till vs conventional tillage, with and without cover crops), thereby overlooking other management differences that could also be crucial. Moreover, on-farm studies have revealed that classifying fields into broad categories such as organic, no-till, and conventional systems can obscure significant management variations within each category (Büchi et al., 2019). Transforming nominal management data into continuous soil management indicators offers an approach to analyse gradients in soil management intensities. While an increasing number of studies are adopting soil management indicators, the comparability of results across studies is hindered by the lack of standardized management data and readily available tools for calculating management indicators.

To tackle these limitations, we developed the SoilManageR package for R. This package includes routines for deriving numerical management indicators and a comprehensive template for collecting management information in different contexts (field experiments, monitoring programs, farm networks). The current version of SoilManageR incorporates indicators for estimated soil carbon input, tillage intensity, soil cover, nitrogen fertilization intensity, and livestock integration, with the potential for further indicators to be added in the future. The routines allow to work with different levels of data availability and the package contains tables with default values that were extracted from the literature to represent the conditions of temperate agro-ecosystems.

We illustrate the utility of the SoilManageR by comparing soil management between Swiss agricultural long-term field experiments and management data collected in different on-farm networks. Additionally, we demonstrate that the soil management indicators are closely correlated with differences in earthworm populations and soil organic carbon contents.

Keywords: soil organic carbon input, tillage intensity, soil cover, long-term experiments, monitoring, on-farm studies

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New soil quality monitoring tools in the Soil Web Portal of Sardinia (Italy): automatic calculation of SEs at regional scale

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Keywords: ecosystem services; quality indicators; soil quality monitoring

According to the definition of the MEA - Millennium Ecosystem Assessment (2005), Ecosystem Services (ES) are "the benefits that people obtain from ecosystems" and can be divided into four broad categories: life support, provisioning, regulation and cultural values, the latter category not addressed in this paper.

This study addressed how to calculate the SEs of Sardinian soils through the determination of suitable pedofunctions applicable at the regional level, in line with other European soil protection projects, including the SOIL4LIFE - Save Our Soil For Life project, which focuses in particular on the quantification of soil Ecosystem Services (SEs).

Good knowledge of the soil characteristics of the territory, supported by adequate data availability, was the starting point for this study, which made it possible to standardise SEs assessments on a regional scale and introduce new tools for monitoring soil quality.

The main source of information for the analysis carried out was provided by the more than 5,000 pedological data in the Sardinian Soils Database (DBSS), the actual engine of the Sardinian Soils Web Portal, which made it possible to normalise the SEs on a regional scale and standardise the pedofunctions developed.

Eight ecosystem services provided by soil were considered in the study: BIO - biodiversity of soil organisms, BUF - purification capacity, CLI - effect on microclimate, CSP - potential carbon stock, PRO - agricultural productivity, SUP - infrastructure support, WAS - water storage and WAR - deep water infiltration.

Each service was described by means of indicators based on measured (or quantitatively estimated) properties, which were then standardised from 0 to 1 for the entire regional territory so that they could be used in different spatial contexts. Subsequently, a Soil Quality Index IQ, obtained as the sum of the indicators, was determined in order to have a summary picture of the provision of the SEs.

The automatic SEs evaluation method thus obtained represents an important step forward in the management and conservation of natural resources.

Furthermore, the integration of these new algorithms for the automatic calculation of SEs into the Sardinian Soil Web Portal provides easy and transparent access to soil information for researchers, farmers, planners and other interested stakeholders.

In summary, the DBSS and the Sardinian Soils Web Portal play a key role in providing reliable data and assessment tools to support spatial planning and natural resource management, thus contributing to the environmental sustainability and socio-economic development of the region.

Adaptability of tillage practices for waterlogging risk reduction on two soil types with different texture

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The occurrence and severity of extreme meteorological events is predicted to increase even under moderate climatic conditions. This situation is the reason to revise management practices adaptability in different soils. A high amount of water during crop vegetation and post-vegetation period may involve the risk of short- and long-term waterlogging on glacial till.

Four field trials were carried out on loamy *Dystric-Epihypogleyic Retisol ((Retisol* (L))*, Endocalcari-Epihypogleyic Cambisol ((Cambisol* (L)) and *Cambisol* (SL) of morainic genesis and on clayey *Endocalcary-Endohypogleyic Cambisol* ((*Cambisol* (CL/C)) of limnoglacial genesis in Lithuania. Three contrasting tillage practices were investigated in each of the experiment: 1) CT - Conventional tillage (stubble cultivation + deep (20-22 cm) mouldboard ploughing + presowing shallow cultivation), 2) RT - Reduced tillage (shallow stubble cultivation + presowing shallow cultivation), and 3) NT – no soil disturbance in *Cambisol* (i.e. direct sowing) or shallow (12-14 cm) mouldboard ploughing (ShPL) in *Retisol*.

