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Towards climate-smart sustainable management of agricultural soils

Deliverable 6.3

Proposal of methodological development for the LUCAS programme in accordance with national monitoring programmes

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2	WR	Wageningen Research	
3	BIOS	BIOS Science Austria (Association for the Advancement of Life Sciences)	
4	EV-ILVO	Own capital of the institute for agricultural and fisheries research / Eigen Vermogen van het Instituut voor Landbouw en Visserij Onderzoek (EV ILVO)	
6	CZU	Czech University of Life Sciences Prague / Ceska zemedelska univerzita v Praze	
8	EMU	Estonian University of Life Sciences	
9	LUKE	Natural Resource Institute of Finland / Luonnonvarakeskus	
10	Thuenen	Johann Heinrich von Thünen Institut Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei	
12	MTA ATK	Magyar Tudományos Akadémia, Agrártudományi Kutatóközpont	
13	Teagasc	Agriculture and Food Development Authority Ireland	
14	CREA	Council for Agricultural Research and Economics / Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria	
15	UL	University of Latvia, Faculty of Geography and Earth Sciences	
16	LAMMC	Lithuanian Research Centre for Agriculture and Forestry, Institute of Forestry	
17	NIBIO	Norwegian Institute of Bioeconomy, Norsk Institutt for Biookonomi	
18	IUNG	Institute of Soil Science and Plant Cultivation – State Research Institute	
19	INIAV	National Institute of Agricultural and Veterinarian Investigations, Instituto Nacional de Investigaçao Agraria e Veterinaria	
20	NPPC	National Agricultural and Food Centre	
22	INIA-CSIC	Spanish National Research Council	
23	SLU	Swedish University of Agricultural Sciences	
24	AGS	Federal Department for Business Education and Research, Eidgenoessisches Deapartement fuer Wirtschaft Bildung und Research	
25	TAGEM	Ministry of Agriculture and Forestry/General Directorate of Agricultural Research and Policies	
26	AFBI	Agrifood and Biosciences Institute	

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27	CNR	National Research Council / Consiglio Nazionale delle Ricerche	CREA
28	ERSAF	Regional Agency for Agriculture and Forests of Lombardy	CREA
29	ISPRA	Italian National Institute for Environmental Protection and Research	CREA
30	KIS	Agricultural Institute of Slovenia / Kmetijiski Inštitut Slovenije	ULBF
31	DGADR	General Directorate of Agriculture and Rural Development/ Direção-Geral de Agricultura e Desenvolvimento Rural	External institution
32	LAMMA	Consorzio LAMMA, Regione Toscana, Italy	External institution

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Executive summary

This document presents the main questions when developing a soil monitoring programme, reviews previous existing studies and documents, analyses the survey made within EJP SOIL partners and underlines possible ways of harmonization and collaboration between national monitoring programmes and the EU LUCAS programme in the frame of the EU Soil Observatory.

Soils are constantly evolving due to natural factors as climate and soil organisms (pedogenesis), but also due to external pressures linked mainly to human activities (e.g. urbanization, management practices, diffuse inputs of nutrients or contaminants through atmospheric deposits or waste spreading). The evolution of soils makes it necessary to set up monitoring programmes to (i) define reference states of soil quality/health, (ii) monitor changes (e.g. estimation of contaminant fluxes, changes in the content of organic matter and trace elements), (iii) detect degradation at an early stage, (iv) evaluate the success of public policies or (in a broader sense) of sustainable management practices, or restoration actions set up to protect or remediate soils and finally, (v) support research for the development and validation of field and analytical methods, models of soil and related environmental processes.

Designing and implementing a Soil Monitoring System (SMS) requires at least to choose: (i) the statistical sampling design, (ii) the field sampling strategy in time and space (including the number of samples to be collected in the field and the area of collection), (iii) the entity that is sampled (i.e. pedogenic horizons or fixed depths increments) and how (e.g pits, augering, spade), (iv) the total thickness over which soil is sampled (i.e. topsoil, down to 1m, 2 m… or the parent material), (v) the way the samples are managed (e.g. composite sample), prepared and analysed and (vi) the metadata that is to be collected and stored (data about the sampling itself, its location and surroundings) to interpret the results. All those choices represent possible variations that enable the results to be compared.

Since 20 years, several projects and initiatives (e.g. ENVASSO, Landmark, SOIL4EU) underlined the existing difficulties to compare and share data from national SMS, either due to technical issues (e.g. sampling designs and protocols, analytical methods, data format) but also on motivations (e.g. why to share the data, for what purpose) and legal requirements (e.g. are we allowed to share the data, see also EJP SOIL D6.2. Report on the national and EU regulations on agricultural soil data sharing and national monitoring activities). The situation is not new and several possible ways of progress were previously identified but it is clear that we are still more or less in the same situation. With the objective of overcoming this blockage a questionnaire was designed and circulated within EJP SOIL partners taking part in WP6 activities (Supporting harmonised soil information and reporting) to identify the technical issues (main differences between SMS) and possible ways of harmonization/collaboration.

The questionnaire asked for information on the SMS design (why, when, how), the way monitoring sites are selected, sampled and the associated data, the soil sample preparation and conservation as well as the analytical menu. Last part of the questionnaire was dedicated to possible harmonization options and collaborations and/or synergies between Member States and LUCAS soil campaigns. We collected 27 answers, representing 18 countries as few countries have different SMS (i.e. designed for different purposes and/or have regional SMS as Italy and Belgium). A monography of each country SMS was proposed with the same frame for ease of reading, and a transversal analysis was also made to identify similarities and differences between SMS.

Most of SMS were developed and started in the 90ies to monitor soil quality (meaning that there are numerous parameters monitored). The main land use investigated is linked to agriculture (note that this may also be a bias from EJP SOIL partners mainly dedicated to agriculture). The majority of SMS have at least 2 sampling campaigns (done or currently running) or even more. The number of sites per country is highly variable but the majority have at least 1 site representing 300 km². In the majority of SMS, the monitoring sites were selected according to several criteria such as land use, soil types, main crops, climatic zone (i.e. identification of representative sites) but regular grids are also used for site selection. On those sites, 50 to 60% of the countries collect information on soil management (e.g. by interviews with farmers, for each campaign) and on the surroundings. The sampling protocol is quite variable as the sampling area ranges from less than 5 m² to 1ha, where subsamples (from 5 to more than 20) are collected according to a diversity of frames (circle, square, rectangle, triangle). The depths of sampling are also quite different as samples are taken according to soil horizons or just at one depth (0-20 or 0-30 cm) or at multiple depths (2 to 5). The analytical menus, even if not detailed, appear also to be quite variable with few parameters highly determined (e.g C, pH) and others rarely measured (e.g. those related to soil biodiversity).

Considering harmonization and collaboration with LUCAS campaigns, with few exceptions, the countries do not want to change their protocols (from the design to the analytical part). A majority of the countries would accept to add new monitoring sites (e.g. that could be in common with LUCAS) and some may also, with a proper budget, consider double sampling/analysis to compare their results with LUCAS ones. Such situation is quite normal as there are quite old SMS, with several campaigns already completed and that any change may impair the use of existing data, unless comparison exercises can be made to develop transfer functions from past situation to the new one. However, this will require more resources and as it was said by one of our colleagues "*lots of SMS struggle each year just to maintain the existing SMS!"*

How can we go further in the frame of the EU Soil Observatory (EUSO)? How to find a way to combine the efforts of Member States in monitoring soils to ones developed by EU-JRC within the LUCAS soil programme? Within EJP SOIL WP6, we identify and discuss several options from the full integration and harmonization of MS monitoring systems and LUCAS to a better collaboration between MS and EU-JRC to produce a coherent information on soils, even if data stay separate. An intermediate solution being that data from MS and LUCAS will populate the EUSO, finding a way to work on data even if not obtained the same way. Those options are presented and debated according to their advantages and limitations. They all need to be shared with EU-JRC in order to be effective and the resulting choices will be implemented in the coming years.

DISCLAIMER
The information released in this deliverable is based on the contribution given by the EJP SOIL partners. The final release of the deliverable has passed through a check and has been partly approved by EJP SOIL partners (some were on holidays or not available for reviewing the deliverable). Despite this, with the awareness that the information included could not be complete, sometimes not well interpreted or not up to date, and that the analysis and conclusion released could be misleading for some countries, the deliverable should be considered a first draft base to be used and tuned during the future activities of the WP6 and EJP SOIL.

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List of acronyms and abbreviations

EEA	European Environment Agency
EJP SOIL	European Joint Project SOIL
ENVASSO	ENVironmental ASsessment of Soil for mOnitoring
EU	European Union
EUROSTAT	European Statistical Office
EUSO	European Soil Observatory
FAO	Food and Agriculture Organisation of the United Nations
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
ISO	International Standard Organisation
LANDMARK	Land Management Assessment Research Knowledge Base
LUCAS	Land Use and Coverage Area frame Survey
MS	Member State
QBS-ar	Soil Biological Quality (in Italian: Qualità Biologica del Suolo)
SDGs	Sustainable Development Goals
SMS	Soil Monitoring System
SOC	Soil Organic Carbon
SOILS4EU	Providing support in relation to the implementation of the EU Soil Thematic Strategy
USDA	United Stated Department of Agriculture
WP	Work Package
WRB	World Reference Base for Soil Resources

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1. Introduction

Due to the time needed to recover after a strong degradation, soil can be considered as a non-renewable natural resource. The preservation of its productive uses, its environmental and ecological functions, and the consideration of its role in land use planning and development, which are often combined under the terms "soil quality" or "soil health", represent a collective challenge for sustainable development.

Soils are constantly evolving due to natural factors as climate and soil organisms (pedogenesis), but also due to external pressures linked mainly to human activities (e.g. urbanization, management practices, diffuse inputs of nutrients or contaminants through atmospheric deposits or waste spreading). The evolution of soils makes it necessary to set up monitoring programmes to (i) define reference states of soil quality/health, (ii) monitor changes (e.g. estimation of contaminant fluxes, changes in the content of organic matter and trace elements), (iii) detect degradation at an early stage, (iv) evaluate the success of public policies (or in a broader sense) of sustainable management practices, or restoration actions set up to protect or remediate soils and finally, (v) support research for the development and validation of field and analytical methods, models of soil and related environmental processes.

This document presents the main questions raised when developing a soil monitoring programme, reviews previous existing studies and documents, analyses the survey made within EJP SOIL partners and underlines possible ways of harmonization and collaboration between national monitoring programmes and the EU LUCAS programme in the frame of the EU Soil observatory.

2. State of the art

The range of purposes for which soil-monitoring programmes can be designed encompasses a vast range of time scales, variables and processes, so that it is difficult to draw up a standard way of organising soil sample collection and analyses. As an example, soil being a key player in several global processes such as food/fibre/fuel production, climate change and adaptation to its impacts, water quality and quantity, biodiversity protection… it is also difficult to decide and set all relevant parameters to be measured in soil monitoring programmes. Analyses to be performed and analytical methods to be applied are just some of many issues to be addressed…

2.1. State of the art

Arrouays et al. (2012) stressed that the establishment of Soil Monitoring System may have several objectives as:

- determination of the current characteristics and properties of soils as well as their environmental stresses, which can be considered as an initial assessment of the soil status, often called "baseline" values[1],
- long-term and/or early determination of changes in soils as a consequence of location-, stress- and use-specific factors, through periodic investigations;
- assessment of the sensitivity of soils to changes, and prediction of their future development;

[1] Although the term "baseline" may be reserved for some assessment of soil state without the impact of human activities, inferred, perhaps, from nearby soils under climax vegetation.

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- development and validation of models for the simulation of ecosystem responses and the use of these to estimate responses to actual or predicted changes and stresses, and to make regional assessments in concert with survey data;
- establishment of reference sites for calibration of environmental measurements; and
- collection of information about soil trends, to inform future national policies to protect soils from degradation and pollution, including the identification of new threats to soil quality and tests of the effectiveness of existing policies.

Note that de Gruijter et al. (2006) grouped those objectives into 3 broad categories that have implications when designing an Soil Monitoring Network or Soil Monitoring System (SMS): i) status/ambient monitoring to characterise or quantify the status of soil and follow how its properties change over time (such as topsoil organic carbon content under different land uses); ii) trend/effect monitoring to assess the possible effects of pressures or drivers on soils to determine not only status but also whether a change was caused by a specific event or process; and iii) regulatory/compliance monitoring to determine whether soils are failing to meet set standards or targets.

The purpose(s) of monitoring being set, several issues have then to be solved.

2.2. Main issues related to soil monitoring

At least, the following questions need to be solved when designing a SMS:
- The statistical sampling design,
- The field sampling strategy in time and space (highly depending on the purpose of sampling: what should be monitored, where…) (see also EJP SOIL D6.1. Report on harmonized procedures for creation of databases and maps, chapter 4.2.3),
- The number of samples to be collected in the field and the area of collection (also called sample support),
- The entity that is sampled (i.e. pedogenic horizons or fixed depths increments),
- The total thickness over which soil is sampled (i.e. topsoil, down to 1m, 2 m… or t the parent material),
- The way the entity is sampled (e.g pits, augering, spade) which may have some influence on the taken volume, and on some other information you can also collect (or not) as the deep soil structure or the measurements of the largest coarse elements content (only visible on pits),
- The way samples are managed[2] (e.g. mixed to create composite samples or kept as individual undisturbed samples),
- The standard sampling protocol or field description protocol to be used,
- The way soil samples are stored until analysis[3], pre-processed (e.g. air dried and sieved to 2 mm) and stored in an archive,
- The analytical protocols,
- The time between consecutive resamplings,
- The way metadata is collected and stored (data about the sampling itself, its location and surroundings).

[2] Note that depending on the analysis to be performed different sampling operations may be needed (e.g. sampling for bulk density).

[3] e.g. in closed bags either at ambient temperature for physical and chemical analysis or chilled in case of biological and biochemical processes to halt all biological processes occurring in the soil after sampling before analysis.

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This information is needed when comparing and using the data collected. All these possible variations are analysed and developed in this report.

2.3. Previous studies and initiatives

In 2001, the European Environment Agency (**EEA)** called for the creation of a European soil monitoring network based on current soil-monitoring activities within member countries, utilising existing sites or gathering relevant data for assessing specific soil issues (Huber et al., 2001). Twenty years ago, it was already identified that harmonisation and coordination between national systems was necessary due to the fact that the nature of the networks differs between countries in concepts, objectives, content, size, scale, accuracy and technical procedures. It was proposed (i) to select the sites by stratifying according to soil regions and land uses so that the network will be as representative as possible of the many soil categories found in Europe[4], (ii) to use key sites as references (i.e. demonstration sites) for national networks to enhance comparability between countries, (iii) to develop a spreadsheet allowing the calculation of the costs of establishment and maintenance of a SMS and (iv) to collect the data into a unique shared database. All the needed concepts and actions were already listed and identified.

Then the **ENVASSO project**[5] (2005-2008) followed up this work. To date this project was the most comprehensive one on soil monitoring. It was funded under the European Commission 6th Framework Programme with the objective of defining a monitoring system for EU, describing its potential implementation and developing a framework for monitoring of European soils. Several indicators were selected to monitor soil threats (e.g. erosion, organic matter decline, contamination, compaction, salinisation, decline in biodiversity, soil sealing, landslides and desertification) and a review of EU monitoring networks covering different soil types and land uses was performed (Arrouays et al., 2008, Morvan et al., 2008).

Main conclusions, at that time were:

- The locations for the installation of soil monitoring sites were selected based on different criteria as grid-based site selection, representativeness (of landform, soil types, land use, specific site-related situations), specific land uses or unusual conditions, documentation and control of land use and practices, or integration of sites into other currently established ecological observation areas.
- Most of the soil mapping units and the land use classes of Europe had at least one monitoring site, however the parameters measured were far from homogeneous. The density of sites in soil mapping units of Europe was highly variable. About 10% of the soil mapping units did not have any monitoring site. For land use classes, the greatest density was reported in grasslands, whereas arable lands and forests had lesser, although comparable, site density. Permanent-crop lands (e.g. vineyards, orchards) and open spaces with little or no vegetation were under-sampled in comparison to other land uses.
- The median density of sites in 50 km x 50 km cells applied all over Europe was 1 site per 300 km² and was close to the density of the ICP Forests grid. This density was, by definition, already reached for half of the European territory. However, a large variability in site densities was

[4] This part is questionable as establishing a grid, as fine as possible, allows to catch the controlling factors already known (as climate, soil type, relief, land-use, etc) but also the unknown ones (e.g. accident, eruption of a vulcano, whatever that is unpredictable that may change the content of an element/a compound in soils). So it is a good reason not to choose only "representative" sites on the basis of our present knowledge because we may miss actual or future gradients.

[5] https://esdac.jrc.ec.europa.eu/projects/envasso

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reported when considering various indicators, as the minimum set of parameters measured differs amongst countries.

- The coverage was very heterogeneous among indicators as indicators related to decline of soil biodiversity and soil erosion were measured very rarely, whereas those related to soil compaction, decline of soil organic matter (e.g. soil organic carbon content) and soil contamination (e.g. Pb), were measured at almost all sites.
- Amongst measured parameters soil organic carbon and pH are the most often measured, whereas some other parameters have a very limited coverage, in particular, indicators related to soil biodiversity and to soil erosion are very seldom measured. Some trace elements are measured in almost all countries (e.g. Pb), whereas others are rarely measured (e.g. Hg).

Main recommendations were to:

- implement new soil monitoring sites and harmonise spatial sampling strategies across Europe to create a minimum coverage of one site per 300 km²,
- select a small area for sampling, ranging from 100 m² to 1 ha (10000 m²) and being homogeneous with regard to soil profile development. Within this area it was recommended to take at least 4 subsamples (to be adapted depending on the size) and to record the exact location of cores (to avoid re-sampling these locations in future campaign),
- sample with fixed depth increments as it ensures standardisation between sites and it is the most relevant approach for assessing some anthropogenic characteristics (e.g. anthropogenic heavy metals, radionuclides, organo-chemicals), and for parameters showing a strong gradient near the surface. It was very difficult to make recommendations on the depths to adopt[6]. Indeed, changing the depth of a national SMS would make it very difficult to use previous campaigns for the assessment of changes. One way to harmonise reporting at the European scale could be to report the results on the basis of an equivalent mineral mass[7]. It was recommended that sampling is done so that at least topsoil concentrations or stocks of elements can be calculated for depths ranging from 0-15 to 0-30 cm,
- resample the sites with a maximum time step of 10 years as for a large number of indicators, shorter time steps would not reliably demonstrate change[8],
- archive soil samples[9] for re-analyse, allow a posteriori analyses, develop bank of samples for research / interlaboratory comparisons.

ENVASSO reviewed national monitoring networks, suggested ways to go forward and also proposed solutions to organise and share soil data (data models and database designs were examined and requirements for future processing of soil data were discussed in the context of developing a Web Soil Service. A data model was proposed and a soil database (SoDa) programmed to provide a harmonised basis for capturing new soil data. Ideally, regional and/or national organisations should provide soil data and information to the European Union. However, it was difficult to obtain harmonized soil data from a national level. As a response, LUCAS Soil was implemented in 2009 to produce soil data at an EU-level, using one methodology and standard.

[6] The depth determination relies also on what the intended aim of the monitoring system is.

[7] Reporting on the basis of an equivalent soil mass is relevant when you look at changes of stocks with time also (because the bulk density, for instance may have changed). But this often requires that you have also sampled at deeper depths than a fixed thickness interval for topsoil for instance. It can be relevant for some parameters as SOC but it makes monitoring much more complicated and expensive.

[8] This recommendation is now less suitable because we have now some parameters indicating more rapid changes (e.g. particular organic matter, microbial abundance and diversity, etc.) than may vary more quickly.

[9] Storing samples is a way of considering new parameters of interest as we don't know what we'll be interested in, nor what we'll be able to measure in the future…

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LUCAS Soil is a harmonized collection and analysis of soil samples from across EU, based on the LUCAS programme (Land Use and Coverage Area Frame Survey). The latter is an EU-wide land use programme, initiated in 2006 by the European Statistical Office (EUROSTAT) in close cooperation with the DG-AGRI and with the technical support of the EU-JRC. LUCAS organises regular, harmonised surveys across all Member States to gather information on land cover and land use. Sampling is based on a regular grid that is defined by the intersection points of a 2 km × 2 km grid that covers the European territory, resulting in around 1 000 000 georeferenced sampling locations. Each point has been classified in accordance with seven land-cover classes using orthophotos or satellite images. From this overall pool, approximately 270 000 points are visited in the field by surveyors to assess the validity of the classification and to collect additional information that cannot be assessed remotely. Points were selected through a stratification process that provides coverage of all possible types of land cover and land use identified over the whole study area. The latest LUCAS survey was undertaken in 2018. In situ observations were made at 273 401 points, and the data were used to produce aggregated statistical tables of land cover and land use (see description in EJP SOIL D6.1. Report on harmonized procedures for creation of databases and maps, chapter 4.1.2.2).

In 2009, the European Commission extended the periodic LUCAS[10] to sample and analyse the main properties of topsoil in 23 Member States of the European Union (EU). This topsoil survey represents the first attempt to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures, with the analysis of all soil samples being carried out in a single laboratory. Approximately 20,000 points were selected out of the main LUCAS grid for the collection of soil samples (approximately 10%). A description of how the sites were selected is available in EJP SOIL D6.1 (chapters 4.1.2.3 and 4.1.2.4). A standardised sampling procedure was used to collect around 0.5 kg of topsoil (0-20 cm) (see protocol described in the next chapter). The samples were dispatched to a central laboratory for physical and chemical analyses. Since that date, new LUCAS soil campaigns were done in 2015 and 2018. The next one is planned by 2022.

Since this first edition in 2009 topsoil samples have been analysed for the percentage of coarse fragments, particle size distribution, pH, soil organic carbon, carbonates, total nitrogen, extractable nutrients, cation exchange capacity and multispectral properties. In 2012 trace elements were included. The third edition (2018) also covers visual assessment of soil erosion, measurement of the thickness of the organic horizon in organic-rich soil, soil bulk density (in 9000 locations) and soil biodiversity in 1000 selected locations (targeted at Bacteria and Archaea, Fungi, Eukaryotes, nematodes, arthropods, earthworms, metagenomics). Soil information can be correlated to land cover (crop) and land use type described in the sampling location (Orgiazzi et al., 2018).

The LUCAS Soil programme created the first harmonized and comparable dataset of topsoil properties at the EU scale. This dataset was then used by several projects as Landmark. Between 2015 and 2019, within the **LANDMARK** H2020 project, an extensive review of the existing SMS was conducted through the lens of the multi soil functionality. The work aimed to assess which soil attributes can be used as potential indicators of five soil functions: (1) primary production, (2) water purification and regulation, (3) carbon sequestration and climate regulation, (4) soil biodiversity and habitat provisioning and (5) recycling of nutrients. This study compared this list of attributes to existing national (regional) and EU-wide soil monitoring networks (van Leeuwen et al., 2017). The overall picture highlighted a clearly unbalanced dataset, in which predominantly chemical soil parameters were included, and soil biological and physical attributes were severely under- represented. Methods applied across countries for indicators also varied. At a European scale, the LUCAS-soil survey was evaluated and again confirmed a lack of important soil biological parameters, such as C mineralisation rate, microbial

[10] https://esdac.jrc.ec.europa.eu/projects/lucas

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biomass and earthworm community, and soil physical measures such as bulk density. In summary, no current national or European monitoring system exists which has the capacity to quantify the five soil functions and therefore evaluate multi-functional capacity of a soil and in many countries no data exists at all. The results stressed the need to add soil biological and some physical parameters within the LUCAS-soil survey at European scale and for further development of national soil monitoring schemes.

Recently, the project **Soils4EU** also reviewed existing projects and SMS across EU to identify priority areas for improving consistency and inter-operability of EU-wide and national soil monitoring and information systems (Wawer et al., 2019). Their main conclusions were that on an EU-level, soil data are available in almost all the Member States. However, it is very difficult to create a complete overview of all existing data and information within the Member States, not least because even within Member States several regions or organizations are responsible for collecting soil data, fragmenting the information on soils status and change. So, data availability and quality vary a lot through EU: soil data are sometimes not collected or in a primary state, sometimes available but not usable, and sometimes not shared. It is unclear what could be the (added) benefit for the Member States to share and harmonize its soil data and information (having in mind that these investments are not easily done). Furthermore, as there is no soil (or less strict) legislation on national and/or European level, there is no incentive for Member States to overcome barriers, update existing SMS to current or harmonized standards or even collect soil data. Finally, breaches of data sovereignty, private data issues and protection of intellectual property are a continued concern.

To reach cooperation between Member States and between MSs and EU they recommended either a top-down (e.g. EU-Directive) or bottom-up approach. A specific national legislation on soils through an EU Directive would help to support SMS and should thus be stimulated. However, the EU being a union of Member States, needs to translate the objectives (reasons and benefits) behind the ambition for harmonisation of soil information, to common objectives for the SMS. These objectives will stimulate countries to work on SMS on a national level by providing mutual goals and finances, especially if responsibility and cooperation for national SMS are fragmented and coordination between the different administrations is needed.

Shared methodologies are also to be encouraged and this may be done by defining suitable indicators and thresholds preferably on EU-level. Standardization of methods to measure those indicators, the periodicity of measurements and the density and distribution of the sampling points network, considering the different soils that are present would be a logical next step. Besides, it is recommended to have samples analysed using unified protocols at EU level and have soil analysis undertaken by a single laboratory to avoid biases.

It is also recommended to solve the problem of privacy and personal data protection laws on the publication of georeferenced soil data and to provide common and clear data access and data protection standards.

The EU must also show the society and the policy makers the importance of soils, what threatens them and what are the benefits of using SMS. By raising awareness, SMS and the need for harmonisation will get more attention. By involving stakeholders and possible financers, soil monitoring can be made more cost-effective for MSs.

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All those previous projects and initiatives clearly underlined the existing difficulties to compare and share data, either due to technical issues (e.g. sampling designs and protocols, analytical methods, data format) but also to motivation (e.g. why to share the data, for what purpose) and legal requirements (e.g. are we allowed to share the data, see also EJP SOIL D6.2). To clearly identify the technical issues (differences between SMS) and possible ways of harmonization/collaboration a questionnaire was designed and circulated within EJP SOIL partners taking part in WP6 activities.

3. Review of existing monitoring programmes based on the questionnaire

3.1. Method

A questionnaire was prepared by INRAE and shared within EJP SOIL WP6 and EU-JRC (Arwyn Jones). Based on the different feedbacks the questionnaire was launched on 21st of April 2021 (asking for answers by 17th of May). After mid-May the questionnaire stayed open as several countries provided late answers (last recorded on 6th of July). We collected 27 answers, representing 18 countries as few countries have different SMS (i.e. designed for different purposes and/or have regional SMS as Italy, or Belgium).

The questionnaire was designed to collect relevant information about the Soil Monitoring Systems (SMS) present in each one of the EJP SOIL countries, on the sampling protocols and on metadata collected, to identify similarities and differences. The questionnaire consists of the following 11 sections (see Annex 1):

1) Institution identification
2) SMS short description
3) Site information
4) Sampling protocol
5) Sampling for bulk density
6) Soil description
7) Soil sample preparation and conservation
8) Litter sample
9) Analyses and methods (this section was optional as partners have previously completed the 1st questionnaire concerning databases and methods)
10) Harmonization options
11) Collaborations and/or synergies between Member States and LUCAS

We present hereafter a review of existing SMS (chapter 3.2) and then a synthesis of the answers (chapter 3.3).

3.2. Description of SMS country by country

Based on the results of the survey, this part describes country by country the existing SMS. Table 1 presents all institutions involved in EJP SOIL that answered to the questionnaire and the answering contacts.Table 1. Institutions and countries involved in EJP SOIL that answered to the questionnaire Figure 1 lists the answering countries and the number of SMS declared.

All individual answers are available under request on a unique file (more than 1000 pages).

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Answering institution	Country	Answering contact
AGES	Austria	Andreas Baumgarten
VPO	Belgium - Flanders	Martine Swerts
SPW (Service public de Wallonie)	Belgium - Wallonia	Esther Goidts
Czech University of Life Sciences Prague (CZU)	Czech Republic	Vít Penížek Milan Sáňka
Department of Agorecology, Aarhus Universitet	Denmark	Morgen Greve
Agricultural Research Centre	Estonia	Priit Penu Evelin Pihlap Alar Astover
EU-JRC	EU	Arwyn Jones
Natural Resources Institute Finland (Luke)	Finland	Visa Nuutinen Jaakko Heikkinen
INRAE Institut National pour la Recherche en Agriculture et en Environnement	France	Line Boulonne Antonio Bispo
Thünen Institute of Climate-Smart Agriculture	Germany	Christopher Poeplau
German Environment Agency; Umweltbundesamt	Germany	Frank Glante
National Food Chain Safety Office, Directorate of Plant Protection Soil Conservation and Agri-environment	Hungary	Gábor Várszegi
Teagasc	Ireland	Lilian O'Sullivan David Wall
ARPAV Environmental Protection Agency of Veneto Region	Italy - Veneto	Ialina Vinci
Regione Puglia	Italy- Puglia	Francesco Bellino
ERSAF	Italy-Lombardia	Stefano Brenna Gemma Chiaffarelli Elena Tondini
Latvia State Forest Research Institute "Silava"	Latvia	Andis Lazdiņš
State Plant Protection Service	Latvia	Gints Zabitis
Lithuanian Research Centre for Agriculture and Forestry (LAMMC)	Lithuania	Kęstutis Armolaitis
Wageningen Environmental Research (WR)	Netherlands	Fenny van Egmond
Institute of Soil Science and Plant Cultivation - State Research Institute	Poland	Grzegorz Siebielec
National Agricultural and Food Centre (NPPC), Soil Science and Conservation Research Institute (SSCRI)	Slovakia	Jozef Kobza Boris Pálka Zuzana Fulmeková
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, CSIC-INIA	Spain	José Antonio Rodríguez Martín
CEBAS-CSIC	Spain	Felipe Bastida Carlos García José Luis Moreno
SLU	Sweden	Johanna Wetterlind Carin Sjöstedt Katarina Kyllmar David Englund Johan Stendahl
Agroscope & Federal Office for the Environment	Switzerland	Fabio Wegmann Corsin Lang Elena Havlicek Thomas Gross Klaus Jarosch Lutz Merbold Reto Meuli

Table 1. Institutions and countries involved in EJP SOIL that answered to the questionnaire

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Note that Portugal and Turkey answered that they didn't have any SMS. In Portugal negotiations are running to install one.

Note also that in few countries Soil Monitoring Systems can be sub-national, under the responsibility of regional authorities (as in Italy). Soil monitoring activities undertaken for research purposes (e.g. in Long Term Experiments) were not the object of this survey.

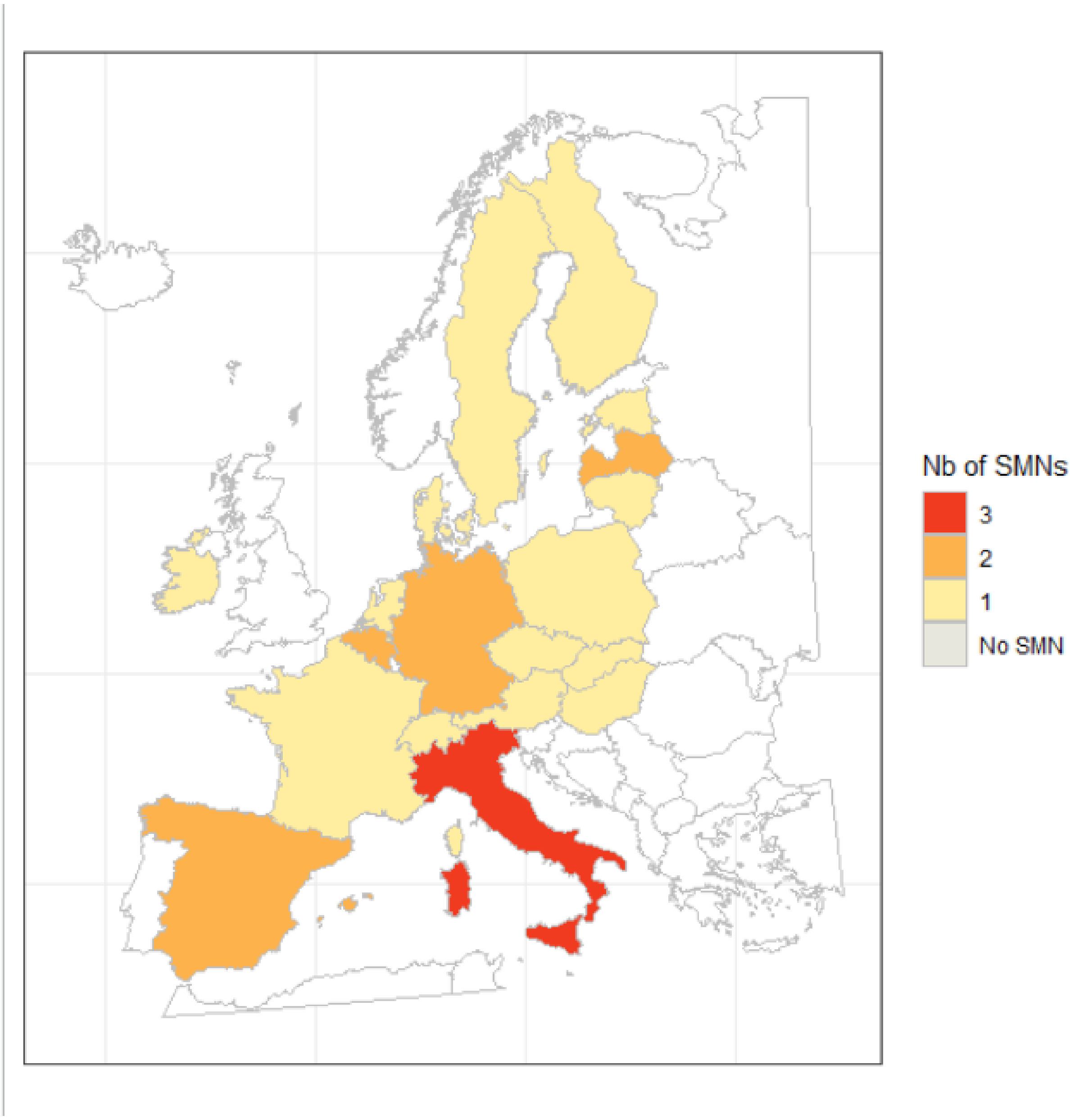

Figure 1. Countries that answered to the questionnaire and number of declared SMS (Soil Monitoring Systems) by country

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3.2.1. Austria

Austria has a soil monitoring system called Bodenzustandsinventur (BZI) and managed by provinces of the country. It started in the 1990ies to report on soil quality on 2000 sites. It is still running only in one province (3 campaigns, with an interval of 10 years between) and stopped in the other provinces (no current activities, just one campaign).

The system was designed to investigate all kinds of land uses and was designed on a grid basis. All sites are georeferenced (precision 50 m) and a composite sample is made of 4 sub-samples on an area of 12 m² (Circle (r = 2m)) at fixed depths (0-30 cm) resulting in approximately 2 kg of soil. Sampling for bulk density is not made. All sampling sites are treated the same.

Before preparation the samples are stored at room temperature. Then before analysis the samples are air dried and sieved to 2mm. Litter is discarded.

Additional information on the sites are available on elevation and lithology.

Considering harmonization options:
- The design of the monitoring can be changed and they are planning to develop a new design, eventually in connection with LUCAS.
- It is possible to collect new information on the monitoring sites (these data will be essential).
- The soil description can be improved by using national and WRB classifications.
- The sampling area can be changed as there will be new sampling sites.
- The sampling depths may also be changed (still to be discussed).
- soil sample preparation cannot be changed.
- Measurement methods may be changed (with pedotransfer functions).
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Austria already collaborated (national research program "LUCASSA", final report in preparation) and is open to further collaboration (e.g by. adding specifically chosen points to the LUCAS points). LUCAS Soil data were used to compare with existing soil data.

3.2.2. Belgium

Two monitoring systems are running in Flanders and Wallonia.

Flanders developed a soil monitoring system called Koolstofmonitoringsnetwerk, managed by VPO (Flemish Planning Bureau for the Environment and Spatial Development, Departement of Environment and Spatial Development, Government of Flanders). It started in 2021 to monitor Soil Organic Carbon (SOC) on 2535 sites. It is still running and the next campaign is planned by continuously over 10 years (each year 1/10 of the locations) (meaning an interval of 10 years between 2 sampling campaigns).

The system was designed to investigate Natural, Agricultural, Forest, Urban land uses (all kind) and designed on a Generalized Random Tessellation Stratified sampling (GRTS) approach basis. The plots are selected using the Generalized Random Tessellation Stratified sampling (GRTS) approach (Onkelinx, 2017), providing a spatially balanced set of Level I plot locations for each landuse class across Flanders. In addition to this set, 20 plots are added to each land use class (5 extra plots for LU change in one direction towards the 4 other land use classes) to ensure a balanced statistical design to compute SOC stock changes for all potential land use changes. All sampling sites are treated the same.

All sites are georeferenced (precision 0.02 - 0.03 m) and a composite sample is taken on an area of 10 x 10 m (16 points (GRTS) in a square (10 x 10 m)) at fixed depths (0-10, 10-30, 30-60 and 60-100 cm, Organic layer/Forest floor (LFH) if present). Sampling for bulk density is also made.

Before preparation the samples are stores at room temperature (bulk density sample < 5°C cooled in fridge). Then before analysis the samples are dried in oven at 40°C (bulk density sample: fresh soil sample), crushed (jaw crusher < 2 mm (bulk density sample: no sieving nor milling)) and sieved to 2mm. Litter is discarded.

Additional information on the sites are available on:
- Elevation,
- soil data management is available (eg. drainage, crop rotation, ...),
- slope, exposition, erosion features,
- soil surroundings (e.g. road, factory, city…),
- lithology,
- vegetation,
- pictures are taken.

Note that several other parameters are available: artefacts, stones, soil disturbance, ...

Considering harmonization options:
- The design of the monitoring cannot be changed but additional points may be added, but no points may be deleted (GRTS sampling points).
- It is nevertheless possible to collect new information on the monitoring sites.
- The sampling area cannot be changed.
- The sampling depths cannot be changed, the only possibility is to add a deeper depth interval than 100 cm.
- The soil sample preparation cannot be changed.
- New parameters can be added but no change in the measurement methods.

Considering collaboration with LUCAS campaigns, Flanders didn't yet collaborate but is open to collaboration (e.g. compare LUCAS and National sampling design strategies, develop transfer functions and use all data together). LUCAS soil data were not used as there are not many LUCAS points for Flanders.

Wallonia has a soil monitoring system called CARBIOSOLS (Carbone organique, biomasse et activité microbienne des sols) and managed by SPW (Service Public de Wallonie). It started in 2004 to monitor Soil Organic Carbon on approx. 590 sites but new campaign is planned. Two sampling campaigns were done (with an interval of 10 years). The system was designed to investigate Agricultural land uses on representative sites (based on Aardewerk (historic DB)).

All sites are georeferenced (precision based on GPS precision with a magnetic ball buried at monitoring points) and a composite sample (based 5 sub-samples) is taken on an area of 50 m² (Circle (radius 4m)) at different depths according to horizons. Sampling for bulk density is also made. All sampling sites are treated the same.

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Before analysis the samples are hand sieved to 2mm.

A soil description is also available and is obtained by opening a soil profile (description Aardewerk). Soil is described and classified according to national standards.

Additional information on the sites is available on soil data management is available (e.g. rotations) and on slope, exposition, erosion features.

Considering harmonization options:
- The design of the monitoring can be changed as any new point will improve the data.
- It is possible to collect new information on the monitoring sites and the soil description can be improved (e.g. conversion in WRB). Any new information is an improvement.
- The sampling area be changed.
- The sampling depths depending on the horizon may also be changed.
- The soil sample preparation and analytical methods can be changed.
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Wallonia didn't yet collaborate but is open to collaboration. LUCAS Soil data were not yet used.

3.2.3. Czech Republic

Czech Republic has a soil monitoring system called *BMP - Basal Soil Monitoring*, managed by Central Institute for Supervising and Testing in Agriculture (UKZUZ). It started in 1992 to monitor physical and chemical soil properties on stable locations under agricultural use, on 214 sites. It is still running and next campaign is planned by 2025 (meaning 6 campaigns with an interval of 6 years between 2 sampling campaigns). The system was designed to investigate Agricultural land uses and based on a representative sites (selected sites representing proportionally various agricultural land use and pedo-climatic conditions). Each land use is treated differently (cropland vs. grassland vs. special crops).

All sites are georeferenced (precision 5 m) and a composite sample (made of 6 sub-samples on the diagonal) is taken from an area of 1000 m² (rectangle 25 x 40 m) at fixed depths (Arable land: 0-25, 35-60 cm, grassland: 0-10, 10-25, 25-40 cm, orchards, vineyards: 0-30, 30-60, hopfields: 10-40, 40-70 cm) ending with approximately 1.5 kg of soil. Sampling for bulk density is also made.

Samples are “fast" transported to lab (no special treatment). Before analysis the samples are air dried at room temperature and sieved to 2 mm. Litter is discarded.

A soil description is also available and is obtained by opening a soil profile, only once at the beginning of monitoring. Soil is described and classified according to national standards (https://klasifikace.pedologie.cz/).

Additional information on the sites is available on elevation and on slope, exposition, erosion features. Note that all the sampling sites being stable, there is no need to record this data every time.

Considering harmonization options:
- The design of the monitoring cannot be changed as changing design would make it impossible to compare the data with the old samples.

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- It is nevertheless possible to collect new information on the monitoring sites (but some support would be needed) and the soil description can be improved (e.g. convert the description to WRB).
- The sampling area cannot be changed as changing the area would make it impossible to compare the data with the old samples.
- The sampling depths cannot be changed as changing depth would make it impossible to compare the data with the old samples.
- The soil sample preparation cannot be changed as the analytical methods.
- New parameters could be measured on the archived soil samples under some conditions; it should be negotiated with the institute and Ministry who is officially the owner of the data.

Considering collaboration with LUCAS campaigns, **Czech Republic** didn't yet collaborate but is open to collaboration. All possibilities mentioned here could be considered. LUCAS Soil data were already used to create and validate digital soil maps in combination with soil spectroscopy.

3.2.4. Denmark

Denmark has a soil monitoring system called *KVADRATNETTET,* managed by Lars Elsgaard (Aarhus University). It started in 1985 to monitor Soil Organic Carbon on 450 sites (4 campaigns to date). It is still running and next campaign is planned by 2024 (an interval nowadays 4 year but before no fixed interval between 2 sampling campaigns). The system was designed to investigate Agricultural land uses and designed on a Grid basis (7x7 km).

All sites are georeferenced (precision < 1 meter m) and a composite sample is taken composed by 10 augerngs in a 10 X 10 meter grid (ramdom within 100 gridcells in the square) at fixed depths (0-25, 25-50, 50-75 and 75-100). Sampling for bulk density is also made. All sampling sites are treated the same.

Soil samples are air dried at room temp. Then before analysis the samples are crushed and sieved to 2mm. Litter is discarded.

A soil description is also available, obtained by opening a soil pit dug (at the beginning of the sampling in 1985). Soil is described (FAO) and classified (WRB) according to international standards.

Additional information on the sites is available on:
- elevation,
- soil data management is available,
- slope, exposition, erosion features,
- soil surroundings (e.g. road, factory, city…),
- lithology,
- vegetation,
- pictures are taken.

Note that a 0,4 meter resolution LIDAR is also available DK.

Considering harmonization options:
- The design of the monitoring can be changed.
- It is possible to collect new information on the monitoring sites and the soil description can be improved.
- The sampling area cannot be changed as the sampling depths.

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- The soil sample preparation cannot be changed.
- New parameters can be added.

Considering collaboration with LUCAS campaigns, **Denmark** didn't yet collaborate but is open to collaboration. They already use the LUCAS Soil data to compare results with the danish SMS.

3.2.5. Estonia

Estonia has two independent monitoring systems. The main aim of both systems is to report on soil chemical quality and monitor changes of soil properties over time. Several soil parameters are included such as pH, SOC, Ca, Mg etc. With those 2 systems natural and agricultural land uses are investigated. All sites are georeferenced (precision 1-3 meters m). These two monitoring programmes are quite contrasting from each other, because their purpose is different.

The first SMS is the National Soil Monitoring, which belongs to the National Environmental Monitoring Programme (NEMP). In the NEMP, we visit national long term monitoring sites (30 sites for Estonia), since 1983 (with a small break between 1991-2001, 6 to 7 campaigns are available). The Ministry of Environment is responsible for the National Soil Monitoring. The NEMP is more detailed, because in addition we investigate hazardous substances in soil, soil physical properties, we describe soil profile according to our national system and WRB. As this monitoring started in 1983, it investigates longer time-series, which has a high value to determine changes in soil properties over time. Next campaign is planned in autumn 2021. At the NEMP sampling is done according to a transect (90 to 180 m) where sampling point is located in every 10 to 20 m, representing 0.2 ha. Along the transect, three sampling schemes are applied: 1) sampling from every sampling point along the transect (in total 10-20 samples) for determining agrochemical properties (pH, SOC, nutrient content); 2) 2 samples from 5-10 cm and 20-25 cm are taken for bulk density; 3) a composite sample made of 10-20 samples. On those composite samples heavy metal and pesticide residue measurements are made. In addition, a soil pit is made in every monitoring site for more detailed soil description and classification (National and WRB). From the soil profile, soil samples are also collected according to the genetical horizons.

The second one is the Monitoring of Agricultural Soils, where we collect soil samples and soil data from local farmers, since 2002. In this second soil monitoring we take closer look at the agrochemical properties and SOC in Estonian agricultural soils (it covers about 80% of Estonian agricultural fields). Agricultural Research Centre is responsible for the Monitoring of Agricultural Soils. The Monitoring of Agricultural Soils looks at the general agrochemical properties and SOC in Estonian agricultural soils, but there we are able to investigate large number of agricultural sites all over the Estonia, which allows to take into account the spatial variability. Next campaign is planed in spring-autumn 2021 (meaning an interval of 5 years between 2 sampling campaigns, 4 campaigns are available). At the Monitoring of Agricultural Soils, the sampling is made on a grid basis (one composite sample made of 25 to 30 sampling points representing 3 to 5 ha). Bulk density samples are not taken in the Agricultural Soil Monitoring. For the Agricultural Soil Monitoring, soil samples are collected by certified persons, who has passed through an official training on collecting soil samples.

For those 2 monitoring systems, before preparation the samples are stored at room temperature. Then before analysis the samples are air drying at room temperature, crushed (bigger chunks are broken by hand, but most samples are crushed by machine) and sieved to 2 mm. Litter is discarded during sieving. A soil description is also available and is obtained by opening a soil pit, where the soil profile is exposed. Soil profile is investigated only during the NEMP. Soil is described (National, FAO and WRB) and

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classified (National and WRB) according to national standards (National: https://geoportaal.maaamet.ee/docs/muld/mullakaardi_seletuskiri.pdf?t=20091211092214, and WRB: http://www.fao.org/3/i3794en/I3794en.pdf).

Additional information on the sites is available on:
- elevation,
- soil data management is available for NEMP (collection from every land owner of documents about the land management, as crop rotation, fertilization etc.) but unfortunately not for the monitoring of agricultural soils,
- slope, exposition, erosion features,
- soil surroundings (e.g. road, factory, city…) available,
- lithology,
- pictures are taken.

Note that we have a model for erosion and also a map for the elevation, which can be used for obtaining information on slope and erosion features. In addition, we have a map for soil type, which can be used as a supportive material.

Considering harmonization options:
- The design of the monitoring can be changed but whenever changing or adapting the sampling design, it has to be done very delicately and carefully because these changes should not harm the consistency in the long term soil monitoring. Data should remain comparable to our previous monitoring, otherwise it won't be possible to make long term observations and data evaluations in a time series. In the end, it would result in that we have to discard the highly valuable dataset that has been collected since 1980s. Because of that, we are willing to adapt the sampling design only when the "new" design won't harm our long-term investigations and would provide benefits and additions to our current monitoring system. We highly value our long term observations and the consistency in time. We are willing to add new points to monitoring sites, when there are financial sources for that. We are not supporting the idea of changing the sampling depths, because changing the sampling depth would change the data directly.
- It is nevertheless possible to collect new information on the monitoring sites and the soil description cannot be improved as we are already applying detailed soil description (national and WRB), thus we do not find improvements necessary.
- The sampling area cannot be changed as NEMP relies on financial resources and if there is not enough financial support, we cannot increase the sampling pattern. Agricultural Soil Monitoring sites are already well sampled with a sufficient intensity and there it directly depends on the budget of a local farmer.
- The sampling depths cannot be changed as all the previous data rely on this protocol. Changing sampling depth has a direct effect on the whole dataset collected in previous years. It will cut down the consistency in sampling design and dataset won't be comparable anymore.
- The soil sample preparation can be changed and new parameters can be added. We are willing to add extra parameters when they are applicable to practical use (e.g. fertilization recommendations to farmers). Whenever changing measurement methods, it is important that results of a new method will be comparable with the previous dataset. In the long term monitoring, there has to be remain an opportunity to validate changes in parameters over a time-series.

Considering collaboration with LUCAS campaigns, **Estonia** didn’t yet collaborate but have used the results obtained from LUCAS campaign to evaluate the soil quality. We have also compared the LUCAS data with our own data collected from soil monitoring systems.

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We are interested in collaborating with LUCAS sampling campaign: assist with building up the sampling design, conduct the sampling campaign in Estonia and help with other incoming questions. We are also willing to conduct the data validation and compare LUCAS dataset with our national dataset. We have consistent and detailed national dataset, which could provide a good support for the data validation and comparison. We are happy to collaborate.

LUCAS data is highly valuable, when there is need to conduct soil quality assessments in EU level. We have used LUCAS data for example for the assessment of EU environmental support programme.

3.2.6. Finland

Finland has a soil monitoring program called Valse (National monitoring of arable soil chemical quality) managed by Natural Resources Institute Finland (Luke). It started in 1974 as a soil survey to obtain a comprehensive view of chemical quality of arable top-soils (SOC, pH, main and minor nutrients, heavy metals). Data from five campaigns with approximately 10 years intervals are available (1974, 1987, 1998, 2009 and 2018). The monitoring is still running and the sixth campaign is planned by 2028. The sampling was originally designed to investigate agricultural land uses and designed on a “geographically comprehensive“ + "representative" + "randomly allocated" sites basis (irregular grid). The present sampling grid consists of 480 sites which have been included from the start of the study (1974) and were not formally randomized + 150 new sites which were randomly allocated among the existing grid in the fifth sampling round (2018). A soil profile description is not available. All sampling sites are treated the same.

All presently included sites are georeferenced (precision a few meters) and a composite sampling (made of appr. 10 sub-samples) is taken on an area of 100 m² (10 m x 10 m) at fixed depths (0-15 cm). Sampling for bulk density is not made. At each sampling site, two composite samples are taken (approximately 100 g (dwt) each), one for the chemical analyses and the other one for soil archive (samples from all campaigns have been archived).

Before preparation the samples are stored at room temperature. Before analysis the samples are air dried at 37°C, crushed and sieved to 2 mm. Litter and large roots are discarded already before crushing and sieving. In the latest campaign (2018) additional, cold stored sample was taken at all sites for the analyses of biodiversity and pesticide residues.

Information on field management is available: a rough classification of the rotation has been obtained from the official field use register based on the yearly data on cultivation plant at the monitoring site. More detailed information on the management is not available (e.g. on tillage, fertilization etc.).
Considering harmonization options:

- The design of the monitoring can be changed by adding new randomly located sites (existing sampling sites must be kept).
- It is nevertheless possible to collect new information on the monitoring sites and the soil description can be improved. The soil description by profile classification could be done but that would increase the field work resources needed far beyond the present resources. Digging of profile pits in farmers fields would also require more close negotiation on field work permissions with the land-owners. Possibilities to obtain more comprehensive information on soil management are currently investigated. It is also possible to consider collection of information on the site surroundings if it is considered useful and cost effective considering the main aims of the monitoring.

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- The sampling area cannot be changed.
- The sampling depths cannot be changed. For reliable monitoring, the depth of the sample cannot be changed. However, additional deeper samples can be included for specific purposes. For instance, in the latest field campaign (2018) separate deeper samples were taken in a sub-set of sites for carbon stock estimation.
- The soil sample preparation cannot be changed as from the monitoring viewpoint, it would seem unwise.
- New parameters can be added: for instance, in the latest sampling round, additional, cold stored composite sample was taken for the eDNA analyses of soil biodiversity and for the analyses of pesticide residues.

Considering collaboration with LUCAS campaigns, Finland didn't yet collaborate except through EJP Soil where it participated the discussion on the allocation of new LUCAS Soil sampling sites in Finland (sites on agricultural land). The conclusion was that the positioning of new LUCAS points can be done independently of the national sampling grid.

The possibilities of collaboration have not yet been discussed in great detail. One interesting opportunity is to compare key soil quality trends in LUCAS Soil and the national monitoring. Unlike the national soil monitoring, LUCAS covers soil structure (bulk density) and usage of that data could complement well the national monitoring which lacks soil physical variables.

The national data cannot be rendered as such open because it has been collected from private land. However, in principle discussions on data sharing with LUCAS Soil are possible. So far one national research proposal on the usage of LUCAS Soil data along with national monitoring data has been made but the proposal was not successful.

3.2.7. France

France has a soil monitoring system[11] called Réseau de Mesures de la Qualité des Sols (RMQS) French Soil Monitoring Network and managed by INRAE-InfoSol (under the supervision of GIS Sol, www.gissol.fr). It started in 2000 to report on soil quality and soil properties changes on 2241 sites including 2174 metropolitan ones and 67 in outermost regions sites. It is still running and next campaign is planned from 2016 to 2027 (meaning an interval of 7 to 26 years between 2 sampling campaigns, according to sites). The system was designed to investigate all kind of land uses and designed on a grid basis (grid: 16 x 16 km).

All sites are georeferenced (precision 0.5 m) and composite samples (made of 25 sub-samples) are taken on an area of 400 m² (square (20x20 m)) at fixed depths (according land uses : ploughing layer and below until 50 cm for croplands, 0-30 and 30-50 cm for others) ending with approximately 8 kg in average for top layer and 4 kg in average for subsoil. Sampling for bulk density is also made on a soil pit. Note that for the second sampling campaign, when possible, deeper samples are taken (from 50-75 cm and from 75- 100 cm).

[11] There is also a dedicated SMS for forests where 102 sites are monitored. Location were chosen based on accessibility and control criteria, and representativeness of the dominant ecosystems (type of forest, soil type, climate)

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Before preparation the samples are stores at 4°C (cold room). Then before analysis the samples are air dryed at 30°C (room at controlled temperature), crushed (by hand) and sieved to 2 mm. Litter is discarded.

A soil description is also available and is obtained by opening a soil profile. Soil is described and classified according to national standards (STIPA et guide de la description des sols (Baize et al) / Référentiel pédologique (1995 and 2008 editions, Baize et al) - other reference for soil description for forest soils (description realized in 1994 and in 1999)).

Additional information on the sites is available on:
- elevation,
- soil data management is available (eg. exhaustive collection of data on soil management, by interview with farmers, once by campaign, covering inter-campaign period, historical management, covering multiple land uses, including detailed crop itineraries (crop rotation, fertilisation, manure, crop residues management, soil tillage, pest management, grass management and pasture...)),
- slope, exposition, erosion features,
- soil surroundings (e.g. road, factory, city…),
- lithology,
- vegetation,
- pictures are taken.

Note that in situ observations by soil scientists are also made as: erosion features, parent material, slope, exposition, water regime, crop, soil cover, stoniness, anthropogenic artefacts on soil surface, day and previous days weather).

Sites are globally treated the same with light differences : 1/vegetation inventory on aged grasslands and forests and less described on anthropogenic sites. 2/ enlighted sampling on forest sites (linked to RSSDF network) : soil description not renewed on 1st campaign, no deep bulk density sampling. Precision geolocalisation on forest sites only since 2nd campaign.

Considering harmonization options:
- design of the monitoring cannot be changed but as we may add new sampling points locally.
- It is possible to collect new information on the monitoring sites and the soil description can be improved. We may describe more parameters about the soil surface (as ploughing layer, soil structure) but it needs trained persons and more time. We may also convert our national information into WRB, also with means and time. We may also collect new information, depending on means. We already did, from one to the other campaigns (pesticides, AWC, biodiversity, deep carbon). We intend to collect more frequent informations concerning soil management.
- The sampling area cannot be changed as all previous data rely on this protocol. Decreasing sampling area may be an option with GPS improvement (we started with a 10 x 10 m). Increasing sampling area would increase soil variability effect.
- The sampling depths cannot be changed unless for deeper samples. We have already sampled deeper from 1st to 2nd campaign.
- The soil sample preparation cannot be changed.
- New parameters can be added and we are currently testing the measurement of biological parameters and pesticide residues in soils.

Considering collaboration with LUCAS campaigns, France didn't yet collaborate unless through EJP SOIL where we participated to the discussion on the allocation of new LUCAS Soil sampling sites in

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France (including the Alps). We are opened to collaborations event if not yet been discussed in great detail. One interesting opportunity is to compare key soil quality trends in LUCAS Soil and the national monitoring. We already used the LUCAS data for research purposes and soil mapping. LUCAS data were already used for comparisons studies (annex 2), merging results for mapping (Caubet et al., 2019) and evaluations of the number of sites necessary to calibrate a merging model for mapping (Chen et al., 2020).

3.2.8. Germany

Germany has 2 monitoring systems, BD and BZE, while the latter one consists of two national grids, one is solely on agricultural soil (BZE-LW), one is on forest soils (BZE-Wald).

BZE-LW is primarily dedicated to the monitoring of SOC stocks.The 1st soil monitoring system called Permanent Soil Montoring in Germany (BD: Boden-Dauerbeobachtung in Deutschland) is managed by Federal States (sub-national system: Bundesländer). It started in 1985 to report and record changes in soil state over a long period of time, on 800 sites. It is still running and the campaigns depend upon the activity of the federal states (but usually with an interval of 4-5 years between 2 sampling campaigns). The system was designed to investigate all kind of land uses and is based on a representative/stratified sites. Monitoring sites are devided into 3-4 plots each sampled with a changing grid.

All sites are georeferenced (precision 1000 m) and a composite samples is taken from an area of 1000 m² (15 to 20 sub-samples taken on a cross pattern) both at fixed depths and according to horizons (depending on landuse (e.g. for agriculture often 0-30 cm or ploughing layer) ending with approximately 1 to 5 kg of soil. Sampling for bulk density is also made.

Not all sampling sites are treated the same as the authorities in the federal states are responsible of sampling their monitoring sites, i.e. each state has its own sampling protocol. Protocols are varying slightly. Depending upon a given element a uniform evaluation of data might be possible.

Before preparation the storage of the samples depend on organic or inorganic elements, soil chemical, biological or physical parameters to be performed. Then before analysis the samples are crushed (all kind) and sieved to 2 mm. If litter is discarded or not is depending on the federal state.

A soil description is also available and was obtained by opening a soil pit. Soil is described and classified according to national standards (reference: Bondekundliche Kartieranleitung (KA 5)). Samples are also collected on the soil pit based on the soil horizons.

Additional information on the sites is available on:

- elevation,
- soil data management is available for several federal states (e.g. depending on the respective federal state no or a comprehensive compilation of soil management data is available),
- slope, exposition, erosion features,
- lithology,
- vegetation,
- Note that depending on the respective federal state a more or less comprehensive descriptions of the monitoring sites are available.

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- The design of the monitoring cannot be changed as changes in the design would affect the time series in the core sampling area.
- it is nevertheless possible to collect new information on the monitoring sites and the soil description can be improved (e.g. by converting our national information into WRB).
- The sampling area cannot be changed.
- The sampling depths can be changed but not in the core area of the monitoring sites.
- The soil sample preparation cannot be changed.
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Germany didn't yet collaborate and will not for the 2022 campaign but maybe in the future. Germany already uses the LUCAS data to get an overview and compare with national data.

The 2nd soil monitoring system is called BZE-LW (Bodenzustandserhebung Landwirtschaft) and is managed by the Thünen Institute of Climate-Smart Agriculture (Christopher Poeplau). It started in 2011 to monitor SOC on 3104 sites. It is still running and next campaign is planned between 2023 and 2028 (meaning an interval of 10-12 years between 2 sampling campaigns). The system was designed to investigate agricultural land uses and designed on a grid basis (8x8 km grid).

All sites are georeferenced (precision <1 m) and in the first campaign, samples were taken on an area of 400m² (20x20 m). A profile pit was opened in the middle of the plot and 8 core samples were taken in a 10 m radius circle around the pitSamples from the profile wall were collected at fixed depth (0-10, 10-30, 30-50. 50-70, 70-100 cm) and according to horizons (if horizon boarder varies more than 4 cm from depth boarder, an additional depth was sampled) ending with approximately 1kg of soil. In contrast, the eight satellite cores were sampled in fixed depth increments only. Sampling for bulk density is also made. All sampling sites are treated the same.

Before preparation the samples are stored at 4°C. Then before analysis the samples are oven drying at 40°C, crushed (partly jaw breaker) and sieved to 2 mm. Litter up to 2mm is quantified and litter less than 2 mm is integrated.

A soil description is also available and was obtained from the central soil pit. Soil was described and classified according to national standards (Ad-Hoc AG Boden "Bodenkundliche Kartieranleitung 5").

Additional information on the sites is available on:
- elevation,
- soil data management is available (eg. 10 years of management data prior to first sampling, not available to the public),
- slope, exposition, erosion features,
- soil surroundings (e.g. road, factory, city…) available,
- lithology,
- vegetation,
- pictures are taken.

Note that the design will be changed from inventory 1 to inventory 2: the auger samples around the pit will not be done again (not comparable to profile results). Instead, three to four profiles will be sampled in direct proximity of the initial profile. Only 0-10, 10-30 and 30-50 cm depths will be sampled, since subsoils below 50 cm are assumed to remain stable in a 10 year interval. The full depth of 100 cm will be resampled at a potential third campaign.

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Considering harmonization options:
- The design of the monitoring cannot be changed. For the next campaign the grid will stay the same, but in situ sampling desing is changed (see previous comments).
- It is possible to collect new information on the monitoring sites and the soil description cannot be improved as conversion into WRB is already done.
- The sampling area cannot be changed (it will change from campaign 1 to 2, but will always be a profil pit sampling).
- The sampling depths cannot be changed as all previous data rely on this protocol.
- The soil sample preparation cannot be changed.
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Germany didn't yet collaborate but is open to collaboration. LUCAS data were already used for digital Soil Mapping.

3.2.9. Hungary

Hungary has a soil monitoring system called TIM that can be translated as "Soil Conservation Information and Monitoring System", with English abbreviation SIMS. It is managed by the National Food Chain Safety Office, Directorate of Plant Protection Soil Conservation and Agri-environment. This institution belongs to the Agroministry in Hungary. It started in 1992 with the following main aims: preserve condition in those areas where soil conditions are satisfactory, prevent or mitigate deteriorations where soil conditions threatened by natural or antropogenic hazards and improve conditions in places where they are not appropriate. It is composed of 1230 sites sampled annually. The next campaign is planned by between Sept.15 - Oct.15., 2021 (28 campaigns are available). The system was designed to investigate agricultural and forest land uses as well as water & wind erosion land and problematical sites (contamination). Representative sites were stratified (sampling sites were established to represent geographical and soil settings).

All sites are georeferenced (precision 50 m, GPS coordinates are converted to geographical coordinates in order to use data in Geographical Information System (GIS)). A composite sample is taken on an area of 1 963 m² (circle with a radius of 25 meters, around the sampling point) at fixed depths depending on the soil layers. On the 1st year of sampling (in 1992) the whole soil profile from soil surface to 150 cm depth was sampled by genetic levels. On the consecutive years the sampling methods depends on the type of points:
- On the information points which are plough lands an average sample of nine taken from three genetic levels (G1; G2; G3) from depth of 0-30 cm; 30-60 cm and 60-90 cm layers.
- On forest lands one sample is taken from three genetic levels (G1; G2; G3) from depth of 0-30 cm; 30-60 cm and 60-90 cm layers.
- Sampling methods on erosion and special points (problematic points) are done on the way of information points (plough land).

The average final weight is 2 kg of soil. Sampling for bulk density is also made.

Before preparation the storage of the samples depends on the type of soil examination (e.g. 4°C for microbiological examination or room temperature for other analyses). Then before analysis the samples are crushed (a special soil grinder is used with 2 mm sieve) and sieved to 2 mm for every soil sample, except for humus (0,25 mm sieve is used after the 2 mm sieve application). Litter is discarded.

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A soil description is also available and was obtained in 1992 where the whole soil profile was exposed. Soil is described and classified according to national standards (the reference is a 150 years old national practical method).

Additional information on the sites is available on:

- elevation,
- soil data management is available (sampling points are designated on plough fields and forest lands. On several forest lands forestry management takes place),
- slope, exposition, erosion features (on the soil sampling points, next to soil profile description several other features are recorded as well as landscape characteristic (equator exposure, slope%, erosion). The soil sampling points were marked on geographical map having scale 1: 100.000,
- soil surroundings (e.g. road, factory, city…) available,
- lithology,
- vegetation description and forms are recorded but inventory is not taken. The soil description was done at the establishment (in year 1992). On consecutive years the changes or differences are recorded only,
- pictures are taken.

Note that the soil samples of the Hungarian SMS are collected by regional soil conservation officers and examined by the soil laboratory of National Food Chain Safety Office.

Not all sampling sites are treated the same: there are four different type of sampling sites (agricultural points cover plough lands, forestry points cover forest lands and so called special points covering problemetical sites (e.g. contaminated sites)).

Considering harmonization options as the whole Hungarian SMS is being updated, discussions are currently running that may change the sampling design, the sampling area, the preparation… and the parameters to be analysed.

Considering collaboration with LUCAS campaigns, Hungary already collaborated as a few years ago Pr Gergely Tóth as a Hungarian soil expert participated in the EU-JRC Ispra project. New collaboration is expected.

LUCAS data were not used as it is a different soil sampling method that is not applied in Hungary. National and LUCAS Soil datasets were compared (see Annex 2).

3.2.10. Ireland

Ireland does not have a soil monitoring system at this time. The Irish SIS, Irish Soil Information System managed by Reamonn Fealy & Lilian O'Sullivan (Teagasc) and available through Teagasc and the Irish EPA (https://gis.epa.ie/GetData/Download) contains a harmonised dataset of the soil types found in Ireland. The SIS started in 2009 to get the baseline of main soil types in Ireland classified to profile pit characterising soil properties on 225 sites that were combined with legacy data that were harmonised to generate 800 sites with profile classification. Sampling has not yet been repeated but points may be used to follow up for properties such as soil organic carbon. The system was not established initially as a monitoring system but as the initial national baseline designed to investigate agricultural soils. It is based on stratified representative sites (based up on a digital soil mapping approach of terra cognita and terra incognita identification). All sampling sites are treated the same.

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All sites are georeferenced (precision 5 m) and a composite sample is taken at different depths (according to horizons) ending with approximately 2 kg of soil. Sampling for bulk density is also made (3 samples per horizon level so often 9 or 12 per soil pit).

The collected samples were prepared by hand by breaking up soil clods to speed up the drying process and removing any large plant material. Samples are placed into an oven set at 40°C for 72 h. After 72 h, we check to see whether soil is dry by placing the soil back into the sample bag and fastening the top with an elastic band. If any water condenses on the side of the bag within 30 minutes, then transfer the soil and sample bag back to the aluminium tray and place back into the oven. When the soil has dried and allowed to stand, we record the total soil weight and sieve the soil to 2 mm. Litter is discarded. A soil description is also available and is obtained by opening a soil pit (excavated using digger). Soil is described and classified according to national standards (http://gis.teagasc.ie/soils/).

Additional information on the sites is available on:
- elevation,
- slope, exposition, erosion features,
- lithology,
- vegetation,
- pictures are taken.

Considering harmonization options:
- The design of a monitoring system can be changed as new points can be added but also these points can be used to link into another system (e.g. LUCAS).
- It is not possible to collect new information on the monitoring sites unless there is a project to support revisiting of sites as these are distributed nationwide.
- The soil description is already correlated with the WRB.
- The sampling area, strategy and depths cannot be changed as this relies on project support that currently is not available.
- The soil sample preparation and analysis cannot be changed (In the Irish SIS all measurements were standardised and adhere to ISO. Legacy data was harmonised to meet this standard already and any deviation in methods were tested to confirm accuracy of different approach).
- New parameters cannot be added.

Considering collaboration with LUCAS campaigns, Ireland already collaborated with a previous campaign as a small number of sites are located in Ireland (~39) and is open to collaboration. Note that LUCAS sites are historically topsoil surveys unlike the SIS data that is recorded to profile depts of 1m where possible. LUCAS data were not used.

3.2.11. Italy

Italy does not have in place a national soil monitoring system. Soil monitoring is running at regional level with differentiated protocols (but not in all Italian regions), 3 of these regions answered to the questionnaire: Lombardia, Puglia and Veneto. Other Italian regions which have currently active soil monitoring systems are: Friuli Venezia Giulia, Sardegna, Emilia Romagna, Toscana and Piemonte.

Lombardia declared 2 soil monitoring systems MOSAC (Monitoraggio dei Suoli in Agricoltura Conservativa) and Regional soil nutrients monitoring network.

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The Soil monitoring of conservation agriculture practices started in 2016 to compare the effect on soils of conservation agriculture practices (no tillage, cover crops, crops diversification) and conventional practices (ploughing) on the following indicators: SOC, soil biodiversity indicators (QBS-ar, earthworms), crop yields on 4 sites. It is still running and sampled each year (next campaign is planned by autumn 2021). The system was designed to investigate agricultural land uses and based on stratified representative sites (sites are representative of soil types and cropping systems).

All sites are treated the same as, georeferenced (precision about 5 m (could eventually be improved)) and a composite sample is taken. The sampling design is the following:

- each sampling site is composed by two- three monitoring units (fields) managed under conservation practices and in one conventionally managed field,
- within each field (monitoring unit) three sampling support area are identified,
- the three sampling support areas are located at the vertex of a right triangle (sides: 40m and 80m),
- in each sampling support area (vertex) we collect a composite soil sample made of 9 sub-samples, collected in a circle of 8 m radius (one subsample is collected in the middle of the circle, then 8 subsamples are collected every 4m along two orthogonal axes),
- in each sampling support area, a sample for bulk density, earthworms, QBS-ar assessment is collected at the middle of the circle.

Samples are collected at 2 different fixed depths (0-10; 10-30 cm) ending with approximately 10kg (for earthworms), 2kg (for SOC) and 1.5 kg (for QBS-ar).

Before preparation the samples are stores at room temperature. Then before analysis the samples are air dryed (for SOC), crushed and sieved to 2 mm. Litter is discarded.

Additional information on the sites is available on:

- elevation,
- soil data management is available (eg. information on tillage (type of tillage, ploughing date, ploughing depth), type of crop, rotations (cerals and forage crops, cover crops, in some cases rotations include orchards (eg. tomato, pumpkin)), yields, soil management (fertilization practices, herbicides, irrigation) and used machineries are available),
- soil surroundings (e.g. road, factory, city…) available,
- lithology,
- pictures are taken.
-

Note that all fields are located in the Po plain, therefore slope, exposition and erosion features are not relevant.