Data revealed that the values of soil structure (water stable aggregate (WSA) and the ratio between large pores which enable water movement and storage (i.e. macropores and mesopores) and micropores) were lower in limnoglacial than in morainic soils. The increase in clay content significantly affected the increase in soil aggregate stability from topsoil to a deeper layer in the *Cambisol* (L, SL and CL/C) only. Hydraulic conductivity (Ks) significantly correlated with water saturation in morainic but not in limnoglacial soil. The increase in WSA contributed to increase in Ks by sequence from deeper to upper layer in morainic *Retisol* (L) only. The increase in clay content decreased water saturation in all soils and decreased Ks in morainic soils by sequence from upper to a deeper soil layer. The action of soil organic carbon (SOC) as driving factor for Ks was clearly pronounced in fine-textured soils rich in silt and clay (*Retisol* (L) and in *Cambisol* (CL/C)). The decrease in SOC content contributed to decrease in Ks by sequence from upper to deeper layer. SOC in morainic *Cambisol* (L and SL) acted as indirect factor. Ks and water flow character determined adaptability of different tillage systems. Thus, considering to possible climate change threats, the controlling of soil management intensity allows maintaining soil physical quality and environment sustainability. Reduction of management intensity is advisable by increasing the sequence of benefits: *Cambisol* (CL/C) → *Retisol* (L) → *Cambisol* (L) → *Cambisol* (SL). On *Cambisol* (CL/C) the long-term CT, on *Retisol* (L) the ShPL, on *Cambisol* (L) the RT and on *Cambisol* (SL) the long-term NT management could be considered as the tillage practices being suitable to prevent waterlogging condition.

Keywords: soil aggregation, water permeability, organic carbon, clay

An innovative approach based on machine learning and satellite data to assess the impacts of land-use change in Europe on soil carbon sequestration

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Keywords: LUCAS 1; Corine Land Cover (CLC) 2, SOC stock, land-use change 3, Soil Carbon Sequestration 4.

Understanding and evaluating the impact of land use changes on soil carbon stocks is essential for developing effective strategies to devise strategies that balance the demands of food security, biodiversity conservation, and greenhouse gas emissions. Countries need robust data to set realistic targets, track progress, and implement policies that contribute to global carbon reduction goals. One of the main challenges in estimating the impact of land use change on soil carbon sequestration is the large measurement uncertainty, mainly caused by limited availability and quality of soil carbon data (Somarathna, Minasny, and Malone 2017; Chen, Smith, and Yang 2015; Stanley et al. 2023). To resolve this issue, we estimate the impact of land use change on soil carbon across Europe, by leveraging field data from LUCAS survey and satellite data from Corine Land Cover (CLC). The LUCAS program, by conducting ground observations at approximately 22,000 diverse land cover points across the EU, stands as the most extensive and uniform topsoil data collection initiative in the European Union. To overcome the short duration of land use history of LUCAS, we train a machine learning model to predict land use since 1990, based on CLC data. We use this novel dataset to produce upscaled estimates of SOC response over time to LUCS with high precision across EU. We then use the estimates to publish country specific emission factors, compliant with the IPCC guidelines and the LULUCF Regulation, and ready for use in national GHG inventories. In assessing Soil Organic Carbon (SOC), we leverage topsoil samples from the years 2009, 2015, and 2018, a 10% subset of the LUCAS survey more generally aimed at monitoring land use change. For changes in land use, our methodology encompasses data from five sequential waves of the LUCAS survey in 2006, 2009, 2012, 2015, and 2018. However, it may take decades for carbon sequestration to achieve equilibrium (Poeplau et al., 2011). To augment the temporal and spatial scope of our carbon response analysis, we adopt a machine learning model to fit Corine Land Cover (CLC) on LUCAS data. The trained model was then used to predict missing values on land use based on CLC data since 1990, and detect probable land-use changes having occurred between 1990 and 2006. We then derive the carbon response function following land use change and provide country-specific guidelines for assessing the impacts of land use change on carbon response.

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SOIL-ES: a methodological proposal for evaluating soil ecosystem services at multiple scales for South American countries.

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Soils can offer multiple benefits to humans, through all their ecosystem functions and flows, relating to water, climate, biodiversity, and food production, known as Soil Ecosystem Services (SES). Comprehensive tools on how soil management practices and land use and land cover (LULC) changes affect SES and the consecutive benefits for society are essential to subsidize consistent decision-making. Due to their importance, we proposed and approved the project titled: *"Soil ecosystem services under sustainable intensification of agriculture: looking for innovative mapping and monitoring at multiple scales (SOIL-ES)"*. It aims to develop and adapt protocols for assessing SES at multiple scales, in intensive agricultural production areas in South American countries (Brazil, Colombia, Argentina and Uruguay). The SES and indicators being evaluated are: food provision (agricultural productivity), climate regulation (carbon stock), water regulation (water infiltration), erosion control (soil structure) and biodiversity maintenance (enzymes). The main land uses are: conventional soybean, integrated production systems (soybean-corn-pasture), conventional pasture, well-managed pasture, coffee and agroforestry. At the local scale, soil samples are being collected and analyzed; at the watershed scale, remote sensing and modeling tools are being used (for example, the InVESTt software); and at the regional scale, an SES zoning is being developed, based on soil types and natural or anthropic characteristics of the landscape. The project began a year ago and therefore does not yet have conclusive results.