Considering harmonization options:

- The design of the monitoring can be changed as we plan adding new sampling sites (we may integrate our sampling design criteria for new sampling sites with other soil monitoring networks criteria).
- It is possible to collect new information on the monitoring sites. We haven't planned new soil profile descriptions within our sampling sites. Previous soil unit cartography was built through soil profiles digging, following the USDA and WRB classification (we currently make reference to these previous soil units descriptions for our soil monitoring needs). Potentially further information can be collected.

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- The sampling area can be changed as we plan to add new sampling sites (farms/ fields). We would not modify the previous sampling support area protocol, as all pre-existing data rely on this protocol.
- The sampling depths and the sample preparation cannot be changed as all the previous data rely on this protocol.
- New parameters can be added if compliant to our budget and organisational resources.

Considering collaboration with LUCAS campaigns, Italy-Lombardia didn't yet collaborate but is open to collaboration (e.g. to evaluate LUCAS representativeness on regional /national level; support the identification of LUCAS monitoring points; compare LUCAS and National design strategies and sampling methods; organize ring-test with national labs; integrate LUCAS network within National and/or Regional Soil Monitoring Networks). LUCAS data were not used.

The Regional soil nutrients monitoring network started in 2010 to monitor nitrate and phosporous concentrations in agricultural soils, in relation to Nitrates Directive requirements and consequent regional Action Plan monitoring activities. Each year, about 90 sampling sites are choosen within a set of 120 potential sites. It is still running and next campaign is planned by Autumn 2021.

Sampling was done once a year until 2020 (autumn, post-harvest) and from 2021 it will be done twice a year (only for a sub-set of 30 sampling sites), late winter (pre-seeding) and autumn (post-harvest), and once a year for the remaining 60 sampling sites. The system was designed to investigate agricultural land uses and based on a stratified representative sites (sites represent a combination of soil types and management practices in relation to diary farms, fertilization practices and nitrates land vulnerability). All sampling sites are treated the same.

All sites are georeferenced (precision about 5 m (could eventually be improved)). The sampling design is the following:
- Six Focus Areas are identified within the Lombardy Po Plain, representative of the variability of soils types, fertilization practices, livestock load, agricultural surface percentage, underground water quality, crop types.
- Within each Focus Area, about 20 sampling sites are identified (about 120 total sampling sites) among diary farms included in Nitrates management Procedure.
- Within each sampling site, one sampling support area is identified (field). For each sampling support area, 5 sub-samples are collected, at the vertices of an X scheme to make a composite sample on an area of about 1 ha (the X scheme is centered in the middle of the sampling support area (field)).
- Samples are collected at fixed depths (0-30; 30-60; 60-90 cm) ending with approximately 2 kg of soil.

Before preparation the samples are stores at -20°C. Then before analysis the samples are crushed and sieved. Litter is integrated in the sample.

Additional information on the sites is available on:
- elevation,
- information on existing crops is collected while sampling,
- lithology,
- pictures are taken.

Considering harmonization options:

- The design of the monitoring can be changed as the sampling design is part of a 4 yr monitoring plan, producing annual reports to answer to Nitrate directive and Regional Nitrate Action Plan requirements: thus, it currently has a fixed form which may vary in the context of future pluriannual monitoring plans (points may change, new points may be added...).
- For current needs and monitoring objectives, further information on the monitoring sites is not needed (and not even compliant with privacy requirements, as the monitoring results are published in an aggregated form, not being aimed at monitoring single farms management practices). This may change in future pluriannual monitoring plans, as their aims could change too.
- We haven't planned new soil profile descriptions within our sampling sites. Previous soil unit cartography was built through soil profiles digging, following the USDA and WRB classification. We currently make reference to these previous soil units descriptions for our soil monitoring needs.
- The overall sampling area (the whole Lombardy Plain Soil Region) will not change, as this is the area of interest for nitrates monitoring. Within this area, sampling sites may vary (increase, decrease, substitutions, ...). New points choice could be done also in relation to other pre-existing soil monitoring networks (national and european level).
- We would not modify the previous sampling support area protocol, as all pre-existing data rely on this protocol. In any case, we may add a further detail on sampling depths (e.g. adding a new sampling depth in-between preexisting boundaries), if new monitoring objectives were integrated in the monitoring program.
- We could add extra parameters to be analysed only if consistent new monitoring objectives and new resources were integrated in the pre-existing soil monitoring plan, in the context of future new pluriannual plans.

Considering collaboration with LUCAS campaigns, Italy-Lombardia didn't yet collaborate but is open to collaboration to evaluate LUCAS répresentativeness on regional /national level; support the identification of LUCAS monitoring points; compare LUCAS and National design strategies and sampling methods; organise ring-test with national labs; integrate LUCAS network within National and/or Regional Soil Monitoring Networks). LUCAS data were not used.

Puglia has a soil monitoring system called 'Carta pedologica di 6 aree della Puglia'. It started in 2010 to program, assist and define on the next survey sites (to develop a 1: 50000 semi-detailed map). It is still running and next campaign is planned by 2020 but sampling campaigns are not regular and do not occur in the same areas. The system was designed to investigate natural, agricultural and forest land uses. It is based on stratified representative sites identified through reasoned relief with photo interpretation.

All sites are georeferenced (precision 1 m) and a composite sample is taken on an area of 4 m² (2x2 m) at different depths (according to horizons, from 0-100 cm) ending with approximately 1kg of soil. Before preparation the samples are stores at room temperature. Then before analysis the samples are crushed and sieved to 2 mm. Litter is integrated in the sample. All sampling sites are treated the same.

A soil description is also available and is obtained by opening a soil profile. Soil is described and classified according to national standards.

Additional information on the sites is available on:
- elevation,
- soil data management is available,
- slope, exposition, erosion features,

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- soil surroundings (e.g. road, factory, city…) available,
- lithology,
- vegetation,
- pictures are taken,

Considering harmonization options:
- The design of the monitoring can be changed by adding new points.
- It is possible to collect new information on the monitoring sites and the soil description can be improved.

Considering collaboration with LUCAS campaigns, Italy-Puglia didn't yet collaborate but is open to collaboration as data provided is totally public. LUCAS data were not used.

Veneto has a soil monitoring system called ARPAV_UOQS. It started in 2012 to monitor SOC, nitrates, heavy metals, POPs, Biological quality (QBS) on 40 sites. It is still running and next campaign depends on the investigation purposes (e.g. an interval between 2 sampling campaigns of 5 years for nitrates and heavy metals, each year for QBS). Up to now QBS monitoring and nitrate/heavy metals are different monitoring projects/schemes, we are planning to organize a unique monitoring network for all parameters (POPs monitoring is still under planning).The system was designed to investigate natural, agricultural and forest land uses and is based on a stratified representative sites (representative sites chosen by means of soil map, land use, impacts).

All sites are georeferenced (precision of 1-2 m) and a composite sample is taken from 16 area of 400 m^2 (16 cells of 20x20 m for nitrates) and 3 triangles of 20m (for QBS) at fixed depths (0-30cm for nitrates and 0-10cm for QBS) ending with approximately 1,5 kg of soil. Sampling for bulk density is also made (for the QBS sites).

Before preparation the samples are stores at lab temperature. Then before analysis the samples are air dryed, crushed (grinding) and sieved to 2 mm for standard analysis (and 0,2mm for heavy metals). Litter is discarded.

A soil description is also available(Yes) and is obtained by soil augering. Soil is described (National) and classified (WRB) according to national standards (https://www.arpa.veneto.it/temi-ambientali/suolo/file-e-allegati/documenti/manuali-e-schede/ARPAV_RilPed2007_Manuale_riv080108.pdf).

Additional information on the sites is available on:
- elevation,
- soil data management is available (eg. monitoring in chosen farms: rotations, crops, fertilization and irrigation known),
- slope, exposition, erosion features,
- lithology.

Note that a form is filled with all information about site and auger profile.

Not all the sampling sites are treated the same: where QBS is assessed more parameters are described (as bulk density, vegetation, etc) and where nitrates are monitored, more information is collected on crop management.

Considering harmonization options:

- The design of the monitoring can be changed as we are just planning the design and are open to suggestions (preferabely not grid).
- It is possible to collect new information on the monitoring sites.
- The sampling area can be changed.
- The sampling depths can be changed as we could add subsoil samples.
- The soil sample preparation cannot be changed but the analytical methods may be changed.
- New parameters can also be added.

Considering collaboration with LUCAS campaigns, Veneto just collaborate to the last request for the positioning of new monitoring sites and is open to collaboration: supplementary soil data for Lucas points can be collected, we would like to sample Lucas points, provide soil analysis by means of our accredited laboratory and collaborate in the derivation of transfer functions.
LUCAS data were already used to compare to our data (more than 20.000 soil samples analysed, 4.800 soil profiles, 32.000 soil augerings), for soil mapping, and analysing the results, etc.

3.2.12. Latvia

Latvia has a soil monitoring system called Crop Monitoring Information System of Latvia and managed by State Plant Protection Service (another monitoring system is maintained for forests – see annex 3). It started at different dates depending on the purpose of the monitoring (agrochemical research in 2004, representative sample holdings in 2018, nitrogen monitoring in 2006 and carbon monitoring in 2018). The number of sites also depends as 23 sites are dedicated ton carbon monitoring, 48 sites are dedicated to nitrogen monitoring, 101 087 sites to agrochemical research and 4158 to representative sample holdings. It is still running and campaigns occurred each year (for carbon, nitrogen and agrochemical monitoring) or every 5 years for sample holdings. The system was designed to investigate agricultural land uses and designed on a stratified representative sites (no grid design).

All sites are georeferenced (precision ~ 10 m) and composite samples are made on an area of
- 314 m² for nitrogen monitornig, based on circle (radius of 10 m) where 3 composite samples (6-8 probe samples) for nitrogen monitoring from each defined depths (0-30 cm, 30-60cm, 60-90 cm),
- 10 000 to 60 000 m² for agrochemical research (depending on soil type and field) where one composite sample (15-20 probe samples) at one depth (0- 20 cm),
- 12,5 m² for carbon monitoring, based on circle (radius of 2 m) where 5 composite samples (15 probe samples) for carbon monitoring from each defined depths (0-10 cm, 10-20cm, 20-40 cm).

Before preparation the samples are stores at -20°C or +4°C (for nitrogen monitoring) and at room temperature (for agrochemical research and carbon monitoring). For nitrogen monitoring fresh samples are used whereas for agrochemical research samples are oven dryed at +40°C, crushed (crushing with grinder mill) and sieved to 1,5 mm (only for agrochemical research). Litter is discarded.

Additional information on the sites is available on soil data management and slope, exposition and erosion features.

Considering harmonization options:
- The design of the monitoring cannot be changed.
- The collection of new information on the monitoring sites is note possible as improving soil description (not our competence).

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- The sampling area, sampling depths, sample preparation and analysis cannot be changed as it is in accordance with Cabinet Regulation No. 833 (Adopted 5 October 2004) “Procedures by which the Information Regarding the Fertility Level of the Agricultural Land and the Changes Thereof is Obtained and Compiled” (point 6) the State Plant Protection Service shall carry out the soil agrochemical research and evaluate the research results in accordance with the methodology approved by the Minister for Agriculture. (https://likumi.lv/ta/en/en/id/94669-procedures-by-which-the-information-regarding-the-fertility-level-of-the-agricultural-land-and-the-changes-thereof-is-obtained-and-compiled).

Considering collaboration with LUCAS campaigns, Latvia hasn’t yet collaborated and is not asking for collaboration. LUCAS data were not used so far.

3.2.13. Lithuania

Lithuania has a soil monitoring system called DirvAgroch_DB10LT (DirvAgroch_DR10LT) - Monitoring of soil agrochemical properties (Dirvožemio agrocheminių savybių stebėsena) and managed by Ministry of Agriculture of the Republic of Lithuania. It started in 1993 to monitor pH, mobile P2O5 and K2O on 10 000 sampling sites each year. From 1993 to 2020 the SMS was carried out in part of the monitoring representative sites every year with every 10 years returning to the same representative sites. A new version of SMS is now being prepared. The system was designed to investigate agricultural land uses and based on stratified representative sites. Monitoring was performed annually for 40 000 ha (about 10 000 representative sites) in which average area of representative site - 4 ha.

All sites are georeferenced (precision 1.5-2 m) and a composite sample is taken on an area of 300-400 m² (in each representative site at 15-20 subsamples are collected on distributed points along the 150-200 meters transects) at fixed depths (0-20 cm) ending with approximately 1kg of soil. Before preparation the samples are stores at 4°C. Then before analysis the samples are air dried at room temperature/at 30°C and sieved to 2 mm. Litter is integrated in the sample.

A soil description is available by using the information of Lithuanian SIS spatial dataset Dirv_DR10LT (spatial dataset of soil of the Republic of Lithuania at scale 1:10000) (www.zis.lt/en). Soil is described and classified according to national standards (Applied / used National Lithuanian soil classification LTDK-99 (Buivydaitė V.V., Vaičys M., Juodis J., & Motuzas A. (2001). Lithuanian Soil Classification. Lietuvos mokslas book 34, 137 p. (in Lithuanian)) was harmonized with FAO-UNESCO Soil Map of the World Revised Legend with corrections and updates (ISSS-ISRIC-FAO, 1994; FAO-UNESCO-ISRIC, 1997) and World Reference Base for Soil Resources (ISSS-ISRIC-FAO, 1996; 1998). Lithuanian soil terminology is used for the soil names and indexes as well as the international one.

Additional information on the sites is available on soil data management (eg. Crop management).

Note that in addition to this SMS, the program “Monitoring of changes in mineral nitrogen in soil” was implemented in 2005-2020. During its implementation, over 200 sites were located in various regions of Lithuania, where the stocks (kg/ha) of mineral N (NH4-N and NO3-N) and mineral S (from 2007, not every year) in soil layers of various depths (0–30, 31–60 and 61–90 cm) was studied in early spring and autumn. Based on the data received, farmers, consultants and specialists were provided with information on the mineral nitrogen stocks in the soil in the spring and the required nitrogen fertilizer rates for agricultural crops.

Considering harmonization options:
- The design of the monitoring cannot be changed as it's a grid of representative sites.

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- It is not possible to collect new information on the monitoring sites as it will take too much time on the sites.
- The soil description can be improved as we may convert our national information into WRB.
- The sampling area, sampling depths, the sample preparation and analysis cannot be changed as all the previous data rely on this protocol.
- New parameters cannot be added.

Considering collaboration with LUCAS campaigns, Lithuania didn't yet collaborate but is open to collaboration: the new LUCAS points could be done at the same locations as national sites, we may analyze a subset of samples with both lab methods and labs (national and LUCAS) to derive transfer functions and use all data together in order to compare LUCAS and National sampling design strategies. LUCAS data were not used so far.

3.2.14. Netherlands

Netherlands has a soil monitoring system called Landelijke Steekproef Kaarteenheden (LSK) / Netherlands Soil Sampling Program (NSSP) and is managed by the Dutch Ministry of Agriculture, Nature, Food Quality. It first started in 1988 with monitoring soil organic carbon and soil quality on 1392 sites in 1998. It is still running and the next campaign is planned by 2023 probably. The following campaigns were performed:

- First two try-outs from 1988 to 1990 (podzols with deep groundwaterlevels) and 1989 to 1990 (12 map units (beekeerdgronden)).
- Then a campaign for all map units from 1990 tot 1998.
- This was repeated in 2018.

The system was designed to investigate natural, agricultural, forest land uses and is based on stratified representative sites (stratified in 96 strata according to soil and groundwater classes - Stratified random sampling design).

All sites are georeferenced (precision 5 m, GPS only used in 2018) and a composite sample is taken on an area of 12.5 m² (LUCAS strategy: circle 2 m radius, 5 samples) at fixed depths (0-30, 30-100 cm) ending with approximately 2 and 4 kg of soil. Sampling for bulk density is also done in 2018 using a soil auger (bulk density measurements are still under research due to lower measured bulk densities with this method compared to rings in a student research. Tests done with a soil bulk density sensor: promising but needs further validation study). All sampling sites are treated the same and that includes the use of a penetrologger for penetration resistance in 2018.

Before preparation the samples are stored at room temperature. Then before analysis the samples are air dried in bag for 2 hrs, then the bag is removed and the sample is dried for 24 hours at 105° C, crushed and sieved to 2 mm. Litter is discarded.

A soil description is obtained with a Dutch soil auger (profile description was made in 1998, not in 2018). Soil is described and classified according to national standards (https://edepot.wur.nl/470901). Additional information on the sites is available on soil surroundings (e.g. road, factory, city…), lithology and pictures are taken.

Considering harmonization options:

- The design of the monitoring can be changed to the extent that new points can be added to obtain information for new domains of interest.
- It is possible to collect new information on the monitoring sites (for soil quality).

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- The soil description can be added to as we may convert our national information into WRB (after description).
- The sampling area, sampling depths, sample preparation and measurement methods cannot be changed as all the previous data rely on this protocol. Harmonisation of data later on can be discussed if the Netherlands are involved in the derivation of the transfer functions. The national dataset is leading for national policy.
- New parameters may be added.

Considering collaboration with LUCAS campaigns, the Netherlands didn't yet collaborate but is open to collaboration. It is possible to discuss this, but this is subject to the policy at the Ministry. This questionnaire was filled in by researchers and cannot be taken as the Dutch opinion or decision on this topic! LUCAS data were not used so far.

3.2.15. Poland

Poland has a soil monitoring system called Monitoring of Arable soils of Poland (MChG) and managed by Chief Inspectorate of Environmental Protection. It started in 1995 to track changes in various features of agricultural soils, especially a wide range chemical properties, occurring at specific time intervals as response to agricultural and non-agricultural human activities on each time 216 sites. It is still running and next campaign is ongoing (sampling in 2020, release of data 2022). The next campaign is planned in 2025 (meaning an interval of 5 years between 2 sampling campaigns). The system was designed to investigate arable soil contamination status and is based on stratified representative sites (selection based on expert knowledge to be representative of soil types and texture and more or less evenly distributed geographically).

All sites are georeferenced (precision depends on GPS devices) and a composite sample is taken from an area of 100 m² (square 10 x 10 m, 20 subsamples collected) at a fixed depth (0-20 cm) ending with approximately 3 kg of soil. All sampling sites are treated the same.

Before preparation the samples are stored in a cold room and prepared as soon as possible. Then before analysis the samples are air dried at room temperature, crushed (combined mechanical and hand crushing) and sieved to 2 mm. Litter is discarded.

Additional information on the sites is available on:
- elevation,
- soil surroundings (e.g. road, factory, city…),
- lithology,
- vegetation,
- pictures are taken.

Considering harmonization options:
- The design of the monitoring only can be changed if there is no more access to a given permanent point (e.g. new road is built or land is afforested, wetland constructed, etc.).
- It is possible to collect new information on the monitoring sites (yet considered for future campaigns).
- The soil description can be improved but not on site - too much work-. The data from the soil map can be less precisely converted into WRB.
- The sampling area cannot be changed as the principle is too keep permanent soil locations. Rather no willingness of the responsible institution to add new locations.

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- The sampling depths and sample preparation cannot be changed to stay the same as in previous campaigns
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Poland didn't yet collaborate but is open to collaboration: we can provide additonal soil data (e.g. chemical, erosion) or agricultural data (at village resolution). We can analyze the LUCAS samples or subsets for additional parameters.

We already use the LUCAS data for testing relationships between agriculture and soil effects.

3.2.16. Slovakia

Slovakia has a soil monitoring system called Partial monitoring system - Soil (Čiastkový monitorovací systém - Pôda - ČMS-P) and managed by several institutions: the Ministry of Environment of the Slovak Republic (coordination), the Ministry of Agriculture and Rural Development of the Slovak Republic (expert group), the National Agricultural and Food Centre - Soil Science and Conservation Research Institute (realization), the National Forest Centre - Research Institute in Forestry (realization) and the Central Control and Testing Institute in Agriculture (realization).

It started in 1993 to know both the most current state of our soils, as well as to monitor those soil properties that are crucial both in terms of productive and non-productive (ecological) soil functions. The sites are shared into 430 basic monitoring sites (318 sites in farming land and soil above the upper forest boundary and 112 sites in forest land) and 21 key monitoring sites. It is still running and next campaign is planned by 2023 as the basic monitoring sites are sampled every 5 years and the key monitoring sites are sampled yearly.

Concrete soil properties are evaluated according to threats to soil relating to European Commission for European soil monitoring performance as follows: soil contamination, soil acidification, soil salinisation and sodification, decline in soil organic matter and macro- and microelements, soil compaction and erosion, as well.

The system was designed to investigate natural, agricultural, forest land uses and designed on a grid basis (16 x 16 km) including also representative sites. The representative sites are selected according to ecological principles and includes the research data of all main soil types and subtypes, soil substrates, climatic regions, emission regions, polluted and non-polluted regions as well as various land use. The 16 x 16 km grid represents the basis for information of the periodic assessment of the health status of forests in Slovakia and selected components of forest ecosystems, which also include soils.

All sites are georeferenced (precision 1 m) and a composite sample is taken from an area of 314 m² on agricultural land (circle, radius 10 m and 5 sub samples) and from an area of 200, 500 and 1000 m² on forest soils at fixed depths (the standard depths are 0–0.10 m, 0.20–0.30 m and 0.35–0.45 m on soils under grassland and 0–0.10 m and 0.35–0.45m on arable land) ending with approximately 5 kg of soil. The standard depths slightly differ on soils under grassland and arable land, but the depth is adjusted to characterize the main soil horizons. On forest soils it also has a circular shape, but an area of 200, 500 and 1000 m2, depending on the age of the stand and the density of trees. Sampling for bulk density is also made for estimating soil compaction (it also includes measurements of porosity and maximum capillary water capacity (wKMK) in 100 cm^3 cylinders).

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Before preparation the samples are stored in standard conditions (room temperature). Then before analysis the samples are air dried at room temperature, homogenized, crushed and sieved by hand to 2 mm. Litter is discarded.

A soil description is also available and is obtained by opening a soil profile. Soil is described and classified according to national (Societas pedologica slovaca, 2014. Morfogenetický klasifikačný system pôd Slovenska. Bazálna referenčná taxonómia. Bratislava: NPPC-VÚPOP Bratislava 2014, 96 p., ISBN: 978-80-8163-005-7,
https://www.pedologia.sk/sites/default/files/publications/2000_Klasifikacia_pod_SR.pdf,
https://www.pedologia.sk/info-mksp2014-1) and international standards (WRB for soil description).

Additional information on the sites is available on cadaster information, elevation, slope, exposition, erosion features, lithology. Pictures are taken from the sites.

Considering harmonization options:

- The design of the monitoring cannot be changed.
- It is possible to collect new information on the monitoring sites (e.g. using relevant national soil databases and international databases: LPIS, LUCAS,…) is possible to increase the information values of SMS).
- The soil description can be improved (even if there is already a conversion to the WRB classification, refinement possible (classification version etc.)).
- The sampling area, the sampling depths, the sample preparation and analysis cannot be changed as all the previous data rely on this protocol.

Considering collaboration with LUCAS campaigns, Slovakia collaborated as National Agricultural and Food Centre (NPPC), Soil Science and Conservation Research Institute realized Lucas survey in 2006, 2009, 2012, 2015, 2018 years. The institute may also analyse a subset of samples with both lab methods and labs (national and LUCAS). NPPC-SSCRI were allowed by EU-JRC to select/reallocate 10 points (within the EJP soil programme) from LUCAS 2022 campaign to compare relevant results and to have closest insight into the pedon/polypedon variability concept (derive potencial transfer functions).

We already use the LUCAS data for comparision of results, data inputs (LULUCF) and testing relationships between agriculture and soil effects[12].

3.2.17. Spain

Spain declared 2 monitoring systems: one mainly dedicated to the restauration of degraded land and the other one to the monitoring of trace elements.

Spain has a soil monitoring system called Soil degradation gradient and restoration in Southeast Spain (Murcia) and managed by Carlos García. It started in 2004 to report on soil quality, SOC and microbial biomass content on 6 sites (with three replicates each). The SMS is now stopped. The system was designed to investigate soil restoration with organic amendments. It was based on different plots (20 m², blok design) with 3 treatments (control, soil +sewage sludge; soil +compost). In the degradation gradient we have 3 sites with different natural cover.

[12] Hutár, V., Saksa M., 2016: Soil component within the land cover and land use survey (LUCAS) in Slovakia. Proceedings of Soil Science and Conservation research Institute. 38. VÚPOP Bratislava, 7 s.
https://www.vupop.sk/dokumenty/vedecke_prace_2016.pdf

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All sites are georeferenced and a composite sample is taken on an area of 200 m² (square 20x20 m?) at fixed depths (0-20 cm) ending with approximately 0.5 kg of soil.

Before preparation the samples are stores at 4ºC. Then before analysis the samples are air dried at room temperature, sieved manually to 2 mm. Litter is discarded.

Soil is described and classified according to FAO standards.

Additional information on the sites is available on: soil surroundings (e.g. road, factory, city…), lithology, vegetation. Pictures from the site are also available.

Considering harmonization options:
- The design of the monitoring cannot be changed.
- It is not possible to collect new information on the monitoring sites.
- The soil description can be improved.
- The sampling area and the sampling depth cannot be changed.
- The sample preparation can be changed but not the analytical part.
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Spain didn't yet collaborate but is open to collaboration (e.g. by providing some soil samples, providing data on samples that haven taken in South East Spain).

We already use the LUCAS data as we are working in the consortia involved in biodiversity analyses of LUCAS (responsible on microbial biomass analyses through fatty acids)

The Spanish soil monitoring system dedicated to trace elements is called 'Investigación del contenido de metales pesados en suelos agrícolas de España' and managed by the Ministry for Ecological Transition and Demographic Challenge. It started in 2002 to monitor heavy metals, SOC, P, K, texture, pH, ... on 4000 sites. A 2nd campaign is planned by 2021 (waiting for financial support). The system was designed to investigate natural and gricultural land uses and is based on a grid (8 x 8 km).

All sites are georeferenced (precision 50 m) and a composite sample is taken from an area of 2500 m² (50 X 50 m, 21 subsamples) at fixed depths (0-20 cm) ending with approximately 3kg of soil. All sampling sites are treated the same.

Before preparation the samples are stored at room temperature (between 10 to 20°C). Then before analysis the samples are air dried between 25 to 30°C in a room, rocky fragments of > 6 mm, and between 6 mm and 2 mm are separated and measured to determine coarse fragments (% mineral particles 2 mm in diameter). The sample is then crushed and sieved to 2mm to collect fine soil (> 2 mm). Litter is discarded.
Additional information on the sites is available on: elevation, slope, exposition, erosion features, soil type, crop type, soil surroundings (e.g. road, factory, city…), lithology. Pictures from the site are taken

Considering harmonization options:
- The design of the monitoring can be changed by adding new points.
- It is possible to collect new information on the monitoring sites (e.g. collect information on land use).

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- The soil description cannot be improved as it's too much work and needs an expert ....
- The sampling area cannot be changed as all the previous data rely on this protocol.
- The sampling depths can be changed (e.g. we may sample deeper 0-30 cm).
- The soil sample preparation cannot and the analytical methods cannot be changed.
- New parameters can be added.

Considering collaboration with LUCAS campaigns, Spain didn't yet collaborate but is open to collaboration (e.g. Analyse a subset of samples to compare results and spatial distribution).
We already use the LUCAS data for heavy metal distribution.

3.2.18. Sweden

Sweden has two national soil monitoring systems, one for agricultural soils and one for forest soils. The monitoring system for forest soils is described in annex 3. The monitoring system for agricultural soils is called Soil & Crop Inventory, full name: National Arable Soil & Crop Inventory (English abbreviation) (Mark- och grödoinventeringen/Yttäckande övervakning av jordbruksmark och gröda /Swedish name). It is financed by Swedish Environmental Protection Agency, and managed by SLU (Swedish University of Agricultural Sciences). It started in 1995 (unfortunately without georeferenced sampling sites) and from 2001 an established set of georeferenced sampling sites was defined. The program shall describe the current status of Swedish arable land, as well as the quality of crops in relation to the status of the soil, management measures and type of farming. About 2000 sites are sampled and analysed per campaign. It is still running and next campaign is planned by 2021 (meaning an interval of 10 years between 2 sampling campaigns[13]). The system was designed to investigate agricultural land uses and designed on a grid basis[14] (grid with about 1 sample per 1300 ha).

All sites are georeferenced (precision 1 m) and a composite sample is taken on an area of 28 m^2 (circle radius 3 m, 10 subsamples) at fixed depths (0-20 cm at each sampling site and sampling campaign, 40-60 cm one time only) ending with approximately 0.5 kg of soil (0.25-0.3 kg for sub soil sample).

Before preparation the samples are stored at room temperature, avoiding high temperatures and below 0 degrees C. Then before analysis the samples are air dried at room temperature, crushed (gently crushed removing stones and gravel) and sieved to 2 mm. Litter is discarded.

[13] Comment on sampling intervals:
The last two campaigns (from 2001) consisting of 4 sub campaigns, sampling a quarter of the total number of samples, but covering the total area in each sub campaign. The sub campaigns happens every second year during a period of 8 years.
Example:
Campaign 3:
2010 preparation year, 2011 sampling sub campaign "a", 2012 analysis year, 2013 sampling sub campaign "b", 2014 analysis year, 2015 sampling sub campaign "c", 2016 analysis year, 2017 sampling sub campaign "d", 2018 analysis year, 2019 reporting campaign 3,
Campaign 4:
2020 preparation year, 2021 sampling sub campaign "a" , and so on...

[14] Comments on sampling design:
A first regular grid with random starting point including about 20 000 sampling sites were laid out over the country. All sites on Agricultural land were selected and this first rather dense sampling site set makes up a sort of base set from where new sampling drawn to cover for losses over time. From this first grid, about 2000 sampling sites were systematically selected to evenly cover all agricultural land. The resulting sampling site density is about 1 sampling site per 1300 ha. To protect private integrity and to avoid all coordinates to be known based on the knowledge of one, all sampling sites are randomly moved up to 500 m from the grid center.

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Additional information on the sites is available on soil data management. The farmers answers a few questions about their management on the field where the sampling is done: 1) the main orientation of the farm (animal, crops or both), 2) organic or not, and if yes for how long, 3) general crop rotation (mainly cereals no ley, cereals and 2-3 years leys, almost only ley, or other) and if the crop rotation has been changed recently, 4) if they apply manure regularly on the field, if yes, from what animal, if no, has it been done before and how long has it been since then).

The vegetation inventory that takes place are the cutting of the crop, if it is winter wheat, spring barley or oats. If not, only a soil samples is taken and no further description of the vegetation on the site is done. A top soil sample is taken on each site, but a subsoil sample is only taken ones on each site, that is only on new sites.

Considering harmonization options:

- The design of the monitoring cannot be changed but probably only if the change means adding points and not removing or moving, and also adding financial means for that. So, not without a lot of considerations.
- It is possible to collect new information on the monitoring sites if it does not requires too much extra time at the site. It would probably also be possible to add some questions to the protocol that is used for a short interview of the farmers over the phone.
- The soil description cannot be improved as it is too much work, and we do not really use that information much in agricultural soils in Sweden, so not many people could do that description.
- The sampling area cannot be changed (but of course it depends on how large the change would be).
- The sampling depths cannot be changed as, this would be difficult if we would like to be able to compare with the previous campaigns which is really the main goal. Not without a rather substantial addition of funds, so that we could do a type of double perhaps.
- The soil sample preparation cannot be changed (it may be possible to some extent depending on what the change would be. But it is restricted by what is needed for the analysis that we do and by the facilities that we and the subcontractors have).
- Analytical methods cannot be changed. Since the purpose is to monitor changes, changes in the measurement methods is relay problematic, and would probably need some double analysis for some time, which means increased costs.
- New parameters can be added but only with additional funds are available since the program is already struggling to manage the basic properties that we need. It also depends on the requirements of the sample preparation or storage.

Considering collaboration with LUCAS campaigns, Sweden didn't yet collaborate but is open to collaboration. Collaboration is something that would be good. However, this is partly depending on extra funding. It would be good to be able to do some kind of comparison both of analysis methods and sampling protocol and to look at the possibilities to better harmonize the monitoring. But the priority with the limited funding for our monitoring would still be to continue with the national monitoring program, since that is better adopted to our needs in terms of monitoring on agricultural soils.

LUCAS data were not used.

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3.2.19. Switzerland

Switzerland has a soil monitoring system called National Soil Monitoring Network (NABO) and managed by Agroscope and the Federal Office for the Environment that started in 1984. It records and documents the temporal development of the quality of Swiss soils based on chemical, physical and biological soil properties in order to early detect and forecast changes. A long-term monitoring system was implemented that monitors natural, agricultural, forest, urban and national park land uses, under their normal management. A monitoring network of around 110 sites spread across Switzerland is sampled every 5 years. All sites are treated the same but in addition to this long-term monitoring, NABO conducts supplementary studies on specific scientific questions on other sites.

NABO is still running and the new campaign is ongoing (eighth sampling campaign – 2020 to 2024). Seven are yet completed with an interval of 5 years between 2 sampling campaigns. The system was designed to sample representative sites, based on a stratified scheme (mainly agricultural and forest sites were selected complemented with city parks and natural sites).

Another important module of NABO is the National Soil Information System NABODAT, which brings together soil data from different sources, harmonises them and makes them available for further needs. This soil data management is an essential part of the value chain from soil sample to soil data to its interpretation. As a service, NABO offers consultation services for a diverse clientele with various needs. These services include developing recommendations for cantonal authorities, addressing specific soil-related questions of federal offices and offering technical advice to private clients. In addition, NABO regularly performs proficiency testing. These evaluations are commissioned by the federal government and conducted for interested laboratories to ensure data quality.

All sites are georeferenced (precision less then one meter) and a composite sample made of 25 sub-samples is taken from an area of 100 m² (square 10 x 10 m). Sub-samples are taken with an auger at fixed depths (0-20 cm) ending with approximately 2 to 3 kg. Sampling for bulk density is also made on a subset of sites. A soil description is also available based on a soil profile and according to national standards.

Before preparation samples are stored at 4°C. Before analyses soil samples are dried at 40°C during 48h and sieved at 2 mm. Litter is discarded.

Additional information on the sites is available on:
- elevation,
- soil use and management (annual management files of 46 agricultural sites going back from today to 1985 are available allowing for example to derive mass balances needed to verify the measured temporal trends)
- slope and exposition
- soil surroundings (e.g. road, factory, city…)
- lithology

Pictures from the sites are taken.

Considering harmonization options:
- the design of the monitoring can not be changed but new sites may be added and it is nevertheless possible to collect new information on the monitoring sites. The soil description can be improved depending on scientific questions.

- The sampling area, the sampling depths, the sample preparation and analyses can not be changed as all the previous data rely on this protocol
- New parameters can be added

Considering collaboration with LUCAS, Switzerland already collaborated with LUCAS campaigns in 2015 and intend to contribute to the next 2022 campaign. They compared LUCAS and National sampling methods (see Fernandez-Ugalde et al. 2019; DOI: 10.1111/ejss.12862) and if there is a concrete research question they may also participate. Switzerland used the LUCAS datasets to compare soil carbon contents of the Swiss topsoil with the surrounding NUTS2 regions of Germany, France, Italy and Austria.

3.2.20. EU

EU developed a soil monitoring system called LUCAS Soil and managed by EU-JRC. It started in 2009 on 22000 sites. It is still running and next campaign is planned by 2022 (with an interval of 3 to 4 years between 2 sampling campaigns) (see also chapter 2). The system was designed to investigate different land uses and based on a regular grid (but allocated according to land cover type defined by area-frame). A subset of sites is assessed for bulk density, soil biodiversity and grass botany (not all sites).
All sites are georeferenced (precision 1 m) and a composite samples is taken on an area of 16 m² (cross around sampling point, 5 subsamples) at fixed depths (0-20 cm) ending with approximately 0.5kg of soil. Sampling for bulk density is also made during one campaign.

Before preparation the samples are stored at ambient conditions. Then, before analysis the samples are air dried, crushed (mechanical) and sieved to 2 mm.

Soil is described according to FAO standard.

Additional information on the sites is available on: elevation, soil data management, slope, exposition, and erosion features.
Considering harmonization options:

- The design of the monitoring can be changed as new points are possible as long as they conform to LUCAS grid.
- It is possible to collect new information on the monitoring sites with some limited flexibility.
- The soil description can be improved by conversion of national soil classification to WRB (for LUCAS sites it would be advantage).
- The sampling area can be changed as replicates can be changed to accommodate more complex sampling designs.
- The sampling depths will be increased to 30 cm.
- The soil sample preparation and analysis can be changed.

Considering collaboration with other countries, EU-JRC recently collaborated by providing input to new locations and is open to collaboration (e.g. use LUCAS campaign to collect samples).
We already use the LUCAS data for model parameters.

3.3. Transversal analysis of the questionnaire

Based on the answers collected, the following conclusions can be drawn concerning the implementation of SMS in the EJP SOIL partner's countries.

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3.3.1. Main aim of the SMS implemented in the countries

Most of the SMS were designed to monitor soil quality meaning that there are numerous parameters monitored (Figure 1, Table 2). Few were developed only to monitor soil organic carbon or nutrients.

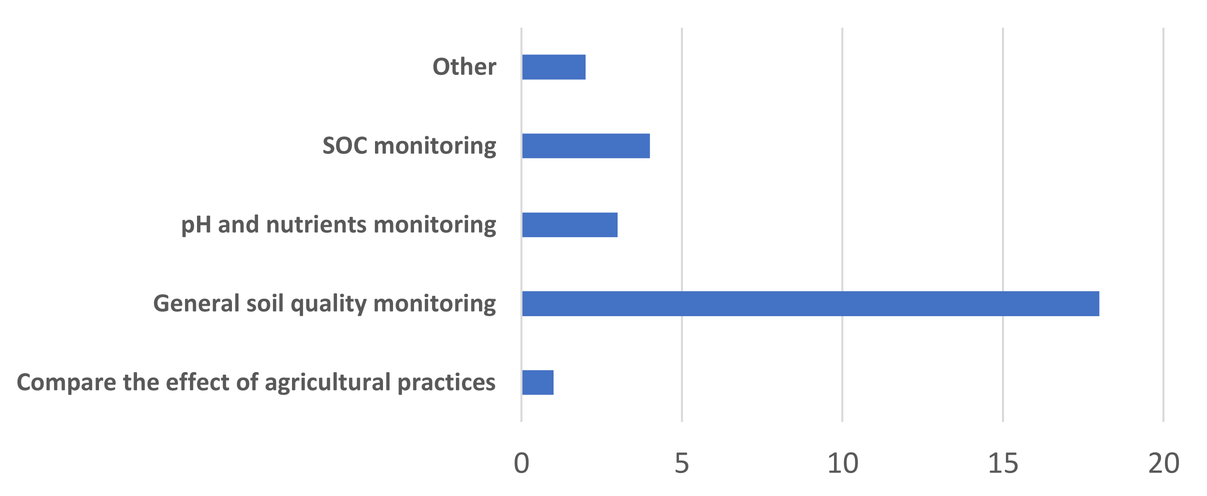

Figure 2. Aim of the SMS developed in the EU Countries

3.3.2. Starting dates

The majority of the SMS were implemented between 1990 and 2005 (Figure 3). A large majority is still running (Figure 4): just 5 were stopped and often it's in order to restart a new campaign or waiting for budget (e.g. Belgium-Wallonia, Ireland, Lithuania and Spain).

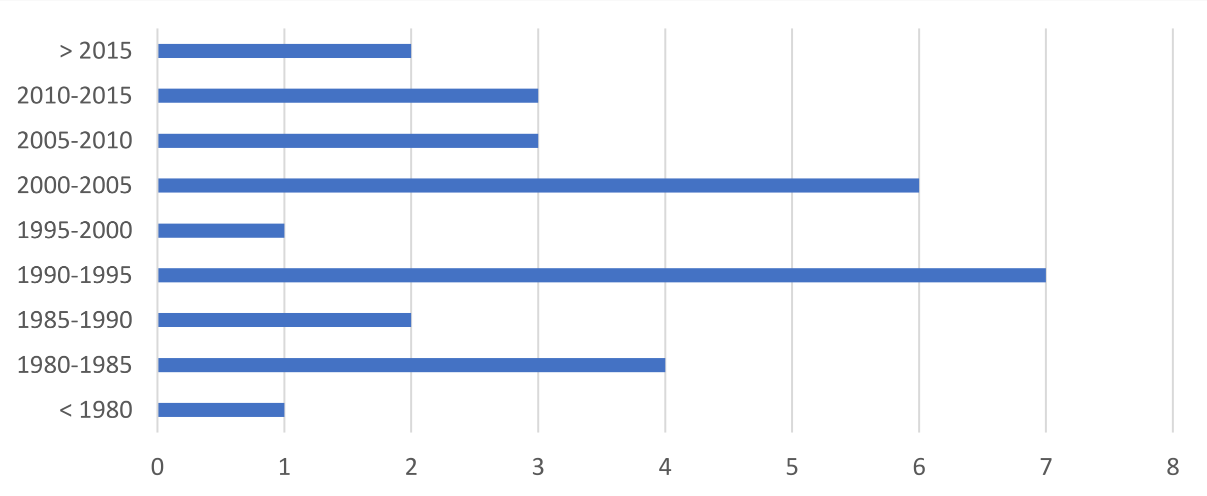

Figure 3. Starting dates of the SMS in the different EU countries (including LUCAS)

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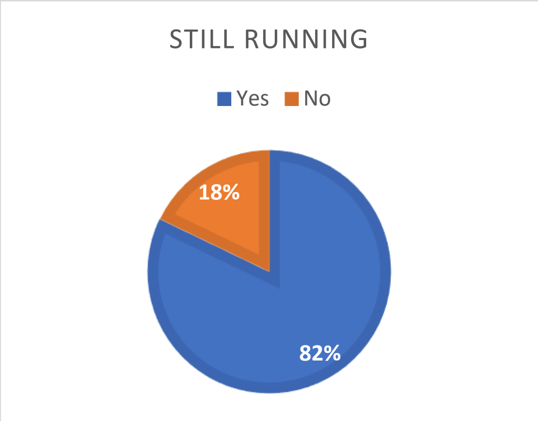

Figure 4. SMS still running in the different EU countries (including LUCAS)

3.3.3. Number of campaigns and interval between each campaign

Seven countries just have 1 campaign completed and planned to resample in the coming years. Twenty countries (meaning the majority) have between 2 and more than ten campaigns (Figure 5).

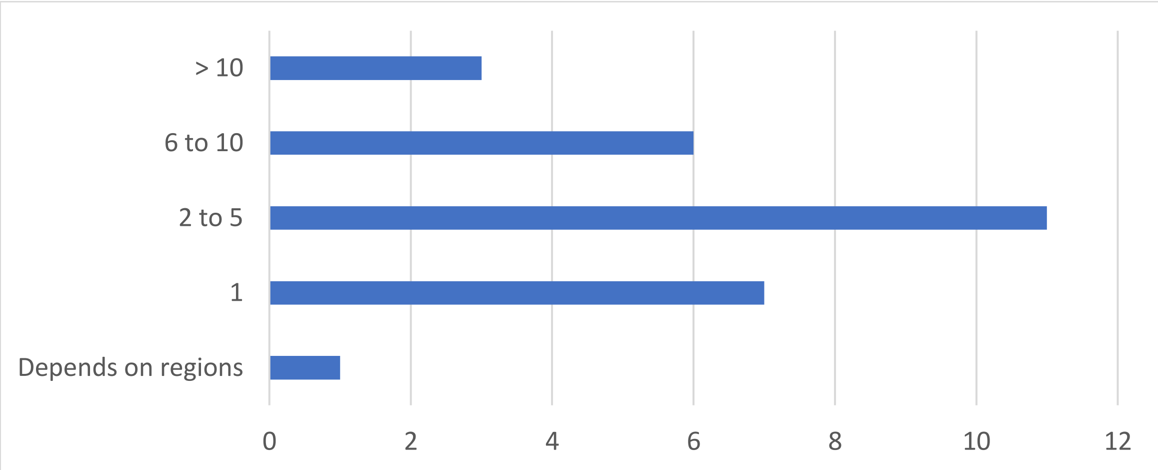

Figure 5. Number of sampling campaigns completed in different EU countries (including LUCAS)

The interval between 2 sampling campaigns varies from one year (meaning the sites are sampled each year) to more than 15 years, the majority being between 3 to 15 years (Figure 6).

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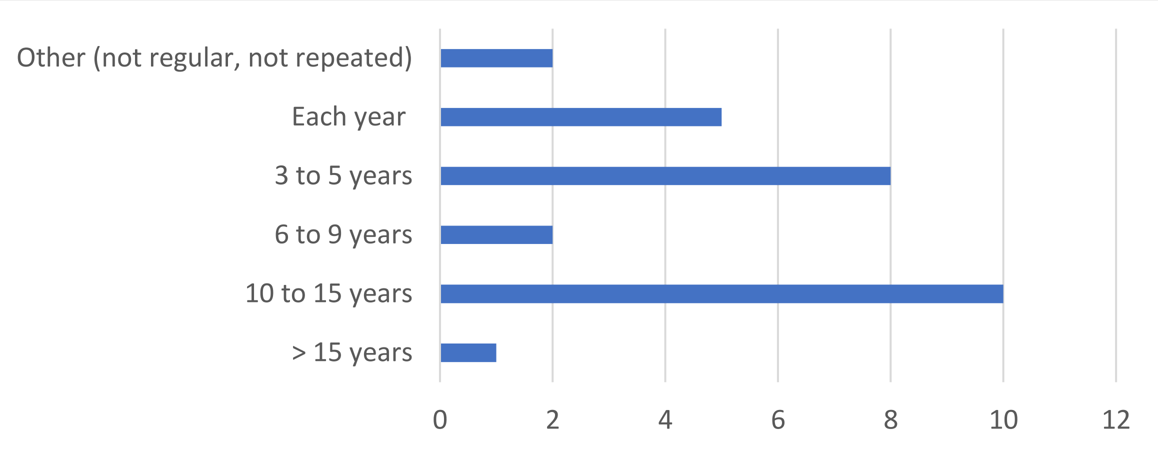

Figure 6. Interval between 2 sampling campaigns in different EU countries (including LUCAS)

3.3.4. Total number of sites

The total number of monitoring sites varies from less than 500 to more than 5000 (Figure 7) and, depends in part on the area of the country.

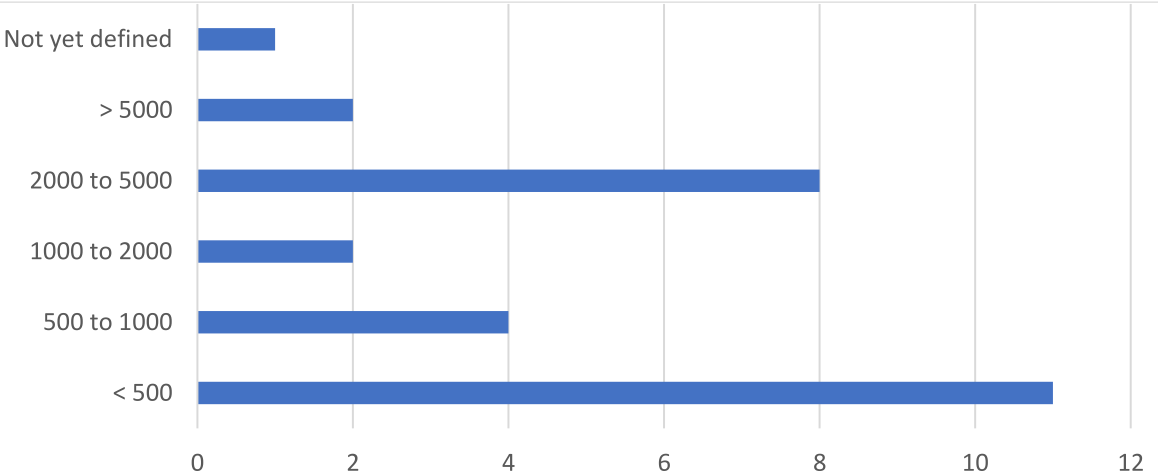

Figure 7. Number of monitoring sites in the different EU countries (including LUCAS)

Figure 8 presents the number of km² that one monitoring site represents, having in mind that the ENVASSO project recommended to have at least 1 site representing 300 km² (meaning 17 x 17 km if it were designed as a grid). The majority of the countries (16 out of 27) fulfil this requirement whereas for few countries 1 site represents more than 1000 (or even 5000) km² (in those cases the sites considered as monitoring sites by the countries seem to be long term research sites dedicated to special soil issues).

Figure 9 presents the number of monitoring sites versus the area of the countries (including LUCAS for EU and regional monitoring sites) where it can be seen that the situation for the same of area (e.g. from 10 000 to 100 000 km²) is quite different as the number of sites range from 30 (Estonia) to 10 000 (Lithuania) sites.

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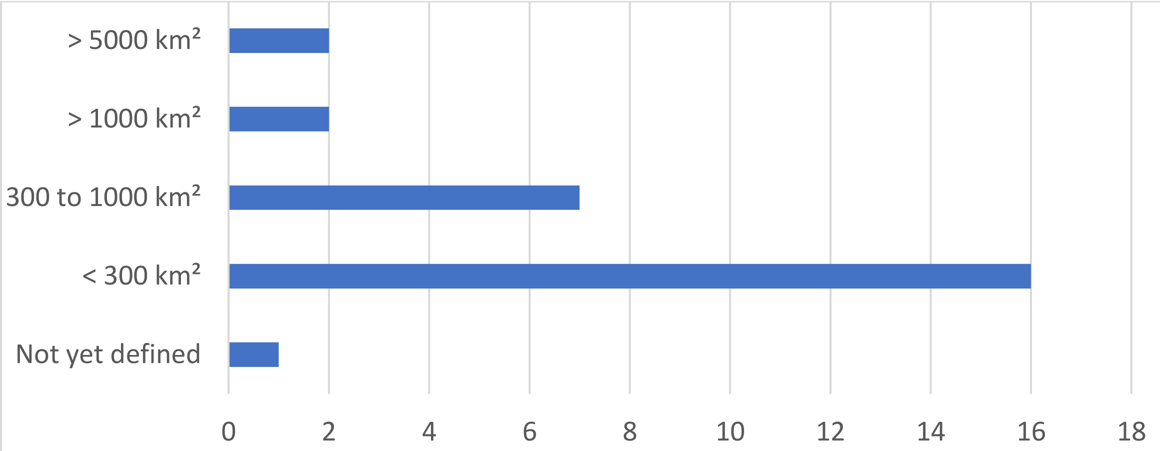

Figure 8. One site representing #km²

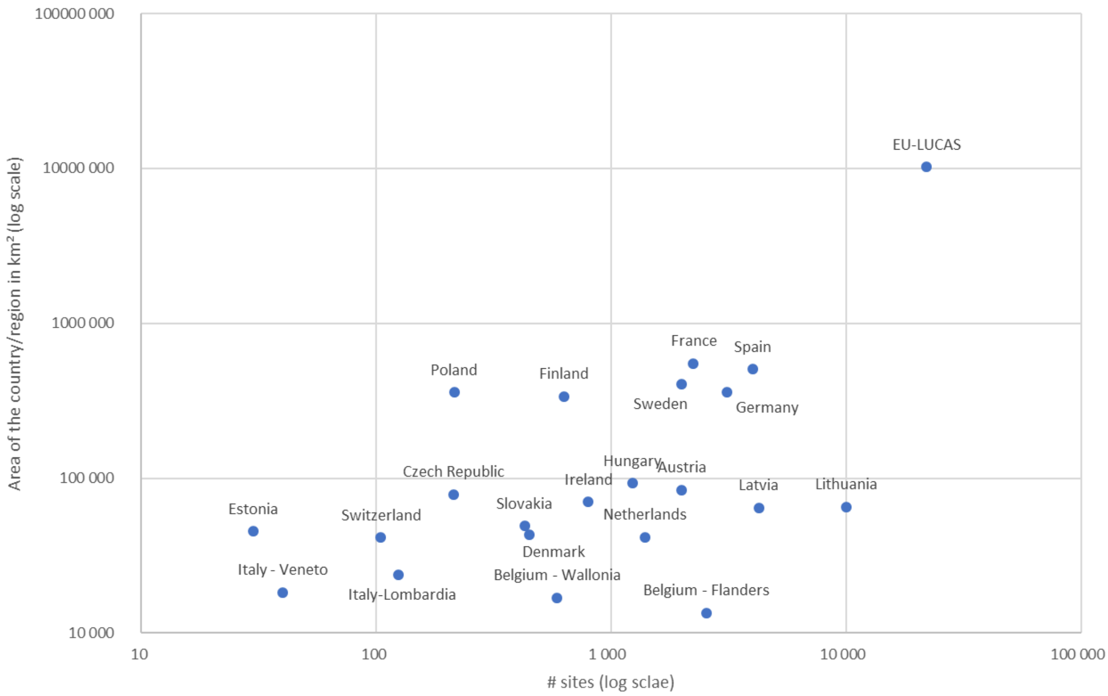

Figure 9. Number of sampling sites versus area of the countries (including LUCAS for EU and regional monitoring sites)

3.3.5. Investigated land uses

The main land use investigated is linked to agriculture: 12 countries only monitor agricultural land uses and 13 monitor other land uses but also include agricultural land uses (this may also be a bias from EJP SOIL partners mainly dedicated to agriculture) (Figure 10). Note that we also collected the information from 2 countries that monitor specifically forest and natural land uses (Latvia and Sweden).

Urban land use is generally included in the category "all kind" (6 countries: EU-LUCAS, Germany, France, Belgium – Flanders, Austria and Switzerland).

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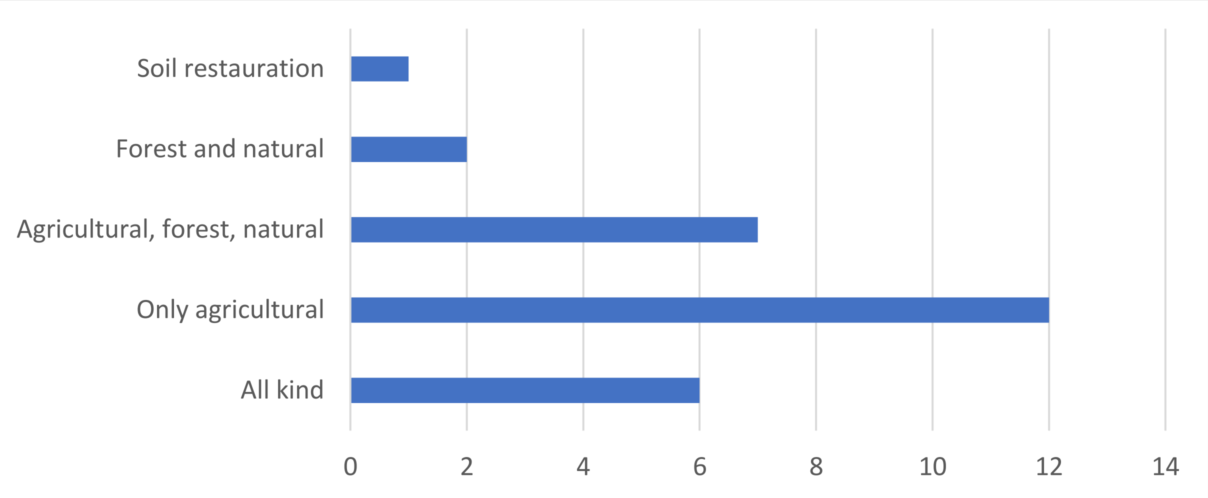

Figure 10. Investigated land uses in the countries (including LUCAS)

3.3.6. Sampling strategy

The majority of the SMS are based on a network of stratified representative sites (17) where the sampling sites are selected according to several criteria as land use, soil types, crops, climate… (Figure 11). Then ten networks use a regular grid (7 x 7 km, 8 x 8 km, 16 x 16 km) to select the sampling sites (note that when using a grid, all the sites may not be sampled but a selection depending on several criteria as land use may also be applied, as for LUCAS campaigns for example).

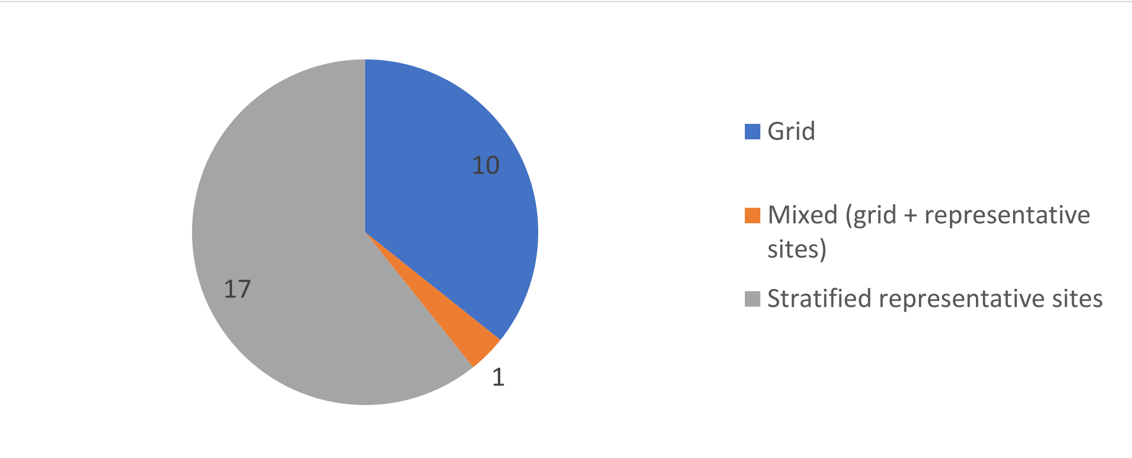

Figure 11. Sampling strategy (grid design and/or selection of representative sites) implemented in the countries (including LUCAS)

3.3.7. Location of the sites and additional information collected

All networks are now using GPS coordinates (note that in Wallonia and France magnetic balls are buried to locate the site for further resampling).

Figure 12 describes the percent of SMS that collect (or not) other kind of information on the monitored sites. Note that more than 60% of the SMS collect information on soil management (e.g. by interviews with farmers, for each campaign, covering inter-campaign period, historical management, covering multiple land uses, including detailed crop itineraries about crop rotation, fertilisation, manure, crop

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residues management, soil tillage, pest management, grass management and pasture...). Half of the SMS collect information on the surroundings of the site.

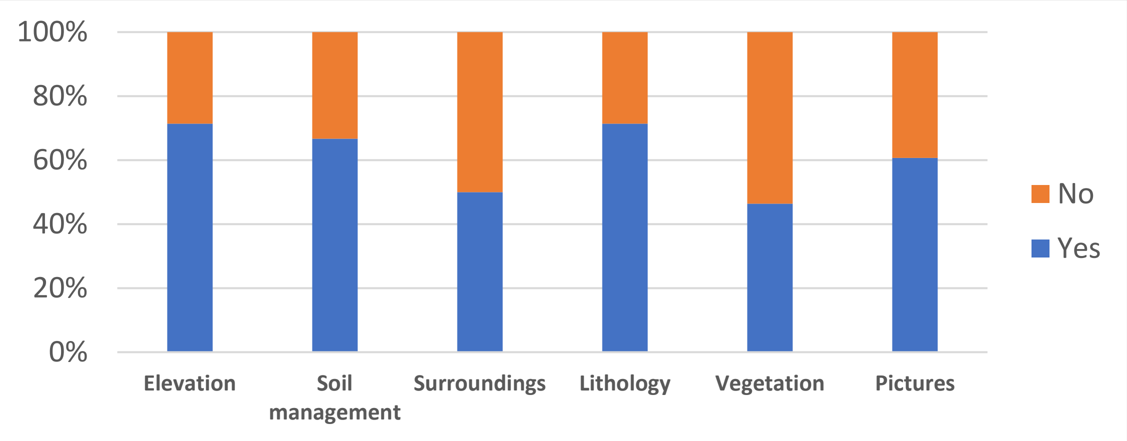

Figure 12. Additional information collected on the sampling sites

3.3.8. Sampling design and sampling depths

The sampling area varies from 3.14 m² to 1 ha (Figure 13). The majority of SMS use an area less than 100 m². Usually, several sub-samples are collected from that area (from less than 10 to more than 20) to form a composite sample. The frames to collect the sub-samples are quite different as it can be a circle (#11, from 25 to 1 m radius), a square (#8, from 2 to 50 m), a cross (#3), a transect (#2), a rectangle (#1) or a triangle (#1). Some do not make composite samples when sampling according to soil horizons.

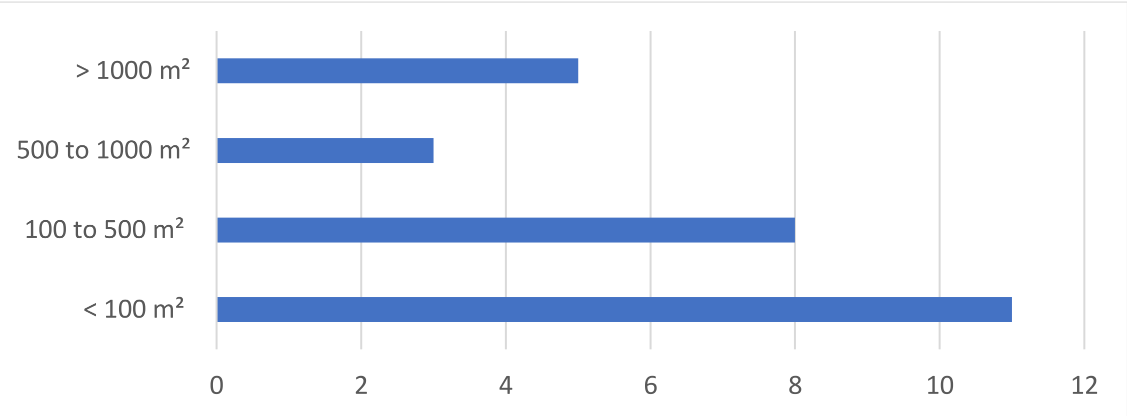

Figure 13. Area considered for the sampling on the site

Concerning the depths of sampling:

- 4 SMS sample soil according to horizons,
- 11 SMS only consider one fixed depth for sampling (#1 between 0-10 cm for QBS analysis, #1 between 0-15 cm, #7 between 0-20 cm, #3 between 0-30 cm),
- 13 SMS sample different depths with fixed limits (from 5 depths as 0-10, 10-30, 30-50, 50-70, 70-100cm to just 2 depths as 0-10 and 10-30 cm or 0-30 and 30-50cm),

Considering depths, it appears that 13 countries are sampling deeper than 20 or 30 cm. Sampling deeper is fundamental to have a better idea of the geochemical origin of some potentially toxic elements and/or their lixiviation and to quantify (and monitor) deep carbon.

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Note that 17 SMS also collect samples for bulk density determination (usually with a steel cylinder generally on the topsoil but others at different depths). Such sampling may be performed on all site, for all campaigns or just for the 1st campaign, or just on a selection of sites…

3.3.9. Soil profile description and soil classification

Soils pits/profiles are opened, sampled and described for 13 SMS (the description/classification is generally made according to national standards but WRB is also available in 4 SMS). For part of the other 15 SMS the sampled area may be attached to a soil type according to existing soil maps.

3.3.10. Soil preparation and analysis performed

Once collected if not processed immediately the samples are generally stored before preparation at room temperature or at 4°C (depending on the analysis to be performed). Then the samples are air dried (generally no more than 40°C) before crushing (either by hand or mechanically) and then sieved to 2 mm. Some countries reported that also measure coarse fragments. The litter/roots are generally discarded (#18) or may be in few cases integrated in the sample.

Concerning the parameters measured at lab (or sometimes estimated on site when sampling as erosion features) (Table 2), not all countries answered to those questions (just 6). Using the stock take made for EJP SOIL D6.1. Report on harmonized procedures for creation of databases and maps, we were able to complete the measured parameters for 12 countries (and 13 SMS). Not all countries filled exactly as expected the questionnaire (and even the previous stock take) meaning that sometimes we have a detailed answer (including the standard method) and sometimes just a cross or “yes” meaning that the parameter is measured but we do not know how… The Table 2 presents the collected results for 13 SMS (a meeting with all countries should be organized to complete the table and obtained the needed information).

Carbon, pH, nutrients and granulometric distribution are the most common measured parameters in the SMS (Table 2). On the contrary parameters that inform on soil degradations as contamination by organic pollutants or salinization are less present in the SMS. Few SMS are investing on spectral IR libraries to characterize soil.

However, this analysis needs to be strengthened by checking the previous stocktakes on the subject.

3.3.11. Long term storage of the samples

A large majority of countries have developed a long-term storage of their samples (24 countries) and quite all are accessible under conditions. The storage conditions are more or less the same, the samples being dried, and being stored at room temperature or in controlled conditions (e.g. constant temperature between 18 to 20°C, in the dark, with or without control on the hygrometry). Few countries documented the nature of the "containers" (e.g. plastic, glass) and the quantity stored. Such information is useful to know as this gives a rough indication of the available material to run new analyses or to provide for inter-comparison/calibration. A meeting will be organized to complete the missing answers.

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	Countries	Sweden	France	EU-JRC	Czech Republic	Latvia		Lithuania	Belgium - Wallonia	Belgium - Flanders	Netherlands	Slovakia	Denmark	Germany	
	Name of the Soil Monitoring System	Soil & Crop Inventory	RMQS	LUCAS[a]	Basal soil monitoring	SPPS	SPPS N	Dirv_DR10 LT	CARBIOSOL	Koolst of monitoring netwerk	Netherlands Soil Sampling Program (NSSP)	CMS-P	DSMDB	Boden-Dauerbeobachtung[b]	Total
Main soil properties, according to Global Soil Map specifications, 2015	total profile depth		x					x		x	x	x		x	6
	plant exploitable (effective) soil depth		x					x			x			x	4
	organic carbon	x	x	x	x	x	x	x	x	x	x	x	x	x	13
	pH in water	x	x	x		x	x	x		x	x	x		x	10
	sand	x	x	x	x	x		x		x	x	x		x	10
	silt	x	x	x	x	x		x		x	x	x		x	10
	clay	x	x	x	x	x		x		x	x	x		x	10
	gravel		x	x				x		x	x	%		x	6
	ECEC	x	x	x	x	x	x	x				x		x	9
	bulk density of the fine earth (< 2 mm) fraction (excludes gravel)		x						x	x	x			x	5
	bulk density of the whole soil in situ (includes gravel)		x	x	x			x			x	x		x	7
	available water capacity							x						x	2
	Electrical Conductivity		x			x		x			x	x		x	6
Other soil properties	calcium-carbonate content	x	x	x	x	x	x	x		x		x		x	10
	Field capacity (mm)							x						x	2
	Plant available amounts of macro and micro nutrients	x	x	x	x	x	x	x		x	x	x	x	x	12
	Total amounts of macro and micro nutrients/trace elements	x	x	x	x	x		x					x	x	8
	quality of clay minerals (e.g. type or ratio of illite, smectite, montmorillonite in clay fraction…etc)			x				x							2
	distribution of soil organisms		x	x							x		x	x	5
	properties for NIR and MIR (near and mid infrared)	x	x	x						x	x				5

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	Countries	Sweden	France	EU-JRC	Czech Republic	Latvia		Lithuania	Belgium - Wallonia	Belgium - Flanders	Netherlands	Slovakia	Denmark	Germany	
	Name of the Soil Monitoring System	Soil & Crop Inventory	RMQS	LUCAS$_a$	Basal soil monitoring	SPPS	SPPS N	Dirv_DR10LT	CARBIOSOL	Koolst of monitoring netwerk	Netherlands Soil Sampling Program (NSSP)	CMS-P	DSMDB	Boden-Dauerbeobachtung$_b$	Total
Links with threats (e.g.vulnerability)	Soil erosion by water	x	x	x		x						x			5
	Soil erosion by wind			x		x									2
	Decline in SOM in peatsoils											x			1
	Decline in SOM in mineral soils					x						x	x		3
	Compaction, stucture degradation		x					x				x			3
	Pollution with potentially toxic elements		x	x	x	x						x		x	6
	Pollution with organic substances		x	x	x									x	4
	Acidification		x			x						x			3
	Salinisation and alkalinisation											x			1
Soil classification	soil type, national classification	x	x	x	x	x	x	x				x	x		9
	soil type, international classification	x	x		x			x				x			5

a. depends on the sampling campaign, not all samples are concerned
b. depends on federal states, not all measure everything

Table 2. List of parameters measured in the different SMS

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3.3.12. Harmonization options and collaboration with LUCAS

The Table 3 includes the questions that were asked about possible ways of harmonization and the answers with main comments from the countries.

Questions	Yes		No	
	#	Representative comments	#	Representative comments
May the sampling design of your SMS be adapted or changed?	16	- New sites are possible (#13) - We are planning a new SMS, changes can occur (#3)	12	- Changing design would make it impossible to compare the data with the old samples - Changes in the design would affect the time series in the core sampling area.
Can you consider collecting new information on the monitoring sites?	24	- Depends on means - Soil management information will improve the use of data	4	- It takes too much time - Financial support needed
Can the soil description be improved?	16	- Translation of national classification into WRB can be made - If there is new funds soil description/classification can be made	12	- Not planned - Needs skilled people - Too much time/work on the site
Can you modify the sampling area?	7	- We are planning a new SMS, changes can occur (#3)	20	- Rather no, all the previous data rely on this protocol. - Changing the area would make it impossible to compare the data with the old samples
Can you change the sampling depths?	8	- We may sample deeper (#4) - We are planning a new SMS, changes can occur (#3)	18	- All previous data rely on this protocol
Can you change the soil sample preparation, before analysis?	5	- We are planning a new SMS, changes can occur (#3)	21	- All previous data rely on this protocol
Can you change measurement methods?	9	*(without comment)*	16	- Since the purpose is to monitor changes, changes in the measurement methods is problematic - Would probably need some double analysis, which means increased costs.
Can you add extra parameters to be analysed?	21	- Depending on funds (struggling to maintain basic analysis)	4	- Costs

Table 3. Harmonization options: answers, main comments and number of responding countries

Considering collaborations with LUCAS Soil programme, six countries already collaborate:

- National Food Chain Safety Office, Directorate of Plant Protection Soil Conservation and Agri-environment, as Gergely Tóth contributed as a Hungarian soil expert involved in EU-JRC,
- National Agricultural and Food Centre (NPPC), Soil Science and Conservation Research Institute in Slovakia that realized Lucas surveys in 2006, 2009, 2012, 2015, 2018,
- AGES in Austria that developed a national exercise with LUCAS Soil (LUCASSA)
- Ireland as a small number of sites are located in Ireland (~39)
- Italy – region of Puglia provided public data on the sampling location
- Switzerland participated in 2015 to the sampling campaign and will also participate in the 2022 campaign

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All other countries just collaborated last year within EJP SOIL to discuss and provide locations for new LUCAS points.

A large majority of partners (23) are ready to collaborate in the future to use LUCAS to collect national samples (double sampling), to evaluate LUCAS representativeness on regional /national level, to support the identification of LUCAS monitoring points, to sample soils for LUCAS, to compare LUCAS and National design strategies and sampling methods/and analytical methods, to organize ring-test with national labs (derive transfer functions), to integrate LUCAS network within National and/or Regional Soil Monitoring Networks…

Considering the use of LUCAS Soil Data, it's quite balanced as 13 partners never used such data (sometimes because there are not enough data in the country) whereas 14 already used data for modelling, mapping, comparing national and LUCAS results.