National soil data in EU countries, where do we stand?

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At the European scale, soil characteristics are needed to evaluate soil quality, soil health and soil-based ecosystem services in the context of the European Green Deal. While some soil databases exist at the European scale, a much larger wealth of data is present in individual European countries, allowing a more detailed soil assessment. There is thus an urgent and crucial need to combine these data at the European scale. In the frame of a large European Joint Programme on agricultural soils launched by the European Commission, a survey was conducted in the spring of 2020, in the 24 European participating countries to assess the existing soil data sources, focusing on agricultural soils. The survey will become a contribution to the European Soil Observatory, launched in December 2020, which aims to collect metadata of soil databases related to all kind of land uses, including forest and urban soils. Based upon a comprehensive questionnaire, 170 soil databases were identified at local, regional and national scales. Soil parameters were divided into five groups: (1) main soil parameters according to the Global Soil Map specifications; (2) other soil chemical parameters; (3) other physical parameters; (4) other pedological parameters; and (5) soil biological features. A classification based on the environmental zones of Europe was used to distinguish the climatic zones. This survey shows that while most of the main pedological and chemical parameters are included in more than 70% of the country soil databases, water content, contamination with organic pollutants, and biological parameters are the least frequently reported parameters. Such differences will have consequences when developing an EU policy on soil health as proposed under the EU soil strategy for 2023 and using the data to derive soil health indicators. Many differences in the methods used in collecting, preparing, and analysing the soils were found, thus requiring harmonization procedures and more cooperation among countries and with the EU to use the data at the European scale. In addition, choosing harmonized and useful interpretation and threshold values for EU soil indicators may be challenging due to the different methods used and the wide variety of soil land-use and climate combinations influencing possible thresholds. The temporal scale of the soil databases reported is also extremely wide, starting from the '20s of the 20th century.

Keywords: survey; soil, data, indicator

Comparison of national and LUCAS soil datasets for soil health mapping and assessment

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Soil is a vital and dynamic component of our planet's ecosystem, and its health plays a fundamental role in sustaining life. Assessing soil health requires data and ways of interpreting the results. In this study, we focused on national and LUCAS datasets comparison for assessing and mapping soil health using pH as an indicator and a scoring function. Using mainland France as a pilot, we used the national RMQS dataset (2145 points) and the LUCAS dataset (2930 points) for the digital mapping of pH in combination with environmental covariates and a machine learning approach. A concept of soil districts (pedo-climatic zones) was implemented through stratification using soil, land use and climate types. We developed scoring functions based on mean, standard deviation, and Z scores using predicted pH values within each unique soil district. The "optimum is best" type of soil scoring function was used for health assessment. Our findings demonstrated that although spatial patterns of soil health levels were similar using both datasets, some regions still showed opposite results. These first set of results will be completed with other parameters such as SOC and developed within other countries. It also demonstrates the importance of appropriate choice of datasets in national soil health assessments.

Keywords: soil health, LUCAS, soil quality, digital soil mapping

The advantage of a dense grid: Comparing LUCAS Soil and the German Agricultural Soil Inventory regarding the distribution of soil organic carbon

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As part of the EJP SOIL project, work package (WP) 6.3 aims to develop a harmonized, reliable soil database for Europe. Data of national soil inventories were compared with the Land Use and Coverage Area frame Survey (LUCAS) Soil. The first nationwide Agricultural Soil Inventory in Germany (BZE-LW) had the goal to analyse soil parameters, such as soil organic carbon (SOC), texture, pH and determine the influence of site factors and management, e.g., tillage, fertilizer and crop rotations. Between 2011 and 2018, soil samples for chemical and physical analyses were collected at 3104 agricultural sites (2233 croplands, 819 grasslands, 50 permanent crops) in Germany using a systematic random approach (8 km x 8 km grid). Sampling was carried out in a profile pit with sampling depths of 0-10, 10- 30, 30-50, 50-70 and 70-100 cm. A multi-stage, stratified random sampling approach was chosen for LUCAS Soil. In the second LUCAS inventory (2015), 1274 German agricultural soils (816 croplands, 411 grasslands, 20 permanent crops) were sampled to a depth of 20 cm.