3.4. Main deviations identified and possible way of harmonisation

When comparing the answers of the different countries, it appears that the SMS are more or less all different in terms of sampling strategy, design, protocols. This latter part, from the choice of the size/frame of the sampling area to the sample collection (including depth) is highly variable. This makes the results hardly comparable across countries.

As a general result it appears that new sites may be added (e.g. to compare national protocols with LUCAS), but when asking countries about other possible changes in their SMS the answers show that few are able/agree to modify one or several steps of their overall procedure (3 countries are newly defining a SMS and may adapt their protocols). Such situation is quite normal as there are quite old SMS, with several campaigns already completed and that any change may impair the use of existing data, unless comparison exercises can be made to develop transfer functions from past situation to the new one. But this will require money and as it was said by one of our colleagues lots of SMS struggle each year just to maintain the existing SMS!

4. Recommendations for the next steps

The context of this report and of future work to be performed within EJP SOIL is to find a way for combining the efforts of Member States in monitoring soils to the ones developed by EU-JRC within the LUCAS soil programme. This should be done in the frame of the development of the EU Soil Observatory (EUSO).

Several options may be questioned from the full integration and harmonization of MS monitoring systems and LUCAS to a better collaboration between MS and EU-JRC to produce a coherent information on soils, even if data stay separate. An intermediate solution being that data from MS and LUCAS will populate the EUSO, finding a way to work on data even if not obtained the same way.

Within WP6 the following technical recommendations were discussed and agreed to be tested (either by all participants or a just group of):

- Compare the designs/locations of points, country by country, with LUCAS,
- Compare national with LUCAS data, country/country,

- When analytical methods are different, work on the development of transfer functions (on selected main parameters),
- Compare the entire sampling/analytical protocol to develop transfer functions between national and LUCAS protocols,
- Identify and test statistical methods to merge or combine national and LUCAS datasets taking into consideration that sampling areas, site distribution, methods… are not the same,
- Identify statistical methods to merge the results of the maps and produce a harmonized map,
- Work on interpretation values/scoring approaches.

All those possible actions should also be discussed and developed in close connexion with EU-JRC in order to provide operational results.

4.1. Comparing national and LUCAS sampling strategies/schemes

As described in EJP SOIL Deliverable 6.1 (Van Egmond et al., 2021), developing a sampling design is complex and depends on the purpose of the sampling campaign (e.g. sampling for estimating global statistics for defined geographic areas or sampling for mapping), existing information and available resources.

One aim of sampling soil for monitoring is to estimate the change of a (soil) variable between two sampling times. For instance, we may be interested in the change in the mean soil organic carbon concentration in the topsoil of a country after implementation of RDP Measures, or the change in a real fraction of degraded soil in a landscape after intervention measures have been put in place. If one has more than two sampling times, then the interest might be in the average change per time unit of the mean, total or fraction, i.e., the temporal trend.

It is crucial for all the partners involved in WP6 activities of the EJP SOIL to study differences and similarities between their national soil monitoring system and LUCAS in order to identify possible ways to combine or harmonise the datasets. This will require to compare the statistical sampling designs in terms of inclusion probabilities and/or the densities but also if all land-uses/landscapes/soils types are covered or if parts of the territory are not represented in LUCAS. Moreover, it is crucial to verify how many LUCAS sampling points are actually representative of such land-uses/landscapes/soil types. Doing so will also allow to define new points for the post 2022 LUCAS sampling campaign, sampling points that may be common with the national design.

Part of this work was already started as, following an urgent request from the EU-JRC, all EJP SOIL partners were asked to contribute to two meetings with EU-JRC and EuroStat in December 2020 to reallocate country by country LUCAS 2022 sampling points. The EJP SOIL partners have sent by the end of December 2020 (directly to EU-JRC or through WP6), suggestions on the location of monitoring sampling points which will be retained by the EU-JRC as national master points, to be obligatorily sampled inside the LUCAS soil monitoring. Countries involved in the Alpine Soil Partnership were also asked to comment beginning of January 2021 on the location of sampling points for the Alps area proposed by Eurostat/EU-JRC (e.g. validate or reallocate sampling points). Note that while examining all sampling points, several were found to be “wrongly” classified (e.g. wrong land use as urban or private parks or hedgerows currently identified in LUCAS database as woodland) and it was suggested

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to strengthen the involvement of national institutions responsible for soil monitoring in the future selection procedure for LUCAS sampling location.

It was suggested that these agreed LUCAS soil sampling locations could become reference monitoring points shared between LUCAS and the national monitoring systems. The involvement of all national soil monitoring representatives in the selection of LUCAS 2022 soil monitoring which took place in the winter 2020 has been a first test for a collaboration, which should be better organised, for future LUCAS campaigns.

This work should be extended and WP6 partners agreed to develop on a common way to be run to test the complementarity between national SMS and LUCAS sampling schemes.

4.2. Comparing national and LUCAS datasets

All partners involved in WP6 of the EJP SOIL also agreed in comparing their national datasets with those from LUCAS. Based on the questionnaire, Austria, Denmark, France, Germany, Italy – Veneto region, Latvia, Slovakia, Switzerland already have made or started to compare distributions, means, spatial representations, statistical designs of both their soil monitoring system with LUCAS (see for example Annex 2). For France, it was just a first test and a more detailed work will be conducted to discuss the results according to the measured parameters and regions.

In the future exercise to be conducted, if possible, to harmonise depths, we may test for instance spline functions, which will add error but make comparable the depths. This may also help in designing transfer functions between their results and LUCAS ones. We should also consider the time of sampling (i.e. comparing data collected within the same time period). A common way of testing will be agreed upon.

4.3. Developing of transfer functions

Looking at all answers it appears that all countries are open to a collaboration with LUCAS Soil campaigns and want to use the data from such campaigns. Nevertheless, it is not so easy to use and even combine data that were obtained through different protocols. As previously exposed the LUCAS Soil sampling strategy and design differ from most of the national protocols. There are, however, ways to produce harmonisation functions, meaning identifying conversion factors to transform data from one system to another one.

The following ways were identified to go further and try to use the national and LUCAS Soil dataset (having in mind that it is illusory to believe that a harmonization of all protocols is feasible):

1) A first approach would be to produce harmonisation functions (also called transfer functions) between analytical methods for selected soil properties (to be agreed e.g. according to main SDGs or indicators to be produced), using the soil sample archives available at the EJP SOIL institutions or at EU-JRC. The LUCAS samples could be analysed by national labs (to be selected checking the list produced by task 7.4) and the national samples by EU-JRC, and the results compared to the ones registered in LUCAS Soil database and in the national databases respectively. Doing so the overall protocol would not be compared but just the analytical part. The advantage would be that this approach might be rather easy to implement.

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2) Another approach is to ask EU-JRC for a double sampling or for a collaboration with MS that may contribute to sampling campaigns and analyse their samples with national analytical methods in the national laboratories currently used. Again, we will only be able to compare the analytical procedures even if the preparation step will be added. In addition, non-Member States European countries such as Turkey, Norway and Switzerland would be excluded.

If points 1 and 2 seem rather easy to implement as only requiring access to archived or fresh samples (and laboratories), being able to develop robust functions will require that a large part of the full range of possible parameter values is covered, and this range may vary depending on the soil parameters, and this is not so trivial at EU scale. Furthermore, since the protocols adopted for soil analysis in different soil laboratories lead to differentiated results even when adopting the same analytical methods, it is also suggested to organise ring tests between the official national soil laboratories (activity to be organised in collaboration with task 7.4).

3) In order to fully compare the different protocols (from the sampling to the analysis) one solution could be to perform such double sampling during the national monitoring campaigns, following the national protocols and the LUCAS protocols; the collected samples being then sent to the LUCAS laboratory. Such solution will only be possible in countries where a sampling campaign is currently running and will require more time for the samplers (meaning also more money). A solution to save money would be to perform this kind of double sampling only on a subset of sites (see below for details).

4) The last solution would be to ask samplers mandated by EU-JRC to perform such double sampling on the LUCAS points adopting the national monitoring protocols for sampling. This should be discussed and of course this will require more time for the samplers (including training). Here, also, the solution to save money would be to select a subset for double sampling (see below for details).

In order to define the number of sites needed to compare LUCAS with national sampling protocols (points 3 and 4) we can refer to the work of Louis et al. (2014). They tested a way to compare data available for French forest soils that were sampled twice simultaneously on the same sampling grid but with different sampling and analytical strategies: a first sampling was made for the French soil quality monitoring network (RMQS) and the second one for the European forest monitoring network (ICP Forests level I second survey i.e. Biosoil). They compared both RMQS and Biosoil strategies for a set of measured variables of interest (carbon, potassium, lead contents and pH) with the aim to define the minimum number of sites and their best location to establish reliable harmonization functions. Their results suggest that the number of sites depends on the parameter and range from around 140 sites for organic carbon and potassium, and more than 230 sites for lead. Considering that all Soil Monitoring Systems in EU need to be compared to LUCAS as they are quite different in terms of sampling strategies, statistical designs, protocols and even in analytical methods, such numbers are unrealistic (usually the number of sites that it is practical to sample is smaller than 50).

Considering all those solutions, there may also be a problem of timing as the next LUCAS campaign will occur in 2022, meaning that the results will only be available in 2023/2024 (depending on the duration of the sampling phase - to be checked with EU-JRC). It will be close to the end of EJP SOIL. This will also require a budget to pay at least for the analytical part. For solutions 3 and 4, an extra problem is the budget and time needed for such an operation: LUCAS and national samplers must be trained.

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Finally, we also should keep in mind that any harmonization functions will add uncertainty to the final EU-level harmonised maps and statistics. Such uncertainty should be balanced against other possible solutions.

4.4. Identifying and testing statistical methods to combine national and LUCAS datasets

Statistical methods exist to combine data that were not collected with the same protocols to produce estimates of global statistics with associated uncertainty. These approaches need to compute the inclusion probabilities of the observations from both datasets. It is also reasonable to combine these datasets in hierarchical Bayesian models using latent variables to produce harmonised global statistics and maps (see Rundel et al., 2015). Such approaches can be experimented with and discussed by a limited number of countries in order to test its feasibility in terms of data and skills needed.

4.5. Identifying and testing statistical methods to combine existing maps

Another way for mapping is to merge the maps produced with different approaches and datasets to create a “hybrid” map (Chen et al, 2020; Caubet et al., 2020). Again, such approaches can be tested by few countries as this approach requires dedicated datasets to calibrate and validate the harmonisation model.

4.6. Developing interpretation values/scoring approaches

In collaboration with the ongoing EJP SOIL internal research project SIREN as well as with SERENA (if founded by the end of this year), it will be possible to work on “interpretation values” or scoring systems. A common approach to interpret results from each SMS can be tested based on common (i) values at country and/or EU level or (ii) scoring functions. Soils, climate and agrosystems differ per country and even per region. Therefore, the input of data and interpretation of these data differs. Harmonisation can only work if these local aspects are considered, and the assessment is done in close interaction with the responsible for SMS in the respective countries.

We all know it is difficult to agree on common values based on expert knowledge as the situation is quite different across countries and this also leads to political issues (different projects already tried and were not successful). Within EJP SOIL we also intend to work on scoring functions that may be based on statistical distribution of the parameters in countries (sort of data driven method) (see Fine et al., 2017). Few countries, involved in SIREN and SERENA, may test such approaches.

5. Conclusions

During the last 20 years different projects and/or studies underlined the need for developing a harmonized EU system to monitor and report about soil status. All reports called for a network of sites from national monitoring systems that will work on the harmonization and/or comparison of their procedures in order to share their data. Twenty years after, it is clear that we are still more or less in

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the same situation, and that also pushed EU-JRC to develop its own monitoring system (LUCAS Soil) to report on the status of soil.

Partners involved in WP6 activities of the EJP SOIL know this situation and started working on the comparison of national and LUCAS monitoring networks. A questionnaire was also prepared to review existing SMS, identify the differences and ask for possible ways of harmonization. From that first work it appears that only very few countries will consider changing their national SMS as it would require an investment to compare the existing dataset with the new one if modified. For countries having no SMS and currently working on such development, it may be suggested to directly adopt protocols similar to those of LUCAS to facilitate future comparisons and/or integration of national data into EUSO.

Based on the questionnaire, it appears that several countries would accept to include new sites (in common with LUCAS) to better compare and use the data from their system and the EU one. They also agree on several ways to go forward in order better combine the existing data (for local/global statistics or for mapping).

Table 4 presents the advantages and limitations of the proposed recommendations to be tested. The analysis of national and LUCAS designs and results can be done by all WP6 partners whereas other options will be tested only by a limited number of countries as requiring more skills, time and money. Those options will also need a close collaboration with EU-JRC to be effective. This roadmap will be implemented in the next year.

	Advantages	Limitations	Timeframe	Costs
Comparing national and LUCAS sampling strategies/schemes	To be done to identify complementarities between networks and possible errors in the land uses.	None, as a common way of comparison will be developed.	Compatible with the duration of EJP SOIL.	Included in EJP SOIL WP6 plan of action.
Comparing national and LUCAS datasets	To be done to identify similarities and differences between networks.	None, as a common way of comparison will be developed.	Compatible with the duration of EJP SOIL.	Included in EJP SOIL WP6 plan of action.
Developing transfer functions	Can improve the use of national and LUCAS datasets.	May introduce uncertainty. Will require time and money for analysis and training.	The delay needed to choose the sites/samples and obtain the results may be long, delaying the production of deliverables.	Depending on the complexity of the selected solution it will require money for the analyses and for the training of the samplers. This was partly included in WP6 budget and plan of action in AWP3.
Identifying and testing statistical methods to merge national and LUCAS datasets or existing maps	Can improve the use of national and LUCAS datasets.	Will require time and skills to be tested.	Compatible with the duration of EJP SOIL.	Included in EJP SOIL WP6 plan of action.
Developing interpretation values/scoring approaches	Can improve the use of national and LUCAS datasets.	Will require time and skills to be tested. Needs in-depth thinking about the scoring approach.	Compatible with the duration of EJP SOIL. Connections with SIREN and SERENA may delay the process.	Included in EJP SOIL WP6 plan of action.

Table 4. Analysis of the proposed recommendations (advantages, limitations, time frame and associated costs)

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7. Annexes

7.1. Questionnaire

WP6 - Supporting harmonised soil information and reporting Task 6.3 - Agricultural potential and sustainable values of SOC, agricultural soil fertility and degradation

AIM OF THE QUESTIONNAIRE

Within EJP-SOIL, WP6 is dedicated to the harmonisation of data (from collection to use), data exchange and data treatment (e.g. mapping). WP6 is analysing the existing data in all EJP-Soil countries and is providing guidance for the future collection, storage, exchange and use of soil data (e.g. to produce new information).

WP6 is collaborating with EU structures dealing with soil information (mainly JRC-ESDAC, but also DG Env, DG Agri and DG Climate) and in particular in the activities related to the development of the next fore coming LUCAS soil campaigns (in 2022 and others) and of the EU Soil Observatory (https://ec.europa.eu/jrc/en/eu-soil-observatory).

In June WP6 will have to redact the deliverable named 'Proposal of methodological development for the LUCAS programme in accordance with national monitoring programmes'. 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.

This proposal, therefore, will tackle both the sampling protocols, and the sampling design, and their harmonization with national monitoring systems. The D6.3 follows the D6.1, where a survey on national soil monitoring systems and suggestions for sampling design have already been given.

This questionnaire was designed to collect relevant information about the Soil Monitoring Systems (SMS) present in each one of the EJP-SOIL countries, on the sampling protocols and on metadata collected, to identify similarities and differences. Based on this stocktake recommendations will be given to pave the way for harmonization and to use the data at EU scale. Note that the Soil Monitoring Systems can also be sub-national ones, if they are under the responsibility of sub-national soil monitoring authorities. Soil monitoring activities undertaken for research purposes (e.g. in Long Term Experiments) are not the object of this questionnaire.

COMPOSITION OF THE QUESTIONNAIRE

The questionnaire consists of the following 11 parts :

1) Institution identification
2) SMS short description
3) Site information
4) Sampling protocol
5) Sampling for bulk density
6) Soil description
7) Soil sample preparation and conservation
8) Litter sample
9) Analyses and methods (optional)
10) Harmonization options
11) Collaborations and/or synergies between Member States and LUCAS.

Giving your email below will allow you to receive a copy of your answers that you may further change.

*Obligatoire

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1. Adresse e-mail *

1. Institution identification

2. Name *

3. Country *

4. Contact name(s) and email(s) *
Other contact(s) name(s)/email(s) of people involved in the SMS (use ';' between each name/email)

2. Soil Monitoring System description

Brief description of the SMS

5. Name of the soil monitoring system *
Give the common abbreviation and the detailed name

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6. Who is responsible for the Soil Monitoring System? *

7. Main aim of the monitoring

Ex: to report on soil quality, to monitor SOC, to monitor nitrate and phosphorus, to monitor pH changes

8. Starting year *

9. Still running ? *

Une seule réponse possible.

- ◯ Yes (tell us the date of the next campaign)
- ◯ No (if no, please tell why)

10. If still running, date of the next campaign

11. If not running can you comment

If the SMS is not ongoing anymore, can you please comment why not? And with details on previous frequency and running period.

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12. Number of campaigns to date *

13. Number of sampling sites on average *

14. Interval between 2 sampling campaigns (in years) if regular or dates of sampling campaigns *

15. Land uses investigated *

Plusieurs réponses possibles.

- [ ] Natural
- [ ] Agricultural
- [ ] Forest
- [ ] Urban
- [ ] All kind

Autre : [ ]

16. Sampling design type *

Une seule réponse possible.

- ( ) Grid
- ( ) Representative sites/stratified
- ( ) Autre :

17. Sampling design specifications *

Quick description (e.g. Grid 16 x 16 km)

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18. Comment(s) to this section ?

3. Site information

Description of the sampling site - metadata collection

19. Is a GPS used do for the determination of site coordinates *

Une seule réponse possible.

- Yes
- No

20. Geolocalisation precision (in meters) *

21. Including elevation ? *

Une seule réponse possible.

- Yes
- No

22. Data on soil management (eg. rotations, crop management, tillage..) available *

Une seule réponse possible.

- Yes
- No

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23. If yes, please comment

24. Other information (e.g. slope, exposition, erosion features,...) recorded *

Une seule réponse possible.

- Yes
- No

25. If yes, please comment

26. Description of soil surroundings (e.g. road, factory, city...) available *

Une seule réponse possible.

- Yes
- No

27. Information on lithology *

Une seule réponse possible.

- Yes
- No

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28. Pictures of the site available *

Une seule réponse possible.

- Yes
- No

29. Vegetation inventory of the site available *

Une seule réponse possible.

- Yes
- No

30. Are all sampling sites treated the same? *

Is the same protocol applied in all sites (e.f. some sites may be highly investigated while other are just sampled...)

Une seule réponse possible.

- Yes
- No (please comment)

31. If not all sites are treated the same, please describe

____

32. Comment(s) to this section?

____

4. Sampling protocol

Describe how the site is sampled. Usually when a site is chosen the sampling support is the area where the soil samples are taken from.

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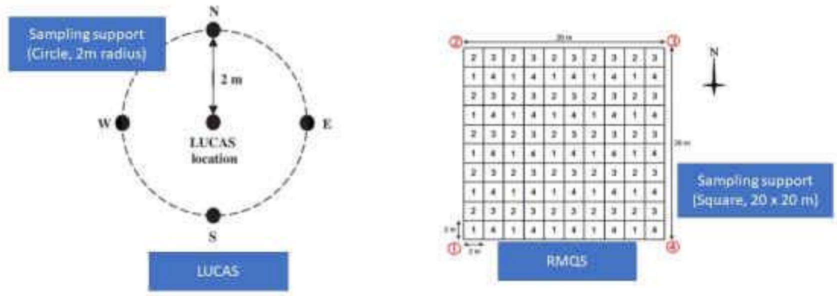
Examples of sampling supports



33. Area of the sampling support (m²) *
Total area used for the sampling (e.g. 400 m², 10 m²...)

34. Design of the sampling support area *
ex: square (20x20 m), cross, random, circle (radius of 2 m)

35. Composite sampling *

Une seule réponse possible.

- ◯ Yes
- ◯ No

36. How many samples are taken in the sampling support area for one depth interval? *
ex : 5, 25...

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37. Sampling depth type *

Une seule réponse possible.

- ◯ Fixed depths
- ◯ According to horizons
- ◯ Autre : ____________________

38. If fixed depths, describe intervals *

ex : 0-30 and 30-50 cm / or ploughing layer and below / just 0-20 cm

____

39. If other way of sampling, please describe

ex : 0-30 and 30-50 / or ploughing layer and below -50 cm

____

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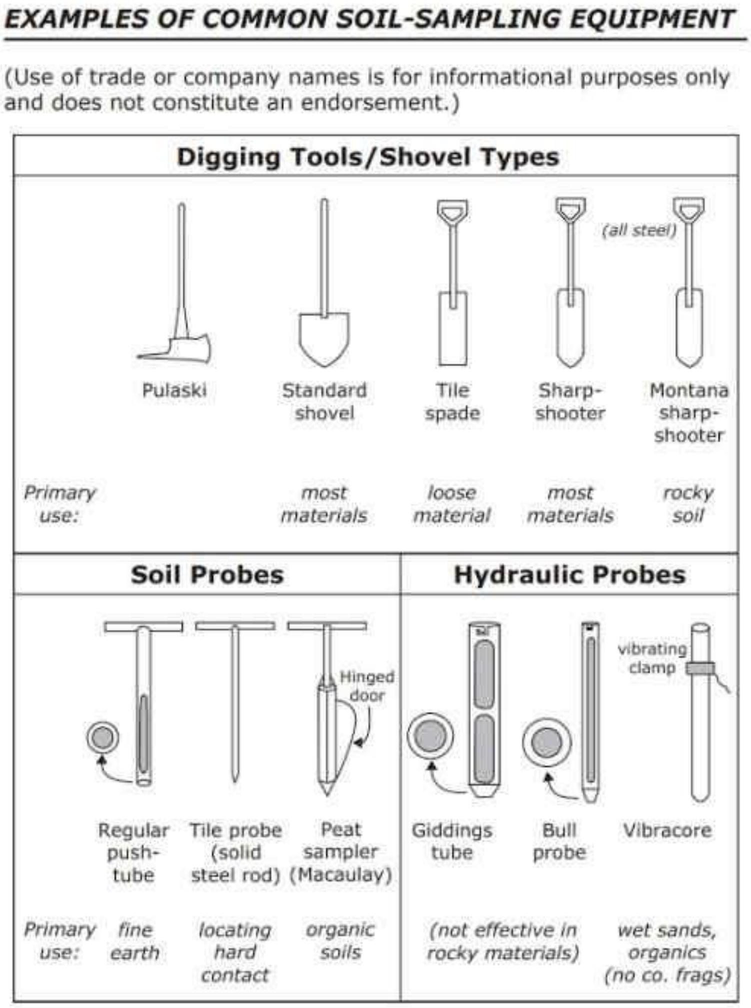
40. Sampling tool(s) *



Plusieurs réponses possibles.

- [ ] Auger
- [ ] Shooter
- [ ] Spade
- [ ] Probe
- [ ] Pulaski

Autre : [ ] ______

41. Weight of the final sample (kg) *

ex : 1, 5, 25...

______

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42. Are proximal sensors used for field analyses (other than GPS) *

Une seule réponse possible.

- Yes
- No

43. If yes, which instrument(s) is(are) used and for which parameter(s)

44. Comment(s) to this section

5. Sampling for bulk density

Describe if the site is sampled for bulk density and how.

45. Do you take samples for bulk density *

Une seule réponse possible.

- Yes
- No *Passer à la question 49*

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46. If yes, what is the number of samples taken for bulk density per location (please describe at which depth)

ex : 3 samples between 0-30 cm and 3 between 30 to 50 cm

47. Please specify the standard used for sampling

48. Comment(s) to this sections ?

6. Soil description

Specify if the soil of the site is described and named when sampling or if the soil of the site is assigned to the representative soil profile of the soil unit where the sampling site is located. In all the cases, this section is dedicated to describe how the soil description is performed, in case it is present.

49. Do you perform a soil profile description? *

Une seule réponse possible.

- Yes
- No

50. Description of the way in which the soil is exposed for description

Ex : soil pit, soil profile

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51. Are pictures taken of the soil profile ?

Une seule réponse possible.

- Yes
- No

52. Are samples taken for soil description analysed to characterize soil type ?

Une seule réponse possible.

- Yes
- No

53. Weight of the final sample (kg)
ex : 1, 5, 25...

____

54. Sampling depth type for soil description
ex : according to soil horizons

____

55. Soil standard used for soil description

Une seule réponse possible.

- National
- USDA
- FAO
- WRB
- Autre : ____________________

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56. Soil classification used

Une seule réponse possible.

- National
- USDA
- FAO
- WRB
- Autre : ____________________

57. Reference or link to the reference documents for description and the classification

____

____

____

____

____

58. If you not describe the soil of the site, do you assign it to a representative soil profile of the soil unit where the sampling site is located.

Une seule réponse possible.

- Yes
- No
- Autre : ____________________

7. Sample preparation and conservation

Describe how the soil samples are prepared for storage and analyse

59. Storage conditions before preparation *

Ex: 4°C

____

60. Preparation *

Ex: Air drying at room temperature/at 30°C, oven drying at xx°C,

____

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61. Sieving/crushing method *
Ex: by hand, crushing, sieve

62. Sieve size (mm) *
Ex: 2 mm

63. Litter and roots in the soil sample *
Ex: discarded, integrated in the sample...

Une seule réponse possible.

- Discarded
- Integrated in the sample
- Autre :

64. Long term storage of the sample

Une seule réponse possible.

- Yes
- No

65. Long term storage conditions
Ex: 18°C, 4°C, in the dark, controlled hygrometry...

66. Availability of long term stored samples

Une seule réponse possible.

- Yes, under condition
- No

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8. Litter samples

Describe how litter samples are sampled and prepared

67. Is litter also sampled ? *

Une seule réponse possible.

- Yes
- No *Passer à la question 83*

68. Storage conditions before preparation
Ex: 4°C

69. Preparation
Ex: drying at 80°C

70. Sieving/crushing method
Ex: by hand, crusher

71. Long term storage of the litter sample

Une seule réponse possible.

- Yes
- No

9. Soil parameters measured and methods

This part is optional if you already completed the previous questionnaire from WP6 where existing national databases were stock taken. If you didn't aswer to that questionnaire or if you answered but you didn't detail the database linked to your monitoring system, then please complete this part.

Nevertheless, feel free to answer even if you already detailed the soil parameters analysed in the previous stock take made by WP6.

If you have existing documents (e.g. tables with the parameters and methods/standards used) you may also skip this part and send us such documents (please send to: antonio.bispo@inrae.fr)

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72. Did you already complete the previous questionnaire from WP6

Une seule réponse possible.

- Yes
- No

73. Are the analysis performed by one laboratory of by several ones ?

Une seule réponse possible.

- Just one
- Several
- Autre : ______________________

74. Main soil properties analysed

Plusieurs réponses possibles.

	Yes	No
Total profile depth	☐	☐
Plant exploitable (effective) soil depth	☐	☐
Organic carbon	☐	☐
pH in water	☐	☐
Sand	☐	☐
Silt	☐	☐
Clay	☐	☐
Gravel	☐	☐
ECEC	☐	☐
Bulk density of the fine earth (< 2 mm) fraction (excludes gravel)	☐	☐
Bulk density of the whole soil in situ (includes gravel)	☐	☐
Available water capacity	☐	☐
Electrical Conductivity	☐	☐

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75. Comment(s) if needed

76. Other soil properties *

Plusieurs réponses possibles.

	Yes	No
Calcium-carbonate content	☐	☐
Field capacity (mm)	☐	☐
pH KCl	☐	☐
Saturated hydraulic conductivity (Ksat)	☐	☐
Plant available amounts of macro and micro nutrients (PLEASE SPECIFY)	☐	☐
Total amounts of macro and micro nutrients/trace elements (PLEASE SPECIFY)	☐	☐
Quality of clay minerals (e.g. type or ratio of illite, smectite, montmorillonite in clay fraction...etc)	☐	☐
Properties for NIR and/or MIR (near and mid infrared, please specify)	☐	☐
Major elements (e.g. Fe, Al,...)	☐	☐

77. Please specify here for nutrients, major elements, NIR/MIR...

Ex: Nutrients : N, P, K, Mg.... Major : Fe, Al, ... NIR measureaments

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78. Contamination

Plusieurs réponses possibles.

	Yes	No
Trace elements (e.g. Cd, Cr, Pb, Zn...)	☐	☐
Persistent organic contaminants (e.g. PAHs, PCBs..)	☐	☐
Pesticides	☐	☐
Other (e.g. microplastics)	☐	☐

79. If others, then describe

____

____

____

____

____

80. Soil biodiversity

Plusieurs réponses possibles.

	Yes	No
Earthworms	☐	☐
Nematodes	☐	☐
Collembola	☐	☐
Mites	☐	☐
Bacterial diversity	☐	☐
Fungi diversity	☐	☐
Activities of soil organisms (e.g. respiration, enzymatic functions, litter bags...)...	☐	☐
Others	☐	☐

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81. If others, then describe

82. Comment(s) to this section

10. Harmonization options

Based on the results of this survey, ways of harmonizing the sampling protocols across countries may be proposed. From your point of view, which parts of the protocol you described may be adapted or changed?

83. May the sampling design of your SMS be adapted or changed ?

Une seule réponse possible.

- Yes
- No

84. Please comment

E.g. Yes we may add new points... No It's a grid no changes...

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85. Can you consider collecting new information on the monitoring sites (e.g. soil management practices, surroundings of the site)?

Une seule réponse possible.

- Yes
- No

86. Please comment

E.g. Yes we may collect information on... No, it will take too much time on the sites

87. If needed can you improve the precision of locations of the monitoring sites ?

Une seule réponse possible.

- Yes
- No

88. Please comment

E.g. we can change our GPS...

89. Can the soil description be improved (e.g. describing the soil of the site if not done, convert into WRB...) ?

Une seule réponse possible.

- Yes
- No

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90. Please comment

E.g. Yes, we may describe the soils of the sites, No it's too much work, Yes we may convert our national information into WRB

91. Can you modify the sampling area (e.g. increase, decrease, review the sampling pattern)?

Une seule réponse possible.

- Yes
- No

92. Please comment

E.g. No, all the previous data rely on this protocol / Yes, we may increase the size of the sampling area

93. Can you change the sampling depths ?

Une seule réponse possible.

- Yes
- No

94. Please comment

E.g. No, all the previous data rely on this protocol/ Yes, we may sample deeper

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95. Can you change the soil sample preparation, before analysis ?

Une seule réponse possible.

- Yes
- No

96. Can you change measurement methods (creating a transfer function to maintain consistency)?

Une seule réponse possible.

- Yes
- No

97. Can you add extra parameters to be analysed ?

Une seule réponse possible.

- Yes
- No

98. Please comment

E.g. No, all the previous data rely on this protocol/ Yes, we may adapt our preparation according to a common protocol...

11. Collaborations and/or synergies between Member States and LUCAS.

This part relates to the collaboration you already had with LUCAS or you intend to have.

99. Do you already collaborate in your country with LUCAS campaigns ? *

Une seule réponse possible.

- Yes
- No

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100. If yes, please describe (when, why, how...)

101. Do you intend to and can you collaborate in your country with the next LUCAS campaign? *

Une seule réponse possible.

- Yes
- No

102. If yes, describe possible collaborations

E.g. Willing to provide supplementary soil data for LUCAS points? Interested in using LUCAS to facilitate sample collection for my country. Analyse subset of samples with both lab methods and labs (national and LUCAS) to derive transfer functions and use all data together. Compare LUCAS and National sampling design strategies...

103. Do you already use LUCAS data ? *

Une seule réponse possible.

- Yes
- No

104. If yes, please explain why

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7.2. Comparison of National and LUCAS datasets

7.2.1. Comparing soil data of national soil monitoring systems with LUCAS Topsoil dataset – a case study for Hungary

András Benő, Piroska Kassai, Brigitta Szabó, Annamária Laborczi, Zsófia Bakacsi, László Pásztor, Gábor Szatmári

Under WP6 Tasks, one of the targets of the EJP Soil project is to provide information on how the LUCAS Topsoil dataset and national soil monitoring databases could be complied with each other. The difference between the national monitoring systems and LUCAS dataset is mainly due to a) the different measurement methods applied to determine the soil properties, b) the different sampling strategy, both in terms of sampling location and sampling depth. Hereinafter we present a possible workflow for the comparison of LUCAS Topsoil dataset and a national soil monitoring system (SMS) as illustrated by using the Hungarian Soil Information and Monitoring System (SIMS).

Recent data inventories at European level

In the last twenty years there were some successful compilation of European measured soil profile datasets (Tóth, 2013) which have also highlighted the need for harmonization. Here we mention the most extended, recent European datasets established with different aims.

The ***Soil Profile Analytical Database of Europe of Measured parameters*** (SPADE/M) database includes the most frequently used basic soil data of 560 soil profiles from 17 European countries. SPADE/M provides a harmonized structure to store soil profile data and aims to provide information about the most characteristic European soil types (Hiederer et al., 2006).

A dataset from forest monitoring in 27 members of the European Union was established under the ***BioSoil*** project. The dataset was built based on existing monitoring networks focusing on the analysis of forest environment to demonstrate how a large-scale European forest dataset can support forest related policy. It contains soil data for some 4035 plots (Hiederer and Durrant, 2010).

The ***European Hydropedological Data Inventory*** (EU-HYDI) holds data on soil physical, chemical and hydrological properties of some 18537 soil horizons belonging to 6460 European soil profiles. The database was created with the cooperation of 29 institutes from 18 European countries (Weynants et al., 2013) to provide more in depth information about the soil physical and hydraulic properties.

These datasets provides valuable soil information, but the ease of access and level of data harmonization can differ within the datasets. SPADE/M is open access, can be downloaded from the European Soil Data Centre website - https://esdac.jrc.ec.europa.eu/ - of the Joint Research Centre (Panagos et al., 2012). BioSoil is not publicly available. EU-HYDI can be accessed through contacting the contributing scientists of the database. The LUCAS Topsoil dataset obviously has the advantage both in terms of data accessibility and harmonized methodology, further to that it provides information on the change of soil properties in time. Although it is important to note that LUCAS topsoil data might not describe local conditions and lacks information about the subsoils. If compliance

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between the LUCAS dataset and other national or international dataset would be provided, it could further enhance the use of these datasets and would allow their joint application.

LUCAS Topsoil Survey

Eurostat has carried out continental scaled soil surveys in 2009, 2012, 2015, and 2018 with the scope to create a harmonized and comparable dataset of physical and chemical properties of topsoil across the EU to support policymaking. The ***LUCAS Topsoil Survey*** is repeated every 3 years (the latest survey was in 2018 and the next survey is expected to be delayed by one year and will be completed in 2022). The samples are analyzed for several properties in a single laboratory using standard analytical methods.

In 2009, 19,967 points were selected across 27 member states (except Bulgaria and Romania) based on a stratified sampling scheme with land use and terrain information as attributes. At each point, samples were collected from a depth of 20 cm using a common sampling procedure. Three years later - in 2012 - only Bulgaria and Romania have been sampled. In 2015 17,613 soil samples were taken by revisiting the LUCAS 2009 survey points, however new soil points at an altitude of 1,000 – 2,000 m were also added to the survey (the altitude limit was 1,000 m in LUCAS 2009 and 2012 surveys). The soil module was also extended by the EU-JRC to Albania, Bosnia and Herzegovina, Croatia, Montenegro, the Republic of North Macedonia, and Serbia. In total, 27,069 points were selected for the topsoil survey in 2015, of which 25,947 were located in the EU-28 MS. In 2018 soil samples were taken in repeated points of LUCAS 2009/2012 and LUCAS 2015. The novelty of this survey was that new physical, chemical, and biological parameters were also analyzed (key parameters for evaluating soil quality, such as bulk density and soil biodiversity). Samples of the 2018 survey are still under laboratory testing, but the results will be available soon.