To align with the sampling depth of LUCAS Soil, the mean SOC content for the 0-20 cm layer of the BZE LW dataset had to be estimated, which was done by a mass-weighted averaging of the 0-10 cm and half of the 10-30 cm layer. In general, the SOC content and the density distribution of SOC of both inventories was similar. The average SOC content in croplands was in BZE-LW (17.4 g kg^{-1}, +/- 15.2 g kg^{-1}) and LUCAS Soil (17.4 g kg^{-1}, +/- 14.5 g kg^{-1}). For grassland the values differed insignificantly with 57.8 g $kg^{-1}$for BZE-LW, and 52.3 g $kg^{-1}$for LUCAS Soil.

A digital soil mapping exercise was performed to evaluate the difference in spatial prediction based on BZE-LW and LUCAS Soil samples. Certain regions, such as the grassland dominated Pre-Alps in southeast Germany, differed systematically. Across the entire region, SOC contents were displayed significantly lower in the LUCAS Soil map than in the BZE-LW map. As the sampling grid of the BZE-LW is more balanced and denser, a more detailed prediction of SOC was possible. The multi-stage, stratified random sampling of LUCAS Soil might thus have a critical disadvantage for regionalization approaches with high spatial resolution. A higher quality of creating SOC maps is shown in the BZE-LW map with a systematic random sampling approach.

Keywords: digital soil mapping, soil monitoring systems, soil organic carbon

Towards soil health assessment establishing a unified framework for monitoring soil microbial diversity across Europe

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Healthy soils play a crucial role in providing essential ecosystem services, such as food supply and climate regulation. With the ultimate aim of having all soils in healthy condition by 2050, the European Commission (EC) has recently proposed a Soil Monitoring Law. One of the key indicators of soil health is the diversity and resilience of its microbial communities. To facilitate the monitoring of soil health across Europe, in 2009, the EC's Joint Research Centre (JRC) initiated a large-scale soil survey named LUCAS Soil (European Land Use and Coverage Area Frame Soil). Since 2018, LUCAS Soil has expanded its scope to include the biological component.

In this context, a lack of evaluation in the comparability of biodiversity data obtained from LUCAS Soil and individual EU Member States is still present. Discrepancies may arise due to various factors, including sampling procedures and computational analysis methods.

As part of the European Joint Programme on Soil (EJP SOIL), efforts are underway to compare the JRC's approach with national strategies for biodiversity assessment. The main objectives are to harmonize the analytical procedures and define standard methodologies for soil health monitoring. In particular, our work aims to assess the impact of different sampling procedures on soil microbial analysis by comparing LUCAS method with a national approach (Italy).

In 2022 LUCAS campaign, the JRC collected 98 fresh soils samples in Italy. Among these, 17 sites were also sampled following the Italian strategies. Soil DNA was extracted from all samples and bacterial 16S (V3-V4 rDNA) and fungal ITS2 regions were sequenced and analysed following the Italian pipeline.

Preliminary findings suggest that environmental variables (e.g., land cover) exert a significant influence on the structure of soil microbial communities, while the sampling strategy itself has minimal or negligible effects. Further comparisons will be made between Italian and JRC soils once they will be sequenced and analyzed following LUCAS' pipeline. That will allow to evaluate the impact of different analytical methods, like DNA sequencing targets and bioinformatics strategy.

Our work aims to contribute to the establishment of standard procedures in both national and European soil monitoring schemes. Additionally, it provides valuable insights for data comparison and harmonization, overall promoting the advancement of soil health monitoring.

Keywords: soil sampling; soil microbiota; data harmonization; Europe

The influence of covariates and sample density on digital soil mapping performance at a national scale

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In the context of Global Soil Nutrient and Nutrient Budget maps, the FAO Global Soil Partnership (GSP) initiated a country-driven digital soil mapping (DSM) approach. This involved predicting ten soil properties using national point data and a set of widely available covariates (GSP_Cov). In this study we demonstrated the impact of including additional national-based covariates and soil observations on prediction model performance, using mainland France as a pilot area. A Random Forest approach combined with the Boruta selection method was employed to map ten soil properties, including soil organic carbon, pH (water), total nitrogen, available phosphorus, available potassium, cation exchange capacity, bulk density, and texture (clay, silt, and sand). The GSP_Cov included common covariates representing terrain, climate, and organisms, whereas the second set included these covariates extended to additional national-level data such as existing soil and geological maps, remote sensing products, etc. Results showed notable enhancements in prediction performance for more than half of the properties, particularly for pH, CEC, and texture, whereas geological variables and previous pH maps significantly improved accuracy. Adding around 25,000 points to the learning dataset improved the performance of soil particle-size fraction predictions. This research emphasizes the importance of incorporating a diverse range of covariates at a national scale and densifying soil information to expand the feature and geographical spaces of multidimensional soil/covariates combinations.

Keywords: digital soil mapping, spatial covariates, sampling size, random forest