Table-1.: Soil properties and description of methods in LUCAS Topsoil database.

Soil properties	Method	Description
Coarse fragments	ISO 11464:2006	Sieving to separate coarse fragments (2-60 mm) from fine earth fraction
Clay, silt and sand content	ISO 11277:1998- (Sieving) ISO 13320:2009-(LDM)	Sieving and sedimentation method (in 2009 and 2012) Laser diffraction (in 2015 only), LDM
pH in $CaCl_2$ and in H_2O	ISO 10390:2005	Glass electrode in a 1:5 (V/V) suspension of soil in H_20 and $CaCl_2$
Electrical Conductivity (EC)	ISO 11265:1994	Metal electrodes in aqueous extract of soil
Organic carbon content (OC)	ISO 10694:1995	Dry combustion (elementary analysis)
Carbonates content ($CaCO_3$)	ISO 10693:1995	Volumetric method
Soluble phosphorus content (P)	ISO 11263:1194	Spectrometric determination of P soluble in sodium hydrogen CaCO3 solution
Total nitrogen content (N)	ISO 11261:1995	Modified Kjeldahl method
Extractable potassium content (K)	USDA–NRCS, 2004	Atomic absorption spectrometry after extraction with NH4OAc
Cation exchange capacity (CEC)	ISO 11260:1994	Using barium chloride solution to saturate samples and extract cations
Multispectral spectroscopy	Soil Spectroscopy Group	Diffuse reflectance measurements

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Clay mineralogy	X-ray diffraction	X-ray diffraction patterns of oriented aggregates (only in 2015)

Both datasets available now (2009 and 2012, 2015) were analyzed for the following properties: clay, silt and sand content, carbonates ($CaCO_3$), soil organic carbon (OC), total nitrogen(N), soluble phosphorus (P) and potassium (K), heavy metals content, electrical conductivity (EC), pH cation exchange capacity and multispectral properties. The main difference between the two surveys is that EC and clay mineralogy was measured only in 2015. Table-1 lists the methods used in the LUCAS Topsoil database to determine soil properties.

In the next survey (2022) the sampling depth is expected to change from 0-20 cm to 0-30 cm. A part of the sample points from 2009/2012, 2015 and 2018 campaigns will be resampled and new sampling points will be added to the survey.

Methods for comparison (statistical/land use-based)

Spatial sampling concerns selection of a subset of individuals from a population to estimate the characteristics of the whole population, where these characteristics could be the total or mean parameter value for a random field, values at unvisited sites or location of target(s). Each sampling is aimed at getting sample, which is representative for the whole population. From a statistical point of view, a sample is said to be representative if it reflects the characteristics of the population the best. ***The proposed methodology is therefore based on the analysis of whether two sets of soil data from a national and a continental (or even global) monitoring system represent the same population.*** Since sampling protocols must be different (e.g., date of sampling, sampling depth or laboratory analysis methods), special attention should be paid to harmonize the two soil datasets (e.g., using unit conversions, mass-preserving splines to derive soil properties for similar soil depth, pedotransfer functions for methods conversion, etc.) before the analysis.

Our proposed methodology applies two approaches:

- First, the empirical cumulative distribution function of a soil property coming from the national monitoring system is compared to the empirical distribution function of the same soil property from the continental monitoring system using the Kolmogorov-Smirnov test. We made the correlations visible with the help of back-to-back histograms, separately for each soil property of interest. –“ *Approach No1*.”
- Second, the mean values of a soil property coming from the national and continental monitoring system are compared at different land use categories and presented on a scatterplot. This is also done separately for each soil property of interest.–“ *Approach No2*.”

We can use the land use categories as a basis for LUCAS vs. national SMS comparison also, indicating whether the two databases describe the given land use category in the same way. It should be taken into account that the land use currently described at the time of sampling may differ from the e.g. the CORINE land use category of the given area in the case of the national SMS (in part because of the variability within the mapping unit or because of the large time difference between the two surveys). Specifications for GlobalSoilMap (ISRIC, 2015) refers the standard methods adopted by the GlobalSoilMap project and provides a set of pedotransfer functions for conversion of data from several widely used methods into the specified reference methods in GSM. We suggest to apply these conversion functions, if possible.

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Methodological conversion between LUCAS Topsoil database and the Hungarian Soil Information and Monitoring System (SIMS)

The basis of the conversation was the LUCAS 2009 Topsoil data, available at 496 points in Hungary. The national analytical data for the soils are available for 1235 sites in the Soil Information and Monitoring System in Hungary (SIMS). Because of the more complete data set of 1993 for SIMS, the data of that year was used for the comparison (Table-2). For the comparison the particle size distribution, organic carbon- and carbonate content, pH in H2O and $CaCl_2$ were selected, because they were considered relatively constant over time. The measured nutrient values were not compared, because their values, especially in agricultural lands, can be strongly influenced by the time of sampling and the actual soil management practice.

Table-2.: Comparison of the measurement methods of selected soil properties for common analyses, the applied units in LUCAS and SIMS are indicated as well.

Soil Property	LUCAS		SIMS	
	measurement method	**unit**	**measurement method**	**unit**
Particle size distribution (sand, silt, clay)	Sieving and sedimentation method (FAO/WRB) ISO 11277. 1998	%	Pipette method based on the Stokes-law (USDA) MSZ-08-0205-1978	%
Organic carbon content	Dry combustion ISO 10694:1995	g/kg	"Székely"-method (wet combustion) using 1:2 mixture of $K_2Cr_2O_7$ and H_2SO_4 MSZ-08-0210:1977	%
Carbonate content	Volumetric method ISO 10693:1995	g/kg	Scheibler-method MSZ-08-0206/2-1978	%
pH(H_2O)	Glass electrode in a 1:5 (V/V) suspension of soil in H_2O ISO 10390. 1994	-	Glass electrode in a1:2,5 (V/V) suspension of soil in H_2O MSZ-08-0206/2-1978	-
pH($CaCl_2$)	Glass electrode in a 1:5 (V/V) suspension of soil in $CaCl_2$ ISO 10390. 1994	-	Glass electrode in a1:2,5 (V/V) suspension of soil in KCl MSZ-08-0206/2-1978	-

The LUCAS points are located along a uniform "master" grid, while the national monitoring points are so-called representative points for landuse and soil type (Figure-1).

All the data harmonization and statistical analysis were performed in R environment (R Core Team, 2020).

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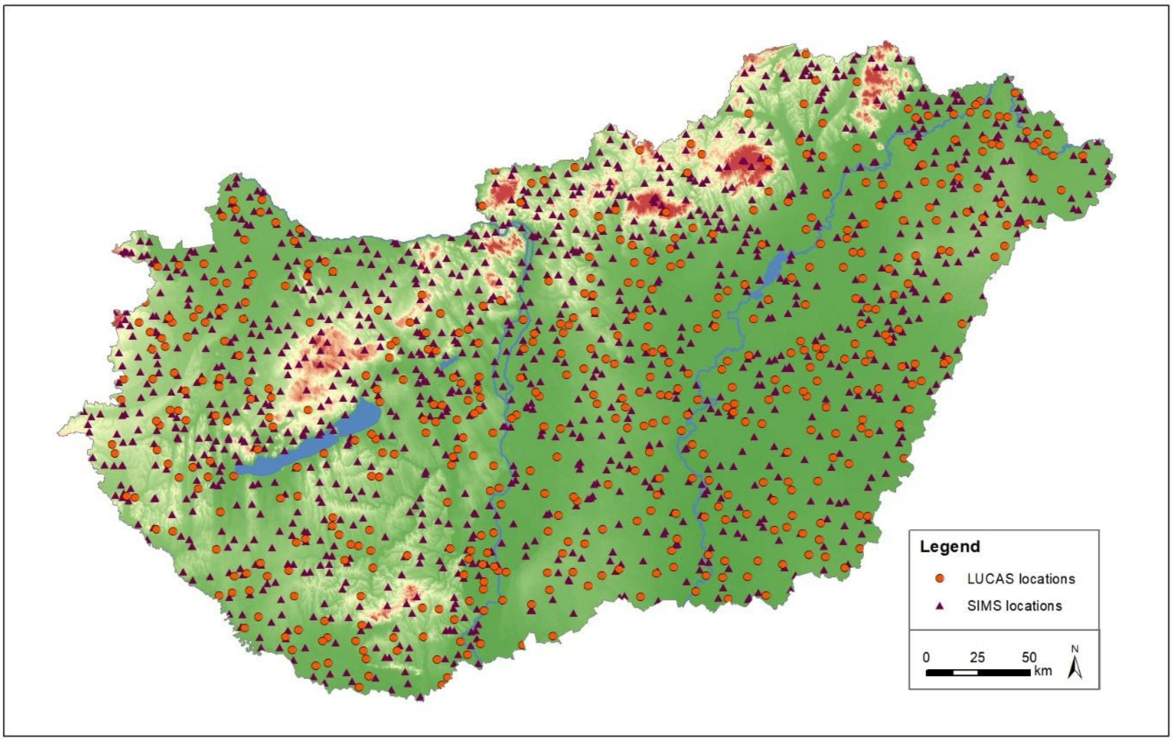

Figure-1. Location of the LUCAS Topsoil data and the Hungarian Soil Information Monitoring System.

Conversion of values to 0-20 cm depth

The soil depth at which the LUCAS samples were taken is 0-20 cm. The soil samples of SIMS were taken at multiple non-uniform depths. To harmonize the two datasets regarding soil depth, we used the GSIF package (Hengl at al., 2020). The *mpspline* function was applied, which interpolated the values of the different soil depths into new uniform depth values in 20 cm increments. The topmost layer was now at 0-20 cm and was in sync with the LUCAS database. It should be noted that the spline procedure can only be used if at least one sampling depths are available below the targeted depth.

Conversion of particle size distribution

The LUCAS Topsoil database used the FAO/WRB method of classifying the particles into clay, silt and sand size classes, which uses the thresholds of: (> 0.002 mm) for clay, (0.002 - 0.063 mm) for silt and (0.063 – 2 mm) for sand. The Hungarian Soil Monitoring System's particle size distribution was based on the USDA limits, which used the thresholds of: (> 0.002 mm) for clay, (0.002 - 0.05 mm) for silt and (0.063 – 2 mm) for sand. To convert the Hungarian data (USDA) to LUCAS (FAO/WRB) we used the *TT.text.transf* function of the *soiltexture* R package (Moeys, 2018).

Conversion of humus content to organic carbon content

The carbon content of the Hungarian soil samples is indicated as humus-content, while the LUCAS Topsoil carbon content is indicated as organic carbon content, therefore a conversion is needed. Humus - on average - consists of 58% carbon, 40% oxygen and 2% hydrogen (Sprengel, 1826) so the generally accepted conversion factor is 100/58 = 1,724 (Wolff, 1864).

Humus (%) = Organic carbon (%) * 1,724   Organic carbon (%) = Humus (%) / 1,724

The unit of the OC content in the LUCAS database is $g*kg^{-1}$ so the converted OC(%) must be multiplied by a factor of 10.There is no conversion relationship developed for temperate soils to convert values

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measured by wet combustion with modified Tyurin titrimetric method into dry combustion organic carbon content. It is worth to consider if higher error is propagated when a pedotransfer function developed for soils under a completely different climate is applied for the conversion – e.g.: a method trained on Australian dataset is available – than not performing any conversion equation at all. Due to the lack of an appropriate conversion equation we did not apply any of them.

Conversion of pH(H_2O)1:5 to pH(H_2O)1:2,5

Since the pH in H_2O in the LUCAS database was measured using a ratio of 1:5 soil to water and in the SIMS a ratio of 1:2,5 was applied during the measurement, a conversion was needed. For precise conversion between $pH_{1:2,5}$and $pH_{1:5}$in $H_2O$the following equations were suggested by polish researchers (Kabała et al, 2016):

$$pH_{H2O\ 1:5} = 0,14 + 0,99*pH_{H2O\ 1:2.5}$$

Conversion of pH(KCl) to pH($CaCl_2$)

The pH was measured in 1:2,5 soil:KCl suspension (SIMS) and 1:5 soil:$CaCl_2$ suspension (LUCAS). We can use the equation by (Kabała et al., 2016) to convert the $pH_{KCl\ 1:2.5}$ in the SIMS database, into $pH_{H2O\ 1:5}$:

$$pH_{H2O1:5} = -1.95 + 11.58*\log 10\ (pH_{KCl\ 1:2.5})$$

Now we can convert the $pH_{H2O\ 1:5}$ into $pH_{CaCl2\ 1:5}$ using the equation by (Aitken & Moody, 1991):

$$pH_{CaCl2\ 1:5} = 0.197\ (pH_{H2O})^2 - 1.21\ (pH_{H2O}) + 5.78$$

The suggested conversion (by GSM methodology) was developed on Australian, mostly acidic soils, which can also affect the results of the conversion.

Conversion of $CaCO_3$

The carbonate content is in $g*kg^{-1}$inthe LUCAS database, while the $CaCO_3$ values in the SIMS database are in weight %, thus the SIMS values had to be multiplied by a factor of 10. The applied lowest detection limit of the methodology used in the SIMS is 0.02% for the carbonate content. Conversion due to methodological difference was not needed, because the measurement method used in the LUCAS and SIMS can be considered similar.

Preliminary analysis of the two databases, according to Corine Land Cover 2018 categories

Since the two databases have points from different locations, we assigned land cover categories to the samples of LUCAS and SIMS dataset based on the 2018 Corine Land Cover (CLC2018) map. This enabled the comparison of the measured values by the land cover categories.

The applied most detailed CLC2018 third level categories available for both databases were 112, 124, 131, 211, 221, 222, 231, 242, 243, 311, 312, 313, 321, 324, 411, and 512, Table-3 shows the meaning of the codes. We focused on common categories (Figure-2).

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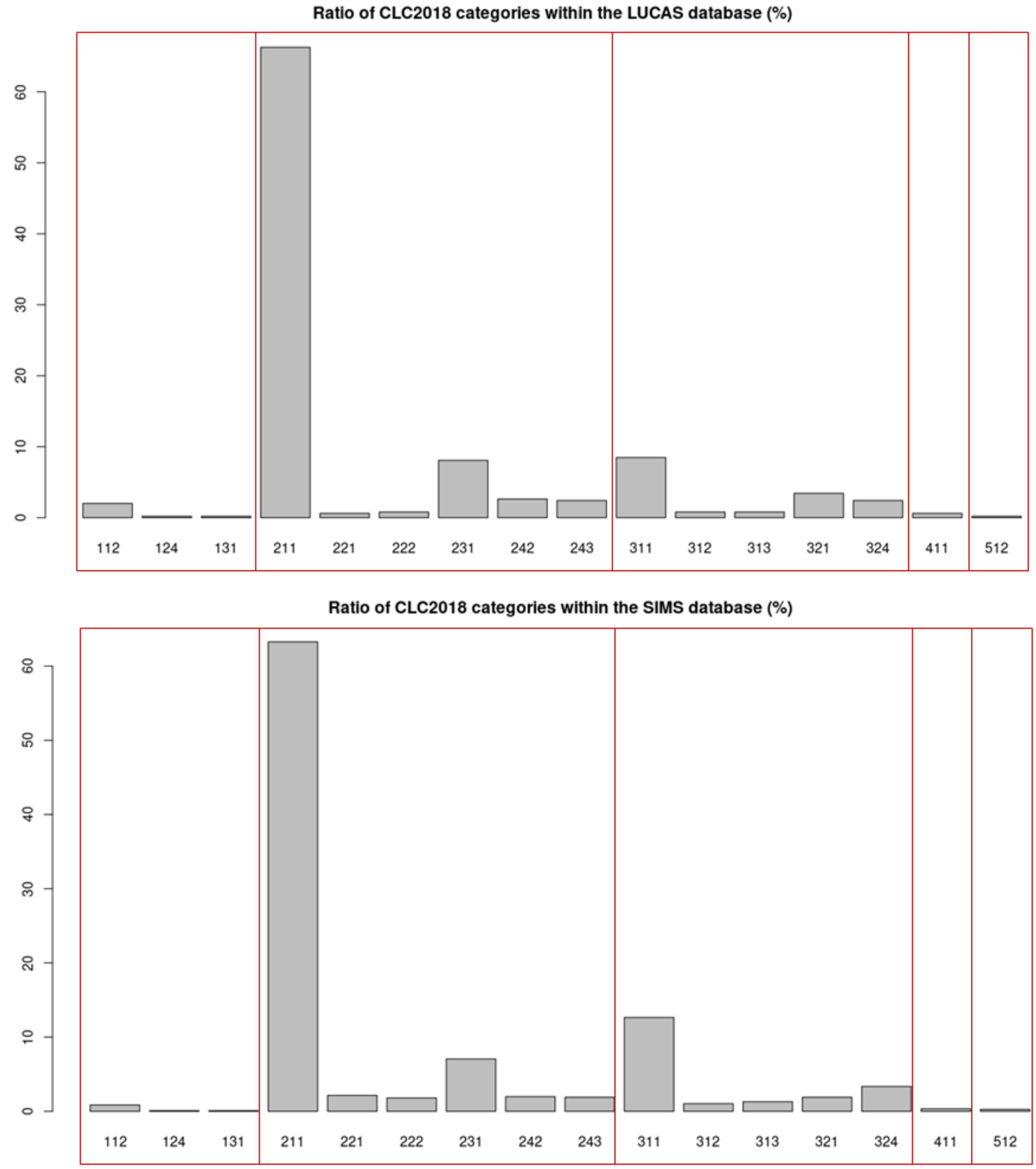


Figure-2.: Frequency of CLC2018 land cover categories in the LUCAS Topsoil database and the Hungarian Soil Information and Monitoring System (SIMS)(Y-axis: %), main categories according to the first digit are (in red outlined boxes): 1- Artificial surfaces, 2- Agricultural areas, 3- Forest and seminatural areas, 4- Wetlands, 5- Waterbodies.

Table-3. The corresponding land cover types of the CLC codes

CLC codes	Land cover type
112	Discontinuous urban fabric
124	Airports
131	Mineral extraction sites
211	Non-irrigated arable land
221	Vineyards

222	Fruit trees and berry plantations
231	Pastures
242	Complex cultivation patterns
243	Land principally occupied by agriculture, with significant areas of natural vegetation
311	Broad-leaved forest
312	Coniferous forest
313	Mixed forest
321	Natural grasslands
324	Transitional woodland-shrub
411	Inland marshes
512	Water bodies

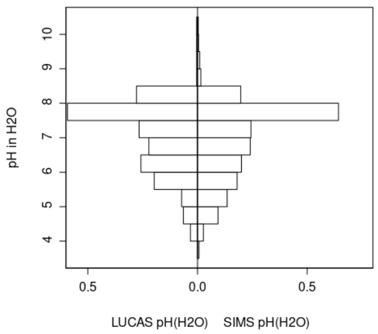
The two datasets represent the different CLC2018 categories in almost the same ratio, despite having different spatial distributions and sample sizes.

Approach No1: Comparison based on the distribution of the data

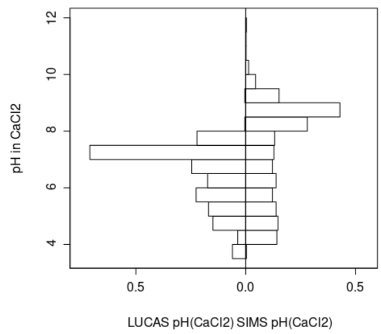
After transforming the soil data of the SIMS into the units, methods and soil depth used in the LUCAS dataset, we plotted the soil properties of the datasets on back-to-back histograms. Then we applied the Kolmogorov-Smirnov test to examine whether samples from SIMS and the Hungarian subset of the LUCAS represent the same population (i.e., whether they were drawn from the same population). The analysis was performed with the *ks.test* function of the *dgofR* package (Taylor and John, 2011). The values are calculated based on the equations of Marsaglia et al.(2003), and according to it " If ***y*** is numeric, a two-sample test of the null hypothesis that ***x*** and ***y*** were drawn from the same continuous distribution is performed".

Results

The Kolmogorov-Smirnov tests' outputs were assessed at a significance level of 0.05. It was revealed that the samples from SIMS and LUCAS represents the same population for each soil property of interest at a significance level of 0.05 (Figure-3.). However, we should note that the visual interpretation of the back-to-back histograms sometimes refutes it and indicates that the distributions can differ from each other in some cases (e.g., pH($CaCl_2$)). Therefore, we suggest the evaluation should not rely only on the Kolmogorov-Smirnov test but on the visual interpretation of the back-to-back histograms as well.



D = 0.286, p-value = 0.617



D = 0.353, p-value = 0.240

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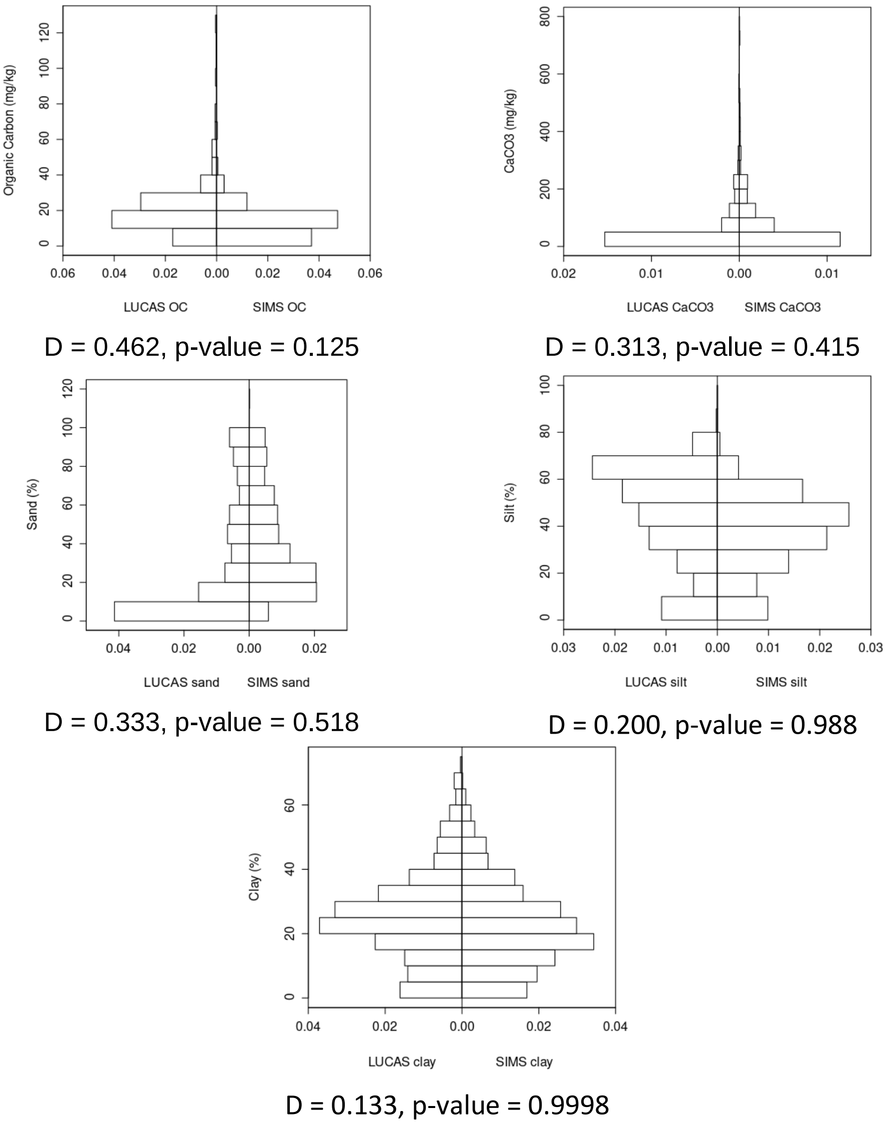

Figure-3. Back-to-back histograms and results of the Kolmogorov-Smirnov test for the comparison of LUCAS Topsoil dataset's Hungarian subset (LUCAS) and the Hungarian Soil Information Monitoring System for pH in H_2O, $CaCl_2$, organic carbon, $CaCO_3$ and sand, silt and clay content.

Approach No2: Comparison by land cover categories

We assigned the mean values of the selected soil properties (pH in H_2O and $CaCl_2$, organic carbon, carbonates, sand, silt and clay content) to each CLC2018 category at two different aggregation levels, namely Level1 and Level3.

Results based on aggregation atLevel1 (less detailed, more aggregated)

Data were aggregated according to the first digit as Artificial surfaces, Agricultural areas, Forest and seminatural areas, Wetlands and Water bodies. Figure-4 shows the relationship between LUCAS and SIMS in case of the mean values of soil properties computed by land use categories (CLC2018) at Level 1.

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For pH in H_2O and $CaCl_2$ and silt content the correlation between the LUCAS and SIMS dataset is weak having R^2 value of 0.301, 0.153 and 0.521 respectively. There is a strong positive linear correlation between the LUCAS and SIMS dataset regarding organic carbon, $CaCO_3$, sand and clay content having R^2 value of 0.908, 0.880, 0.802 and 0.961, when aggregated to CLC level 1 categories.

Results based on aggregation atLevel3 (more detailed, less aggregated)

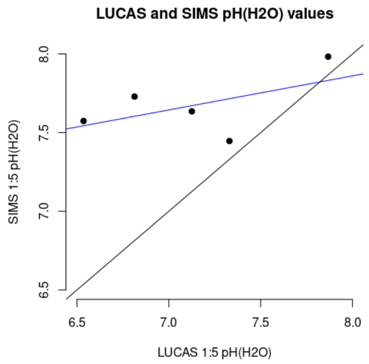
Figure-5 shows the relationship between LUCAS and SIMS in case of the mean values of soil properties computed by land use categories (CLC2018) at Level 3.When soil data was aggregated at Level 3 of the CLC2018 no relationship could be detected between LUCAS and SIMS in case of pH in $CaCl_2$, $CaCO_3$, silt and clay content. For pH in H_2O, organic carbon content and sand content there is a weak linear relationship with R^2 of 0.137, 0.498 and 0.144, respectively.

The comparability of the most detailed, least aggregated versions is weak (Aggregated for Level3). Here the thematic resolution was the highest and the number of samples within each unit was relatively small. The comparison by the least detailed land use categories (Aggregated for Level1) shows better results. The degree of aggregation and the number of samples per unit were the highest in this case. We should note that the aggregation process in case of pH values (derived from the decimal logarithm) with a simple average can give contradictory results (compare the back-to-back diagram for pH in H_2O and its aggregated version).

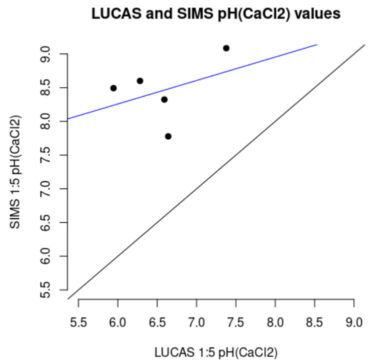
Conclusions

Based on the Kolmogorov-Smirnov test we can conclude that the Hungarian subset of the LUCAS Topsoil dataset and the data of the Hungarian Soil Information and Monitoring System come from the same population based on the particle size distribution, organic carbon and carbonate content, pH in H_2O and $CaCl_2$.

Possibility for more detailed analysis of the relationship between LUCAS and Hungarian Soil Information and Monitoring System by land use categories is limited. It is important to highlight that sampling strategy – in terms of sampling depth and selecting sampling location – used by the SIMS and LUCAS Topsoil database differs, which obviously influence under or over representation of certain soil types or characteristics during the comparison of the two dataset which leads to weak relationship between the datasets based on the mean soil properties computed by land cover categories. Further to that the harmonization of pH values between the LUCAS and the SIMS dataset might be limited due to the lack of direct transfer functions between the methodologies used in the LUCAS and SIMS dataset trained on soil types which are characteristic for Hungary.



R^2= 0.301



R^2= 0.153

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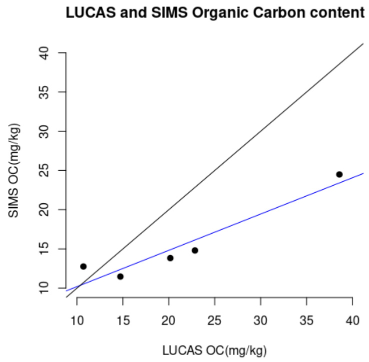
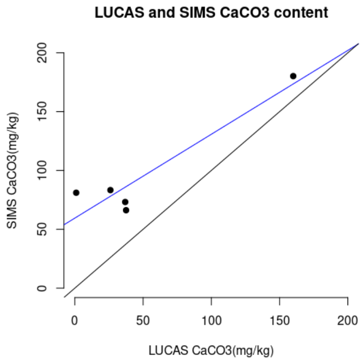
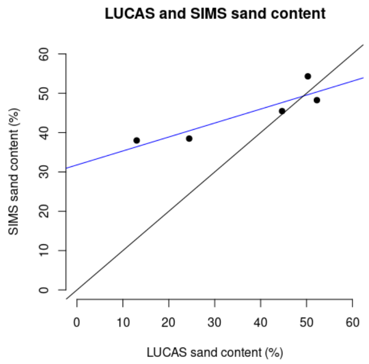


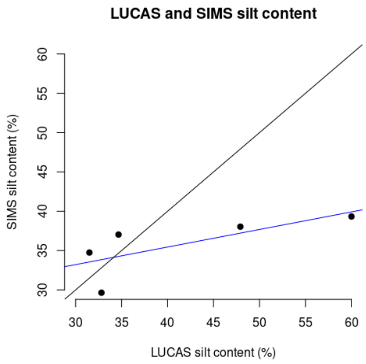
R^2= 0.908



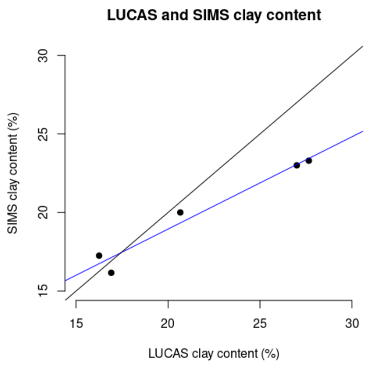
R^2= 0.880



R^2=0.802

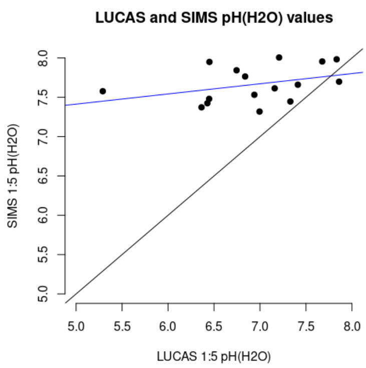


R^2=0.521

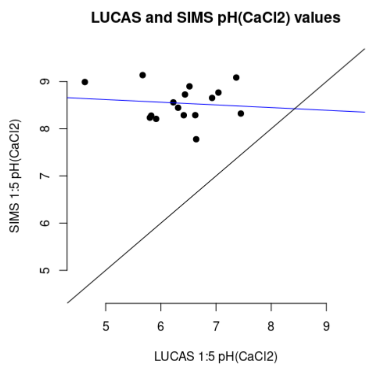


R^2= 0.961

Figure-4. Scatterplot of LUCAS Topsoil dataset's Hungarian subset (LUCAS) vs. the Hungarian Soil Monitoring Soil System (SIMS) for pH in H_2O and $CaCl_2$, organic carbon, $CaCO_3$, sand, silt and clay content data aggregated by CORINE land cover categories at Level 1.



R^2= 0.137



R^2= 0.011

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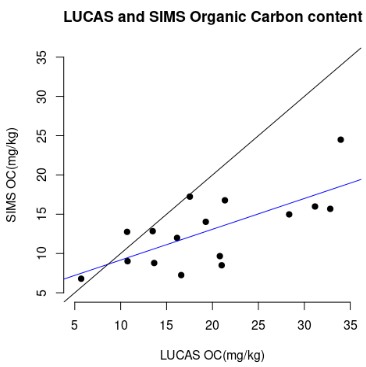
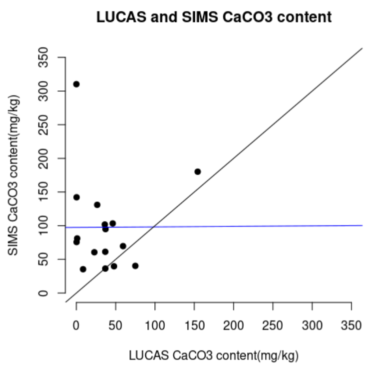
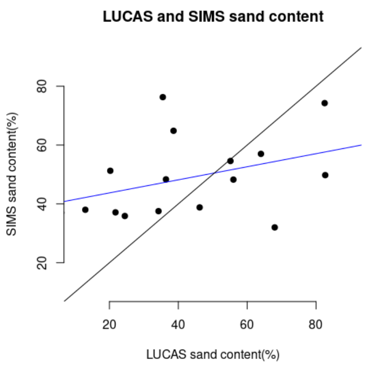


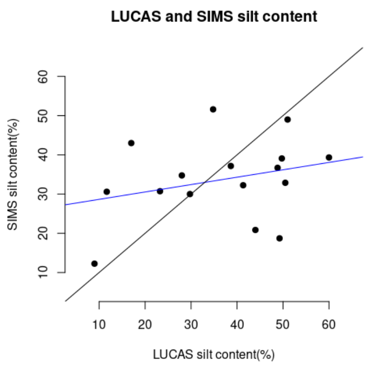
R^2= 0.498



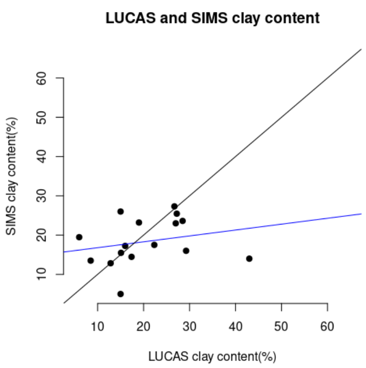
R^2= 0.00



R^2= 0.144



R^2= 0.079



R^2= 0.054

Figure-5. Scatterplot of LUCAS Topsoil dataset's Hungarian subset (LUCAS) vs. the Hungarian Soil Monitoring Soil System (SIMS) for pH in H_2O and $CaCl_2$, organic carbon, $CaCO_3$, sand, silt and clay content data aggregated by CORINE land cover categories at Level 3.

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7.2.2. Comparison of RMQS and LUCAS datasets – French case study

Manon Caubet, Nicolas Saby and Antonio Bispo – (INRAE)

January/April 2021

Harmonization of units

We have converted the variables into the same unit

- LUCAS size fraction [g/100g] * 10 –> [g/kg]
- "K" and "P" in LUCAS dataset are not the total content, thus we could not compare with RMQS values.
- "OC", "CaCO3", and "N" are in [g/kg] in both datasets
- pH has no unit

We checked in the technical LUCAS report that the particle size fraction analysed is the same than RMQS: sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm)

Summary statistics for the following elements for LUCAS and RMQS

- Coarse element (%)
- Clay - Sand - Silt (g/kg)
- pH_H20
- OC (g/kg)
- CaCO3 (g/kg)
- P (mg/kg)
- N (g/kg)
- K (mg/kg)

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LUCAS dataset:

```
##      Coarse          Clay            Sand            Silt
##  Min.   : 0.00   Min.   : 20.0   Min.   : 10.0   Min.   : 10.0
##  1st Qu.: 7.00   1st Qu.:140.0   1st Qu.:130.0   1st Qu.:350.0
##  Median :13.00   Median :200.0   Median :250.0   Median :480.0
##  Mean   :16.48   Mean   :223.1   Mean   :298.3   Mean   :478.5
##  3rd Qu.:23.00   3rd Qu.:290.0   3rd Qu.:440.0   3rd Qu.:600.0
##  Max.   :86.00   Max.   :770.0   Max.   :960.0   Max.   :880.0
##                  NA's   :6       NA's   :6       NA's   :6
##      pH_H20            OC             CaCO3               P
##  Min.   :3.590   Min.   :  0.9   Min.   :  0.00   Min.   :  0.00
##  1st Qu.:5.390   1st Qu.: 13.2   1st Qu.:  0.00   1st Qu.: 18.10
##  Median :6.310   Median : 21.9   Median :  1.00   Median : 31.00
##  Mean   :6.323   Mean   : 33.5   Mean   : 64.92   Mean   : 36.26
##  3rd Qu.:7.420   3rd Qu.: 38.6   3rd Qu.: 23.75   3rd Qu.: 47.50
##  Max.   :9.070   Max.   :494.1   Max.   :976.00   Max.   :697.30
##
##        N                 K
##  Min.   : 0.000   Min.   :   4.3
##  1st Qu.: 1.600   1st Qu.: 113.5
##  Median : 2.400   Median : 180.1
##  Mean   : 3.169   Mean   : 225.7
##  3rd Qu.: 3.800   3rd Qu.: 281.8
##  Max.   :29.900   Max.   :1843.9
##
```

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RMQS dataset:

- P total (g/100g)
- K total (g/100g)

```
##       Clay            Sand            Silt            pH_H20
##  Min.   :  2.0   Min.   :  7.0   Min.   :  2.0   Min.   :3.68
##  1st Qu.:151.0   1st Qu.:158.0   1st Qu.:274.0   1st Qu.:5.40
##  Median :209.0   Median :303.0   Median :401.0   Median :6.20
##  Mean   :244.1   Mean   :352.6   Mean   :403.4   Mean   :6.41
##  3rd Qu.:319.0   3rd Qu.:522.0   3rd Qu.:535.0   3rd Qu.:7.80
##  Max.   :815.0   Max.   :986.0   Max.   :819.0   Max.   :9.20
##
##        OC              n_tot             p_tot              k_tot
##  Min.   :  0.59   Min.   : 0.030   Min.   :0.0005   Min.   :0.020
##  1st Qu.: 13.15   1st Qu.: 1.150   1st Qu.:0.1050   1st Qu.:1.040
##  Median : 19.60   Median : 1.730   Median :0.1550   Median :1.450
##  Mean   : 25.59   Mean   : 2.142   Mean   :0.1766   Mean   :1.606
##  3rd Qu.: 30.40   3rd Qu.: 2.660   3rd Qu.:0.2180   3rd Qu.:2.020
##  Max.   :243.00   Max.   :16.000   Max.   :1.1100   Max.   :5.400
##                                    NA's   :14
```

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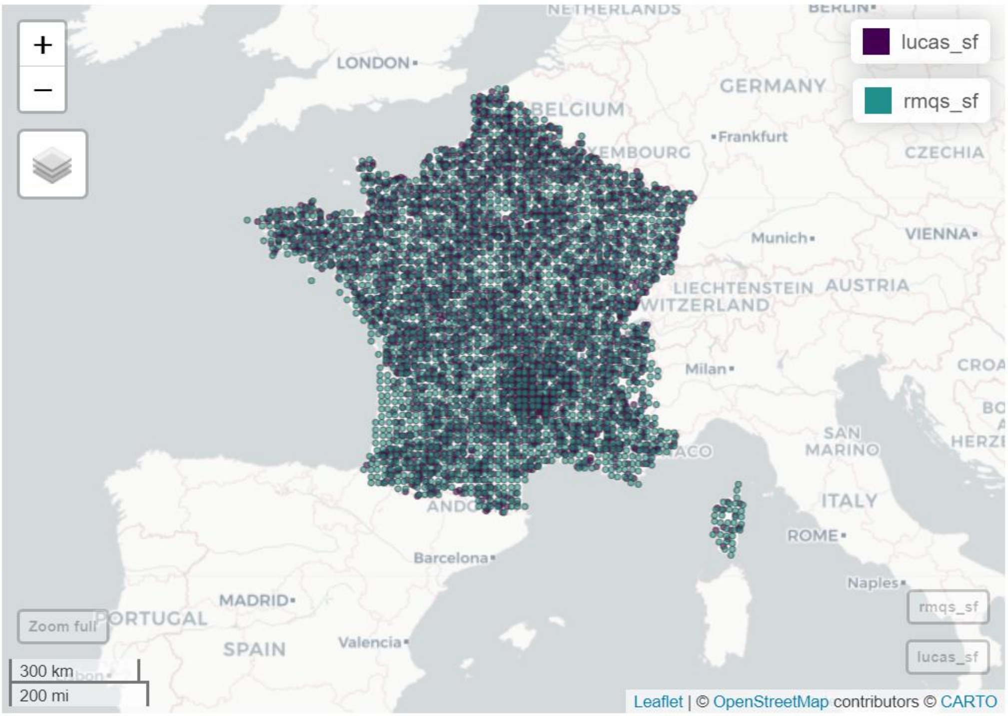
Number of points

RMQS (France and Corsica) : 2144

LUCAS (France and Corsica) : 3050

Spatial distribution of points



Land cover classification

We grouped Land Cover classes of RMQS dataset to obtain the same classification as LUCAS dataset. Here we compare the number of sites in each Land Cover classes. The distribution of land uses and of the points (see map) are not the same. There are areas without LUCAS points.

Land Cover	nb.LUCAS	%	nb.RMQS	%
Artificial land	6	0,2%	6	0,3%
Bareland	54	1,8%	3	0,1%
Cropland	1581	51,8%	937	43,7%
Grassland	785	25,7%	521	24,3%
Shrubland	71	2,3%	88	4,1%
Water	2	0,1%	0	0,0%
Wetlands	2	0,1%	8	0,4%
Woodland	549	18,0%	581	27,1%
	3050		2144	

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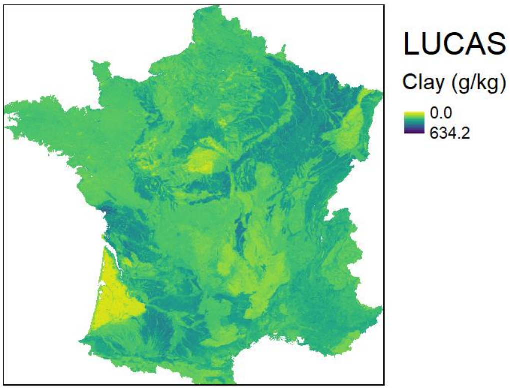
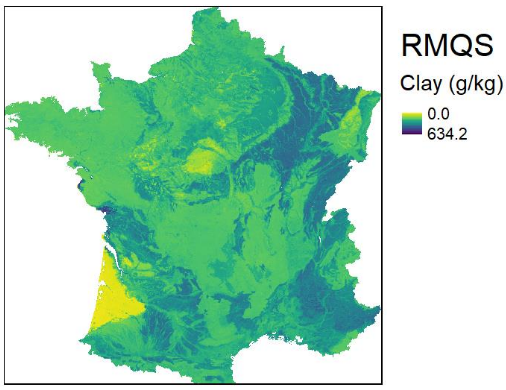
Spatial predictions

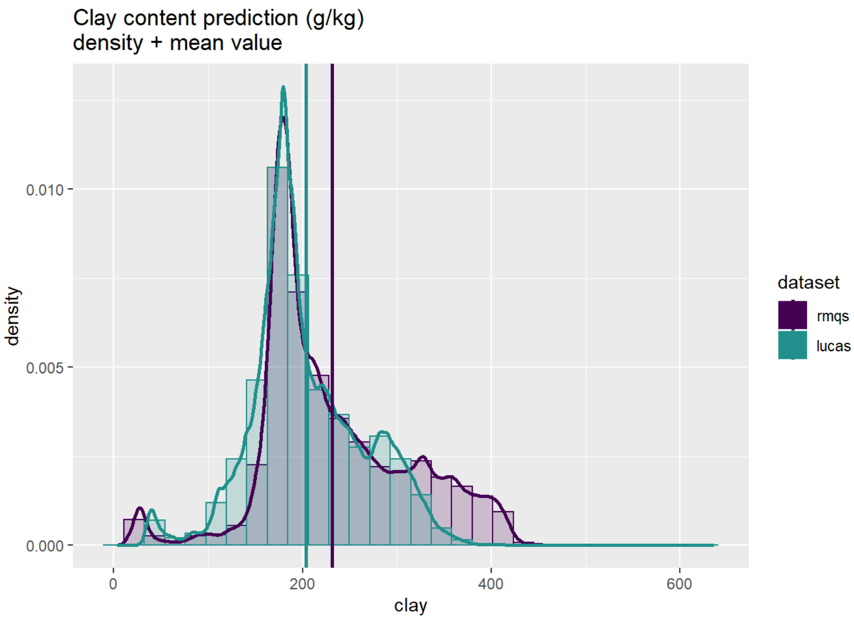
In order to compare LUCAS and RMQS datasets in France, we built maps of Clay, and OC from each dataset. We fitted a QRF using a 10-fold cross validation, a set of environmental covariates was added to the model (as soil type, parent material, NDVI, land cover, climate …)

At each iteration, a prediction map of the target variable is built and validated using the 1/10 validation set. The final results were obtained by calculating the mean prediction and the mean validation indicators over the 10 iterations.

Plot predictions







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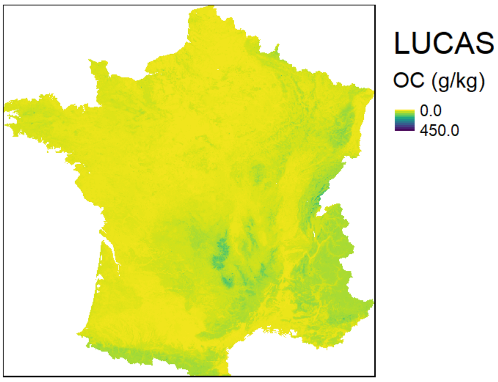

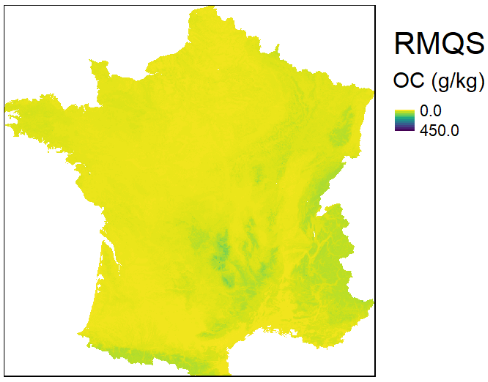

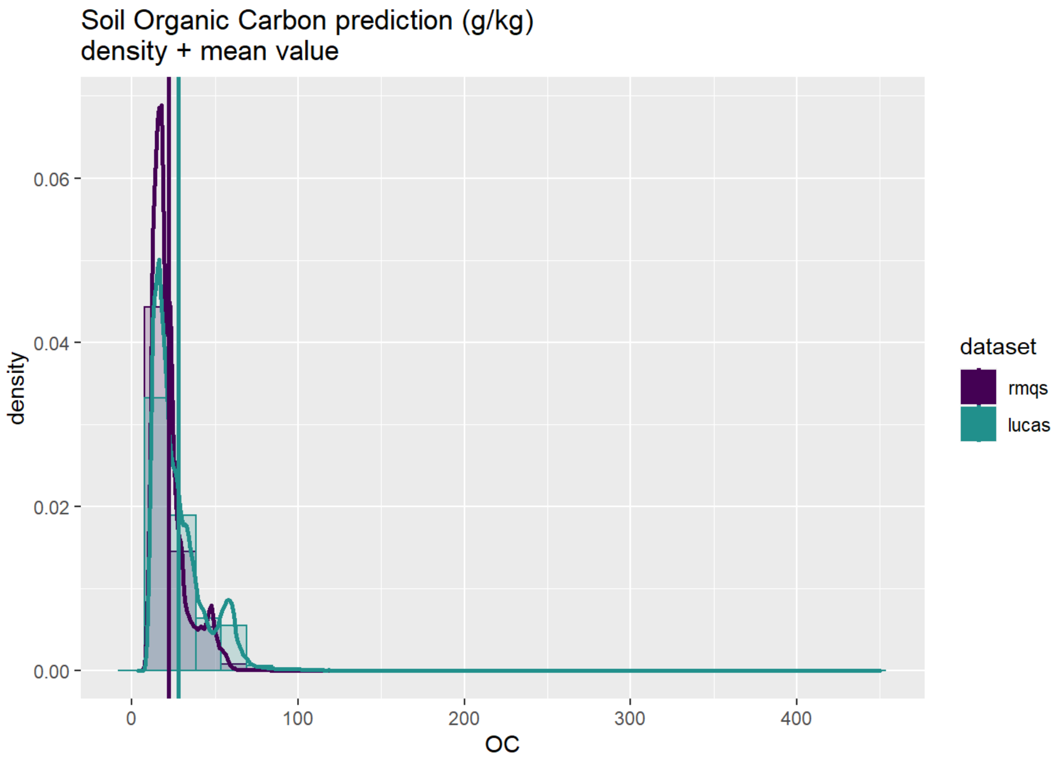

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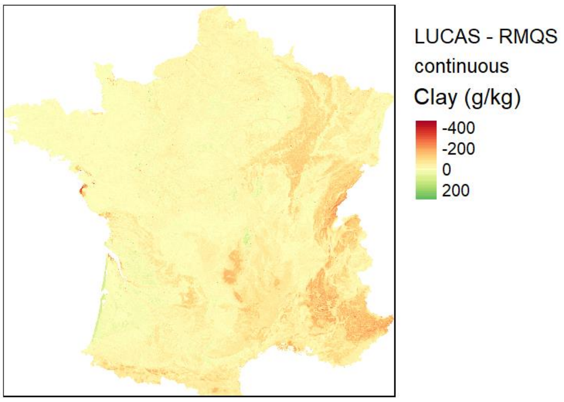
Plot the differences between maps

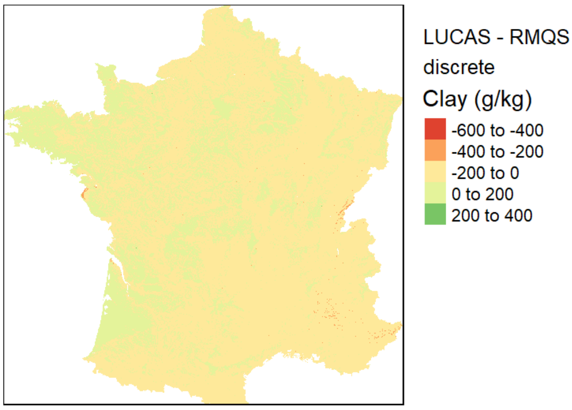
Here we plot the map of the difference: “LUCAS - RMQS” to identify the regions with the highest difference between the 2 prediction maps.

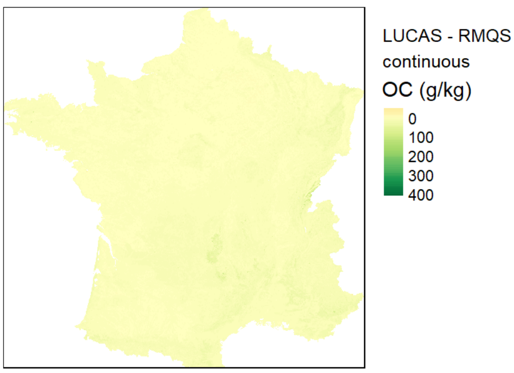
LEFT map: continuous scale
RIGHT map: discrete scale

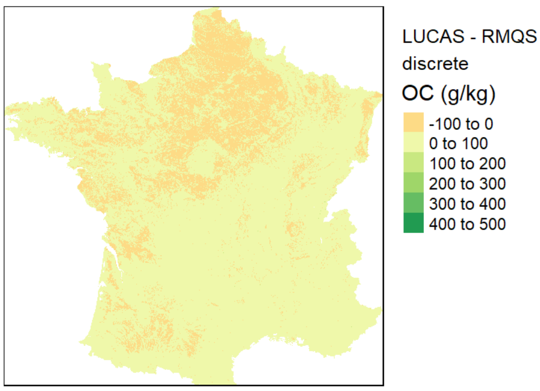
For Clay: LUCAS map is more ‘smooth’, clay predictions are higher than RMQS in Sandy soils and lower in clayey soils.

For SOC: globally, LUCAS map predictions are higher than RMQS predictions, errors are > 0, but are small.









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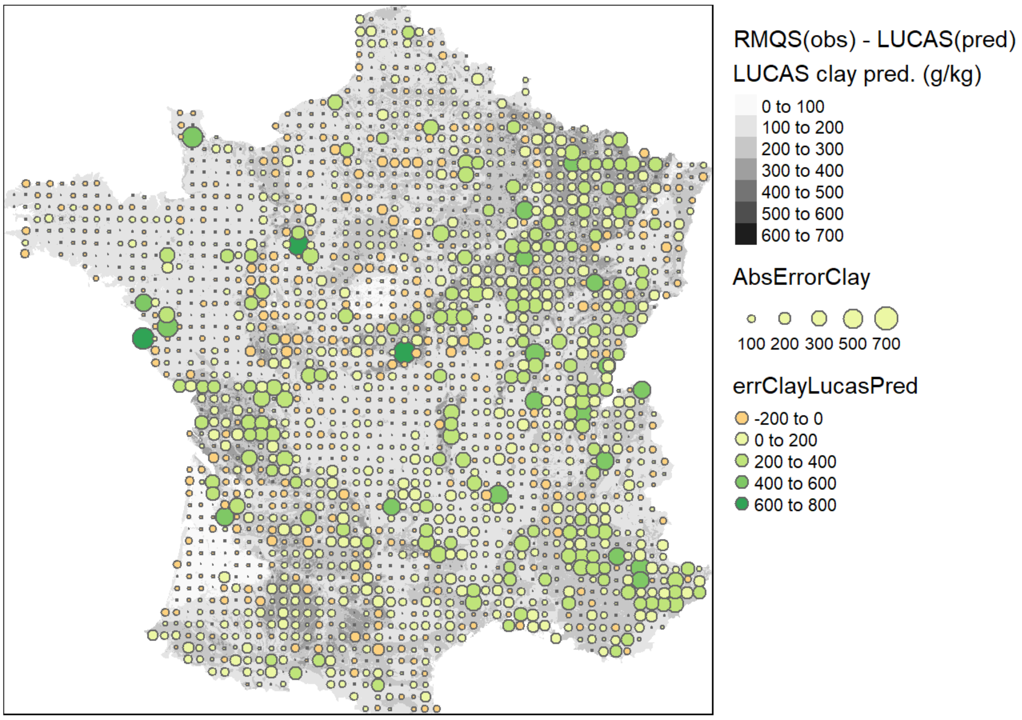
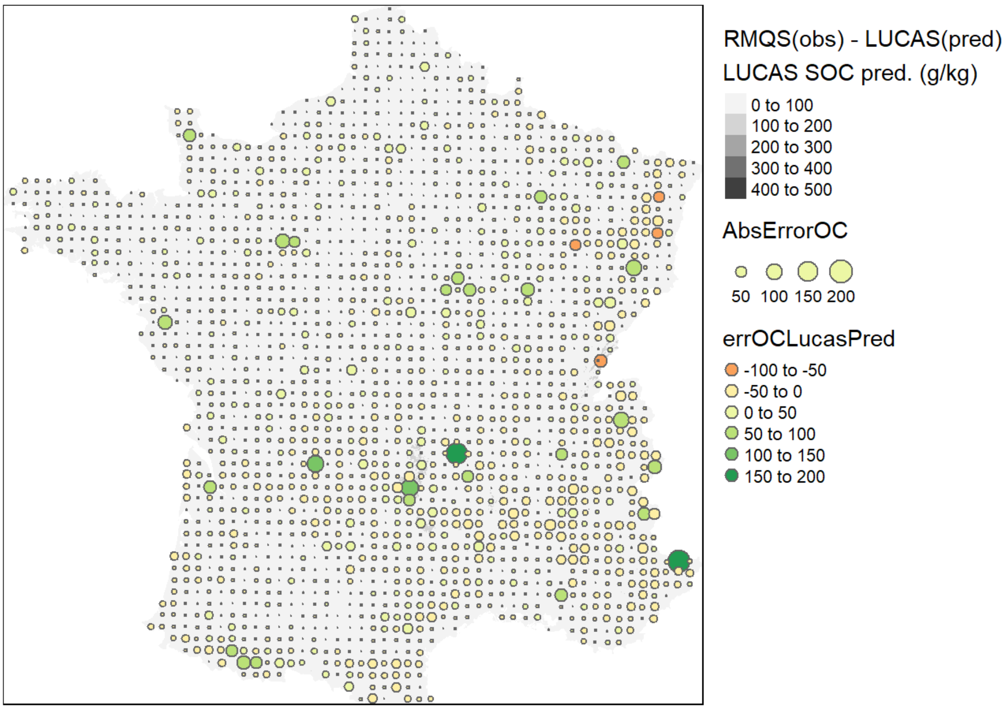
Map: Error of LUCAS maps at RMQS points

In red/orange : LUCAS over-estimates Clay content
In green/yellow : LUCAS under-estimates Clay content



In red/orange : LUCAS over-estimates SOC
In green/yellow : LUCAS under-estimates SOC



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Evaluation of output maps

These results correspond to the mean of validation indicators over the 10 replications.
The validation indicators are quite similar within the replications.

Mean validation indicators

Map	RMSE	R2	ME	Concordance	PICP90
OC LUCAS	0.538	0.524	-0.025	0.671	92.235
OC RMQS	0.459	0.482	-0.024	0.620	92.491
Clay LUCAS	0.406	0.395	0.021	0.536	93.642
Clay RMQS	0.434	0.541	0.023	0.669	93.356

One question was: May be the overestimation of SOC by LUCAS due to the remaining litter in soil samples. It is written in the protocol: “Before collecting the subsamples, stones (>6 cm) (FAO, 2006), vegetation residues, grass and litter were removed from soil surface by raking with the spade.”. But in this study : “However, some improvements are needed in the control of sampling depth and the accuracy of litter removal in woodland, where many soil properties (especially OC) change rapidly with depth.”

Another difference may be the sampling depths that differs from LUCAS to RMQS.

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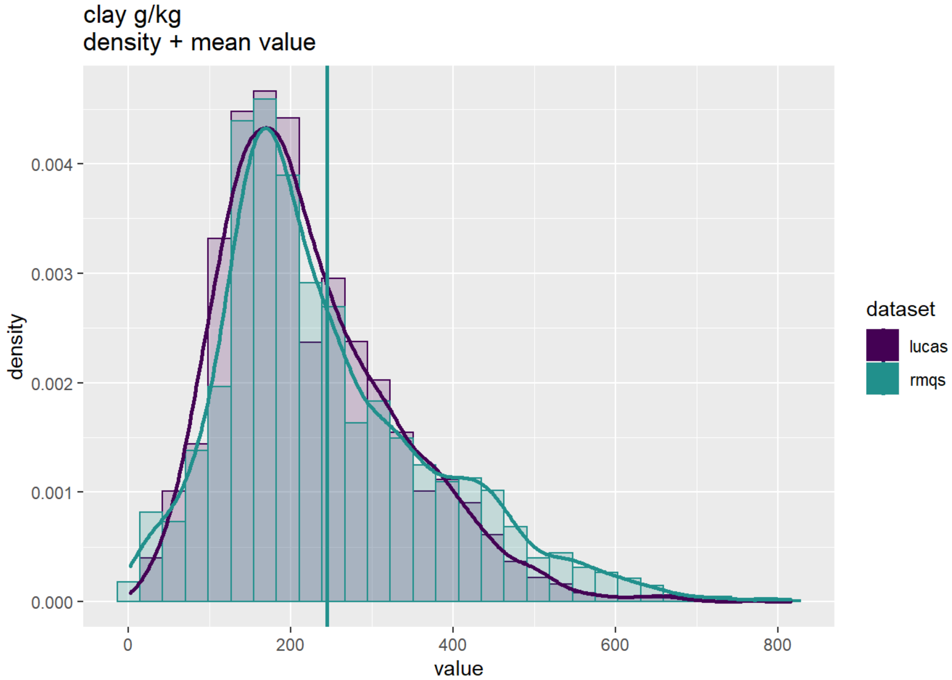
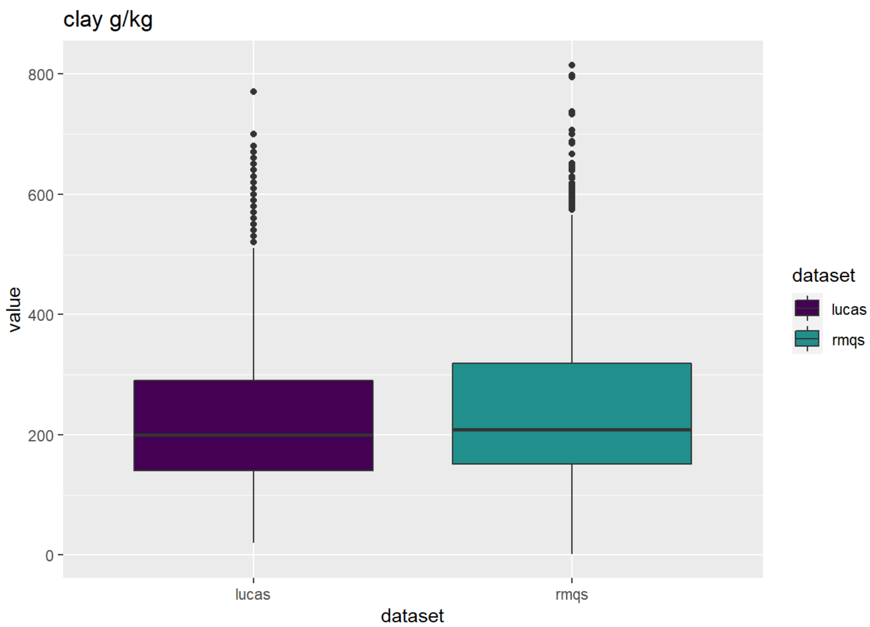
Comparison of variables

Comparison of variables - Clay

Histogramme



Boxplot



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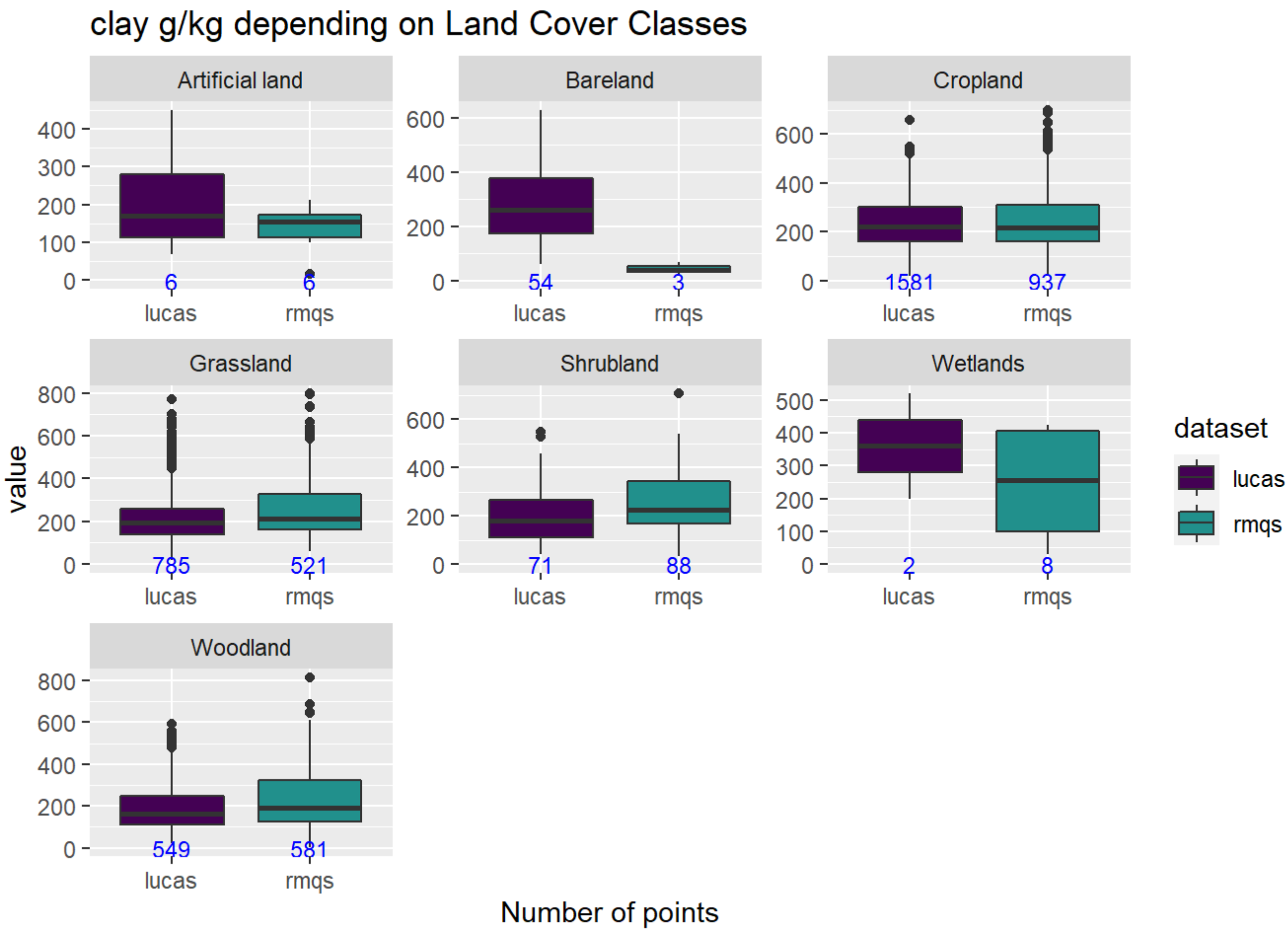
Boxplot by land cover classes



Statistics

Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	20	140	200	223.11	290	770	3044
rmqs	2	151	209	244.07	319	815	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	70	112.5	170	211.7	280.0	450	6
Bareland	60	172.5	260	278.1	377.5	630	54
Cropland	20	160.0	220	235.9	300.0	660	1581
Grassland	20	140.0	195	216.8	260.0	770	782
Shrubland	40	110.0	180	200.3	265.0	550	71
Water	100	145.0	190	190.0	235.0	280	2
Wetlands	200	280.0	360	360.0	440.0	520	2
Woodland	20	110.0	165	192.6	250.0	590	546

RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	16	113.2	154.5	135.8	172.5	212	6
Bareland	24	30.5	37.0	43.0	52.5	68	3
Cropland	19	159.0	217.0	244.6	310.0	700	937
Grassland	62	162.0	214.0	261.9	330.0	798	521
Shrubland	33	167.0	227.0	255.2	343.5	707	88
Wetlands	29	97.8	255.0	247.0	406.8	425	8
Woodland	2	126.0	189.0	227.9	325.0	815	581

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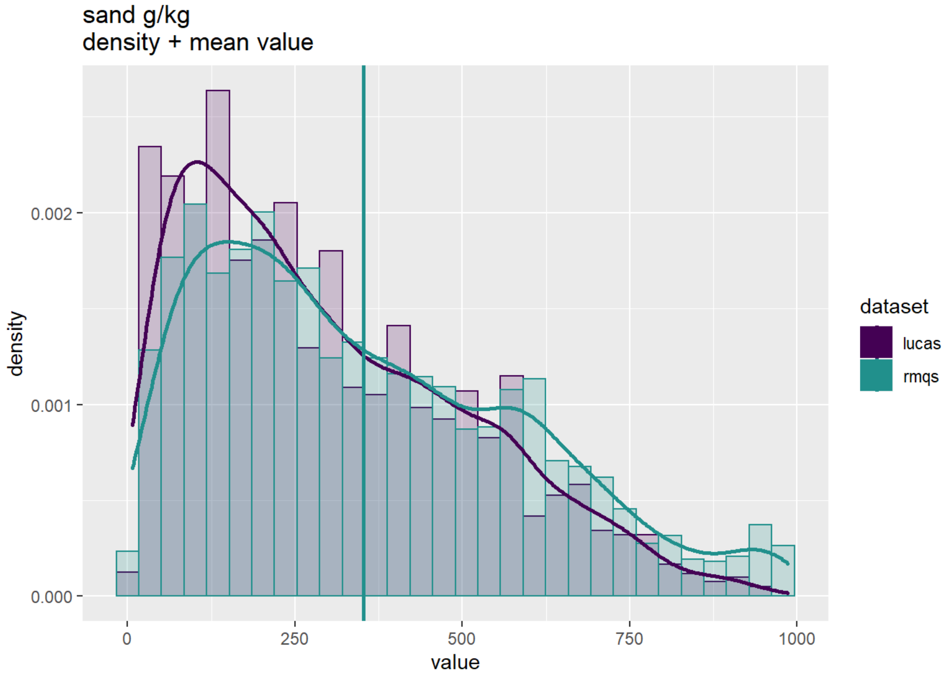
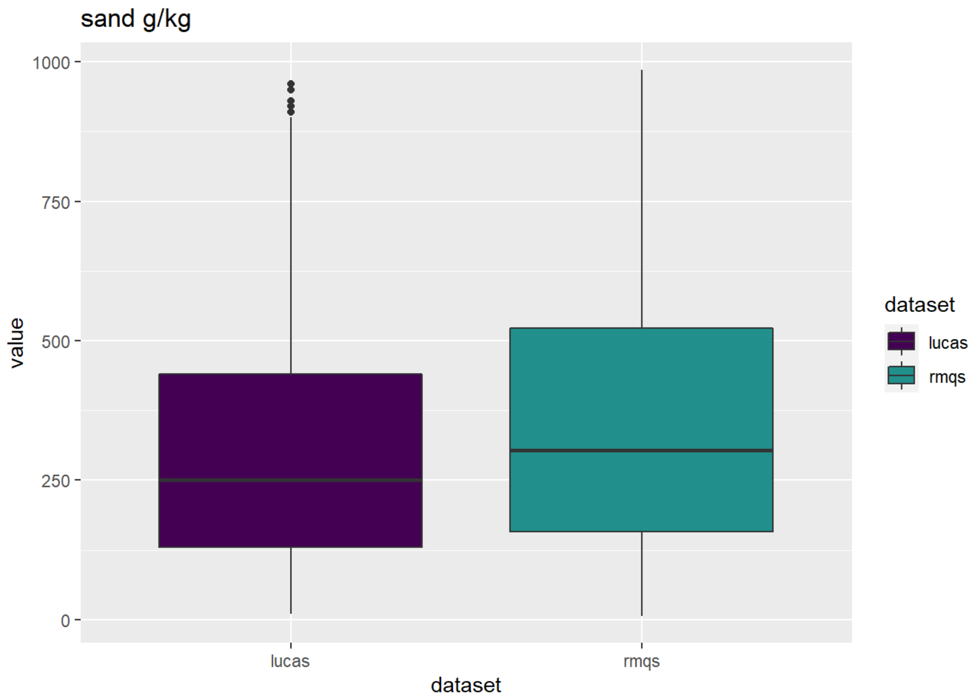
Comparison of variables - Sand

Histogramme

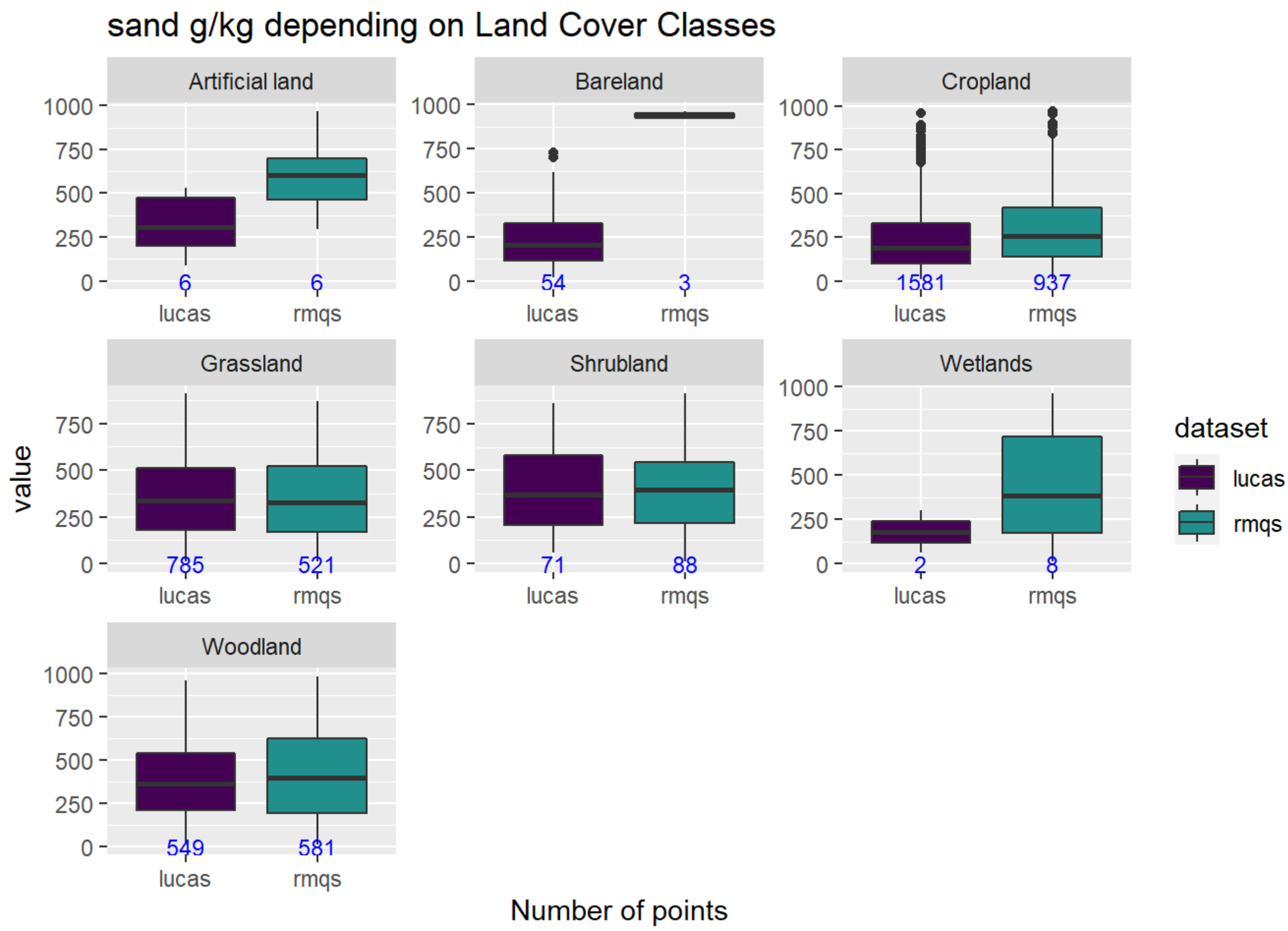


Boxplot



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Boxplot by land cover classes



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Statistics
Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	10	130	250	298.30	440	960	3044
rmqs	7	158	303	352.64	522	986	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	90	197.5	305	320.0	472.5	530	6
Bareland	20	112.5	205	249.8	330.0	730	54
Cropland	10	100.0	190	241.3	330.0	960	1581
Grassland	10	180.0	340	349.7	510.0	910	782
Shrubland	60	205.0	370	388.9	580.0	860	71
Water	60	205.0	350	350.0	495.0	640	2
Wetlands	60	120.0	180	180.0	240.0	300	2
Woodland	10	210.0	365	382.7	540.0	960	546

RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	294	463	604.5	602.8	698.0	969	6
Bareland	923	930	937.0	941.7	951.0	965	3
Cropland	7	141	257.0	302.8	420.0	971	937
Grassland	9	169	329.0	347.9	521.0	867	521
Shrubland	13	216	396.5	387.3	543.5	913	88
Wetlands	12	172	387.0	440.9	719.8	962	8
Woodland	11	194	395.0	424.2	626.0	986	581

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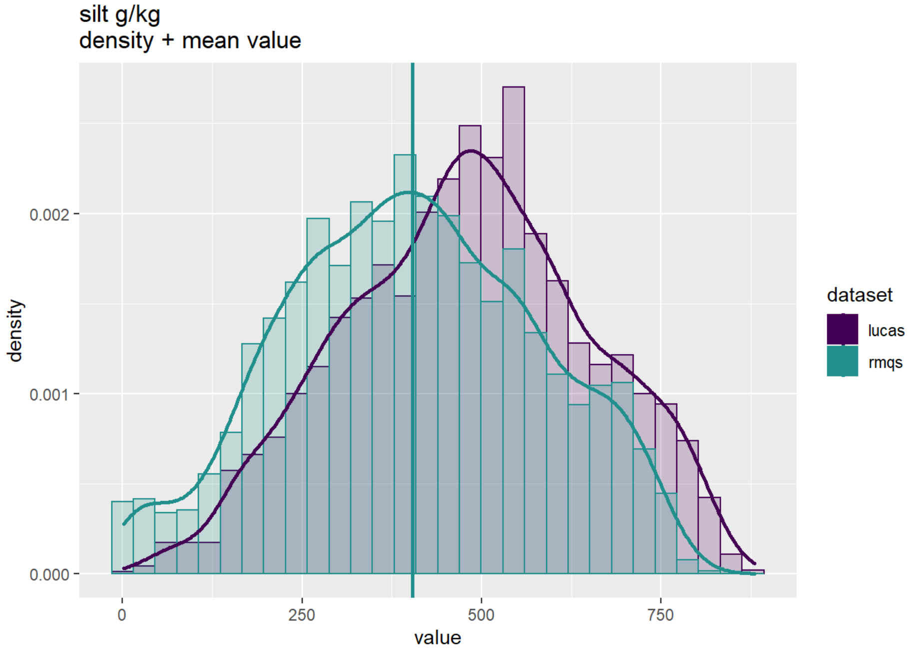
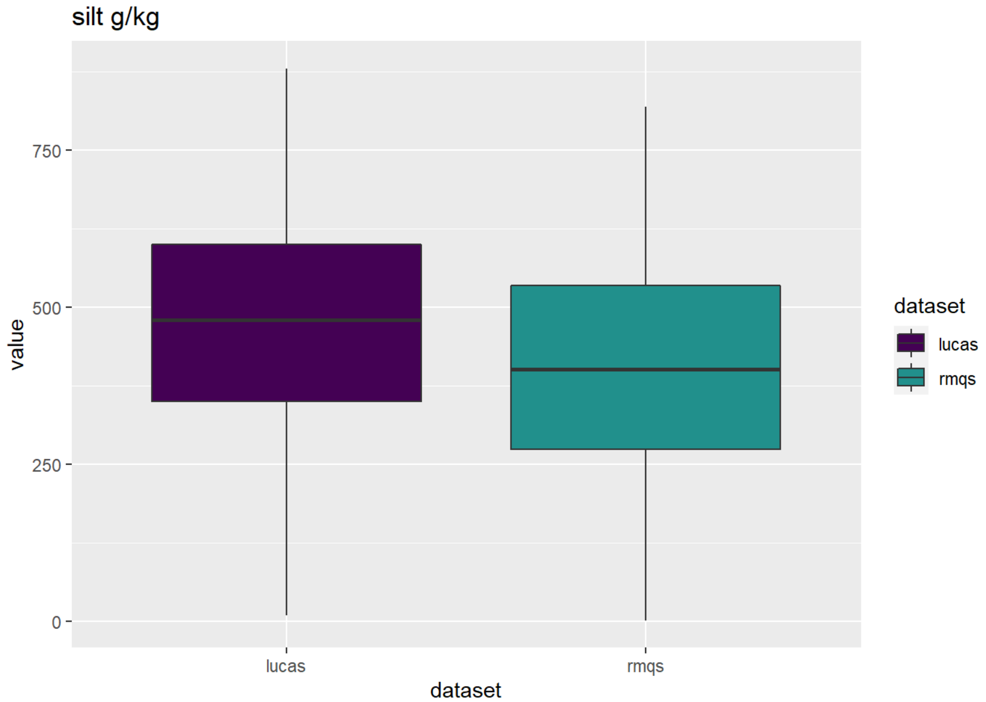
Comparison of variables - Silt

Histogramme



Boxplot



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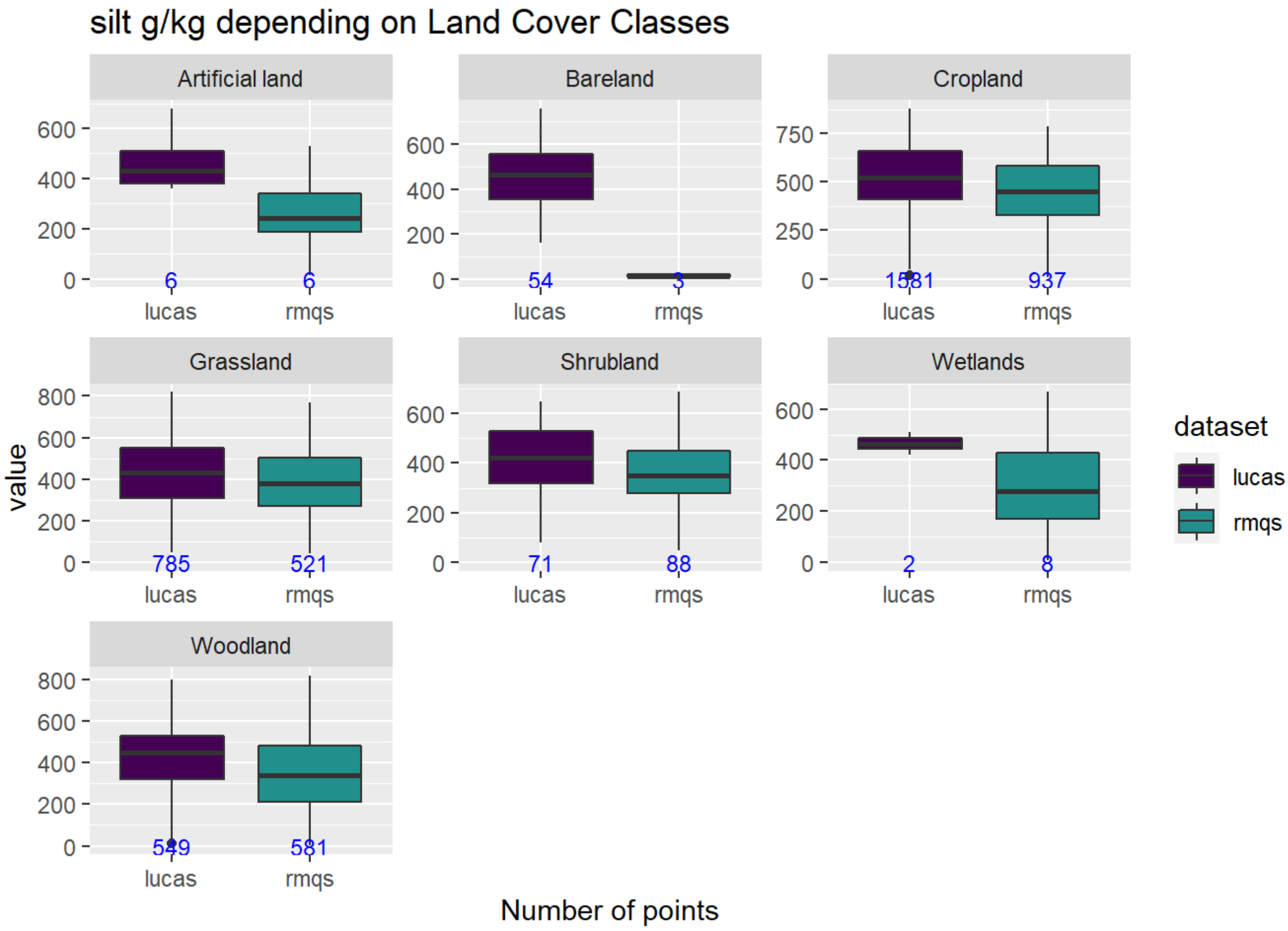
Boxplot by land cover classes



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Statistics

Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	10	350	480	478.47	600	880	3044
rmqs	2	274	401	403.38	535	819	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	360	380.0	430	466.7	510.0	680	6
Bareland	160	352.5	465	472.4	557.5	760	54
Cropland	20	410.0	520	522.7	660.0	880	1581
Grassland	50	310.0	430	433.5	550.0	820	782
Shrubland	80	320.0	420	410.8	530.0	650	71
Water	270	367.5	465	465.0	562.5	660	2
Wetlands	420	442.5	465	465.0	487.5	510	2
Woodland	10	322.5	450	424.5	530.0	800	546

RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	15	188.8	241	261.3	339.0	528	6
Bareland	9	10.0	11	15.3	18.5	26	3
Cropland	10	331.0	451	452.7	583.0	789	937
Grassland	43	269.0	378	390.2	504.0	767	521
Shrubland	48	276.5	349	357.6	449.5	687	88
Wetlands	9	168.2	279	312.1	430.0	667	8
Woodland	2	211.0	341	348.0	482.0	819	581

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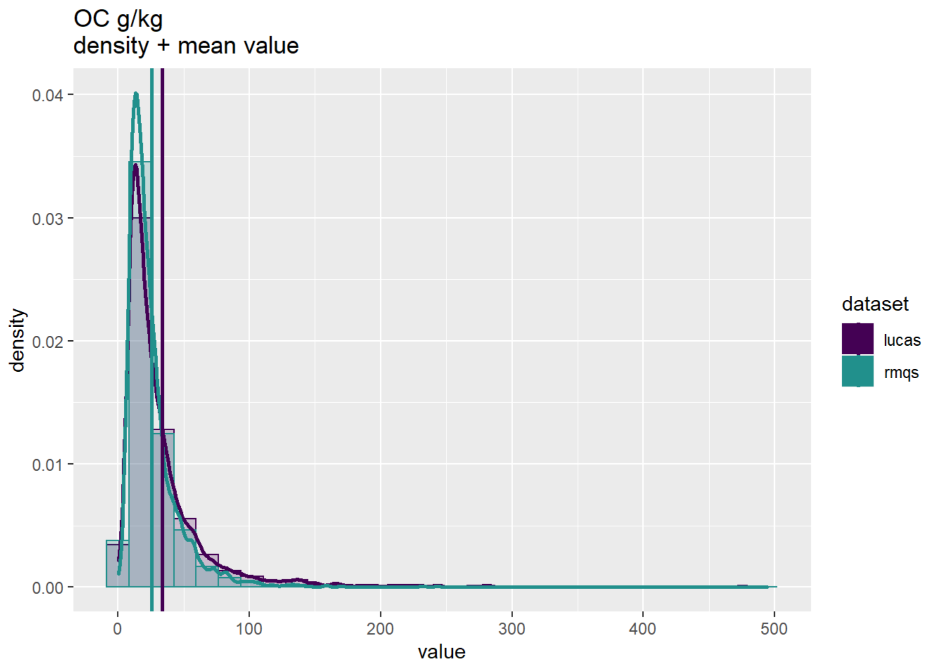
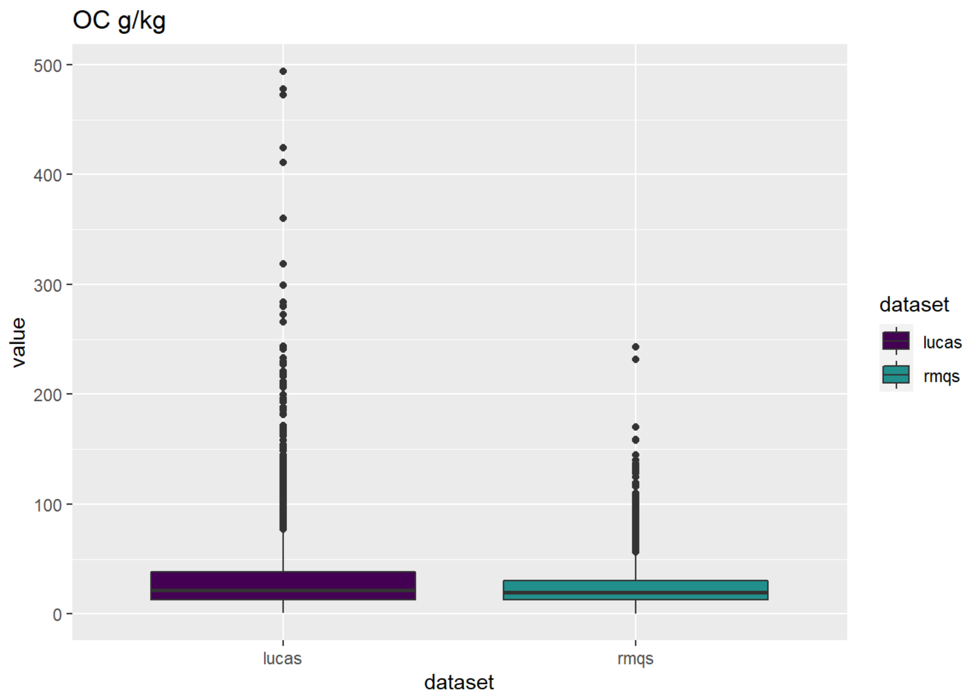
Comparison of variables - OC

Histogramme



Boxplot



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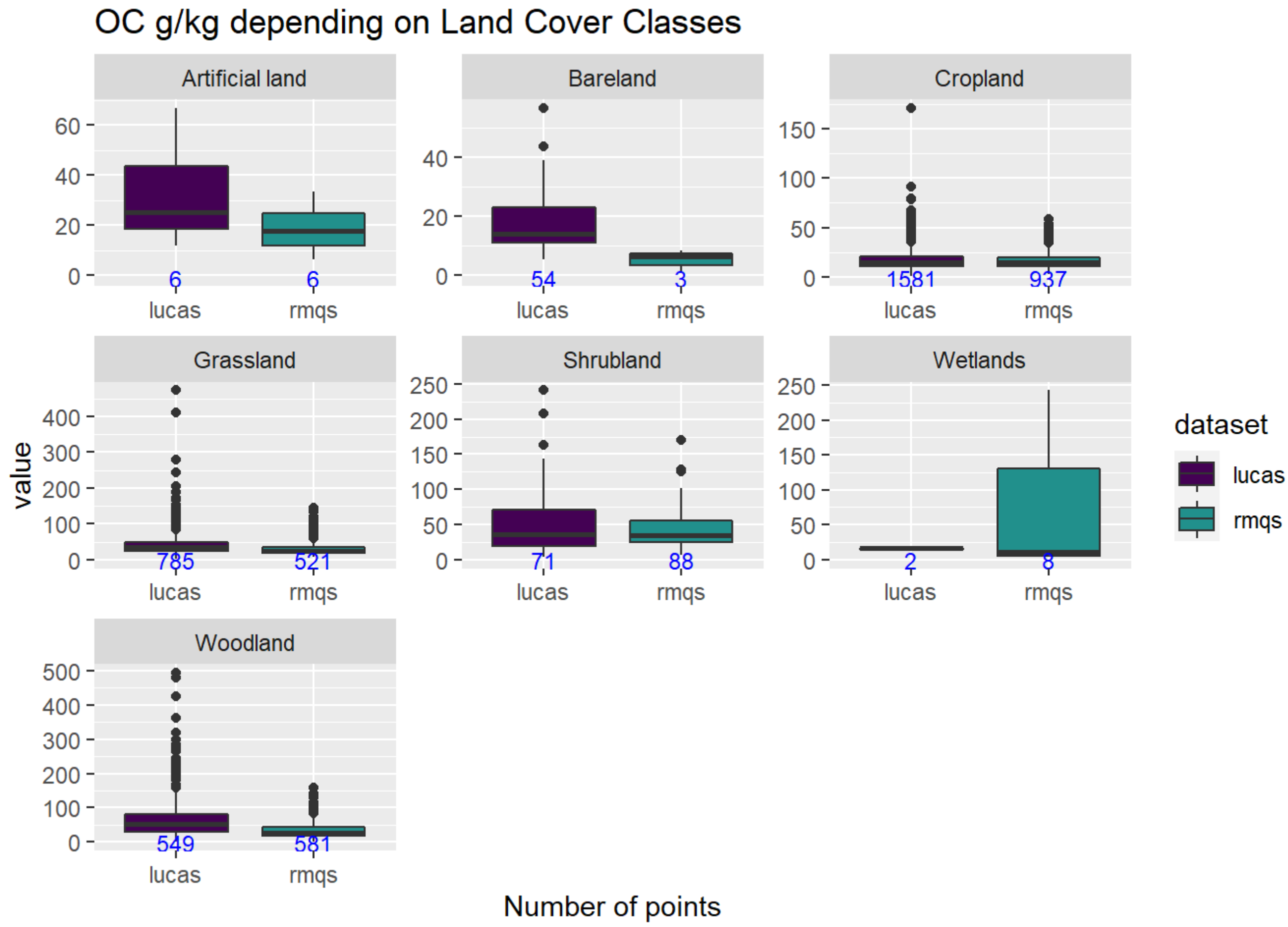
Boxplot by land cover classes



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Statistics

Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	0.90	13.20	21.9	33.50	38.6	494.1	3050
rmqs	0.59	13.15	19.6	25.59	30.4	243.0	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	11.7	18.7	25.1	32.6	43.8	66.9	6
Bareland	5.4	11.1	14.2	18.0	23.0	56.9	54
Cropland	0.9	11.0	14.6	17.1	20.7	171.3	1581
Grassland	2.2	24.7	34.5	42.8	48.2	472.6	785
Shrubland	3.6	19.1	36.4	52.6	71.0	241.3	71
Water	3.7	4.6	5.5	5.5	6.4	7.3	2
Wetlands	15.0	15.6	16.1	16.1	16.7	17.3	2
Woodland	1.0	30.5	51.3	66.6	80.2	494.1	549

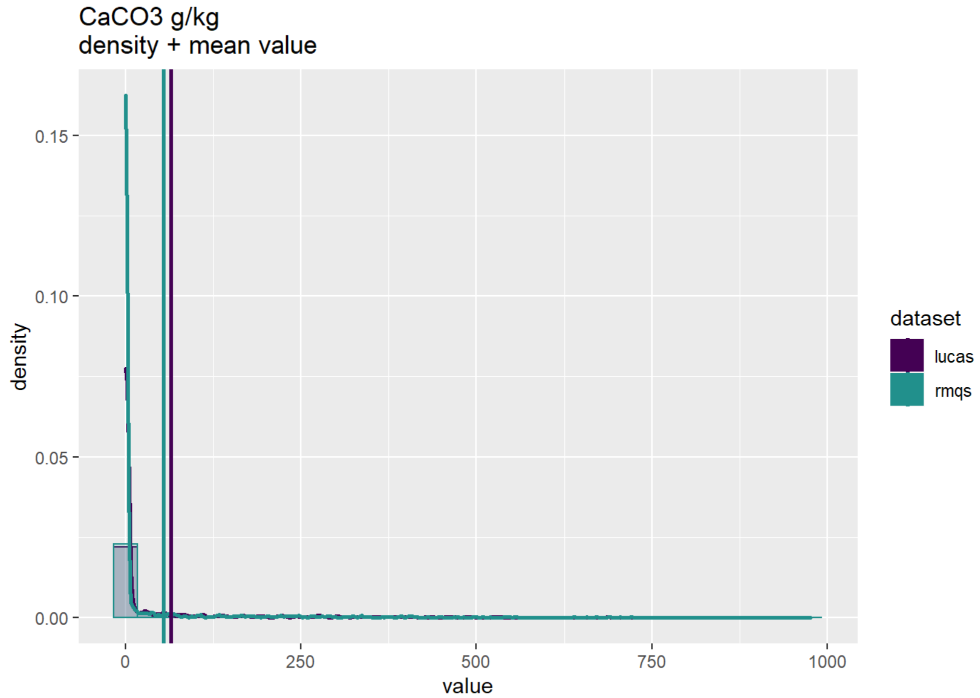
RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	6.5	11.8	17.8	18.7	24.7	33.4	6
Bareland	0.6	3.4	6.2	5.0	7.2	8.2	3
Cropland	2.6	10.4	14.3	16.4	19.9	58.2	937
Grassland	6.8	18.0	25.1	29.4	34.1	145.0	521
Shrubland	6.1	24.6	34.3	43.3	55.8	170.0	88
Wetlands	5.2	5.7	10.0	75.9	129.9	243.0	8
Woodland	1.5	17.4	26.9	33.8	44.5	159.0	581

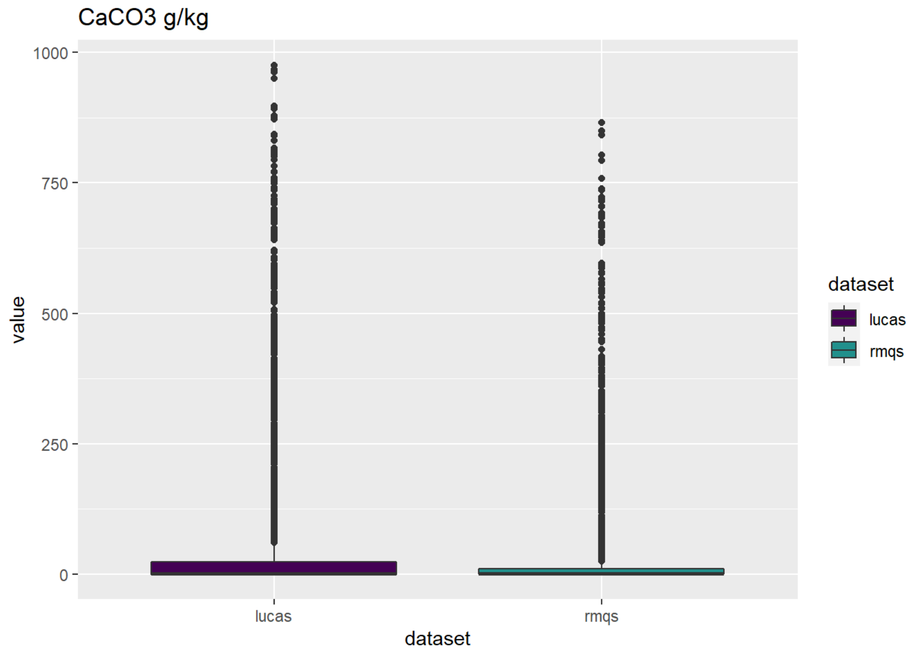
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Comparison of variables - CaCO3

Histogramme



Boxplot



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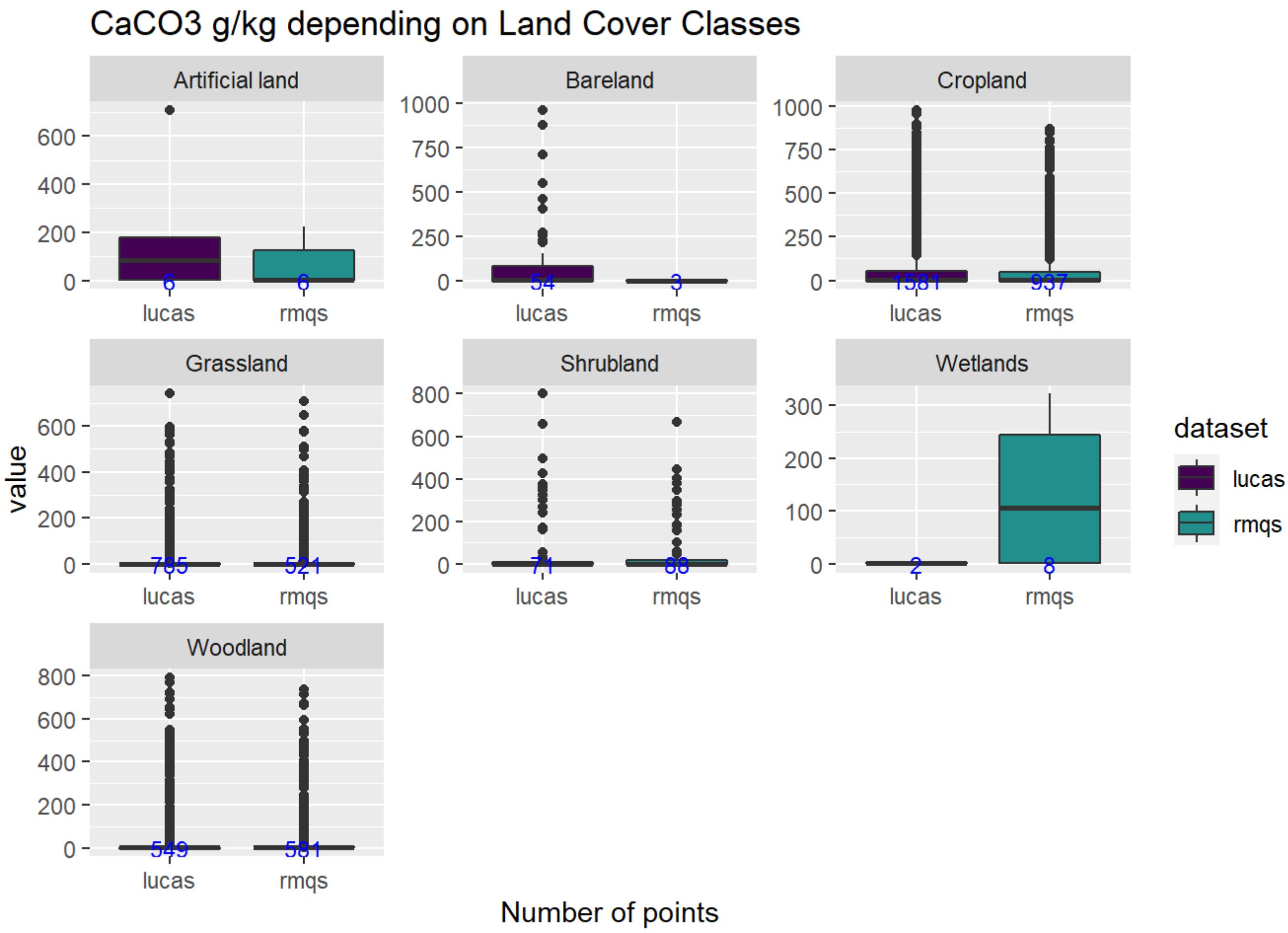
Boxplot by land cover classes



Statistics

Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	0.0	0.0	1.0	64.92	23.75	976	3050
rmqs	0.5	0.5	0.5	53.82	9.70	866	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	0	0.2	83.5	176.5	178.8	709	6
Bareland	0	0.0	1.0	104.3	78.8	962	54
Cropland	0	0.0	1.0	85.3	57.0	976	1581
Grassland	0	0.0	0.0	29.2	1.0	740	785
Shrubland	0	0.0	1.0	72.4	9.0	801	71
Water	341	349.2	357.5	357.5	365.8	374	2
Wetlands	0	1.0	2.0	2.0	3.0	4	2
Woodland	0	0.0	1.0	50.3	4.0	794	549

RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	0.5	0.5	0.5	64.8	123.9	222.0	6
Bareland	0.5	0.5	0.5	2.2	3.0	5.6	3
Cropland	0.5	0.5	1.1	74.6	47.9	866.0	937
Grassland	0.5	0.5	0.5	35.5	1.9	706.0	521
Shrubland	0.5	0.5	0.5	59.2	19.3	670.0	88
Wetlands	0.5	0.5	105.8	133.4	244.0	322.0	8
Woodland	0.5	0.5	0.5	34.5	1.6	739.0	581

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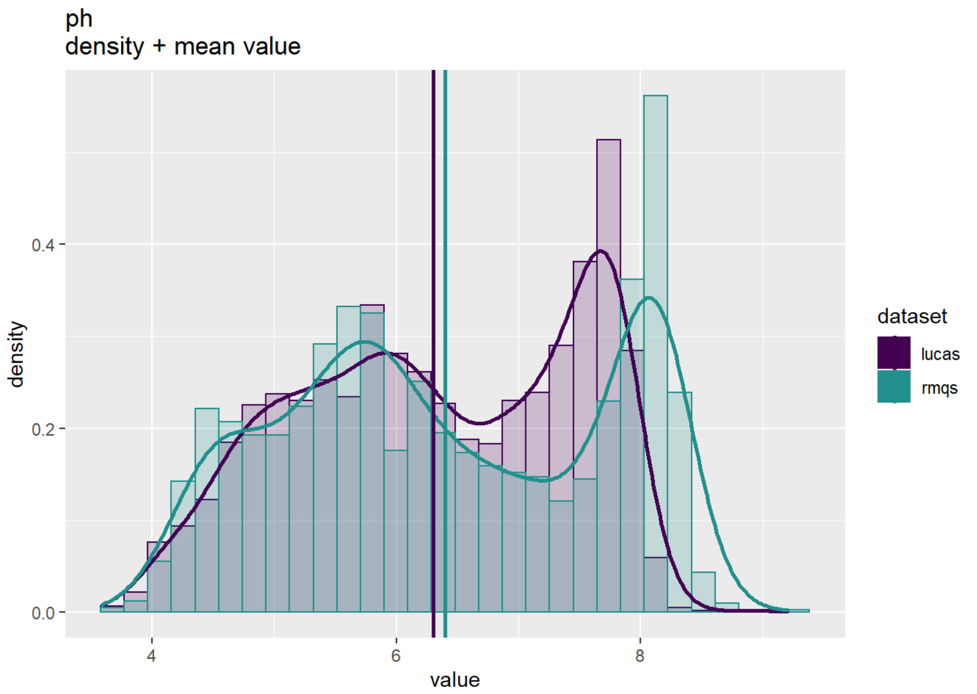
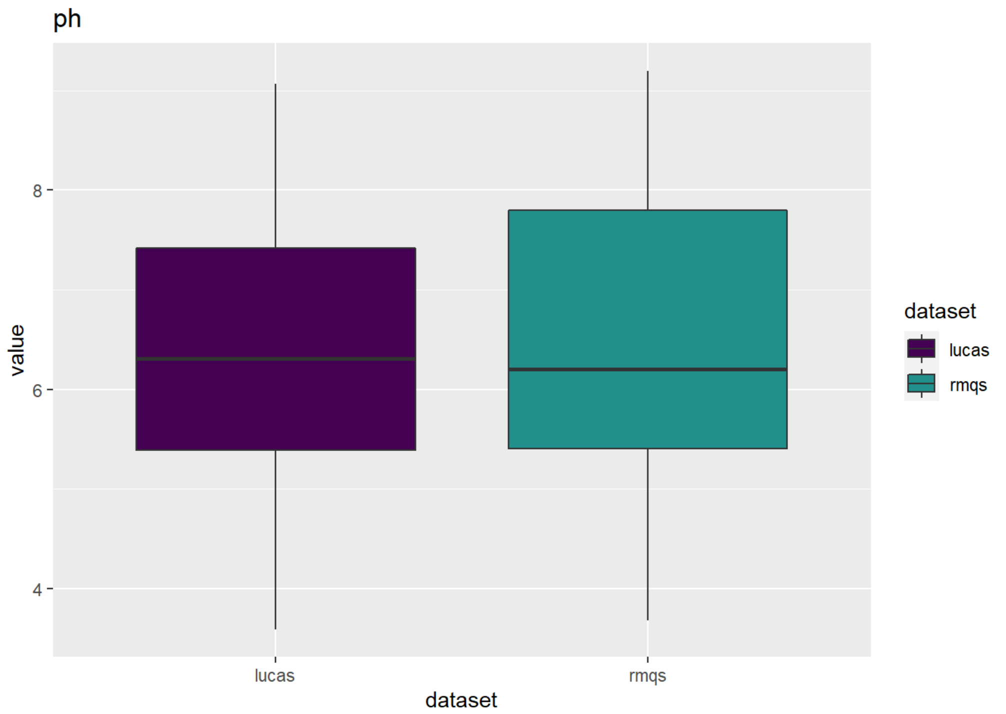
Comparison of variables - pH

Histogramme



Boxplot



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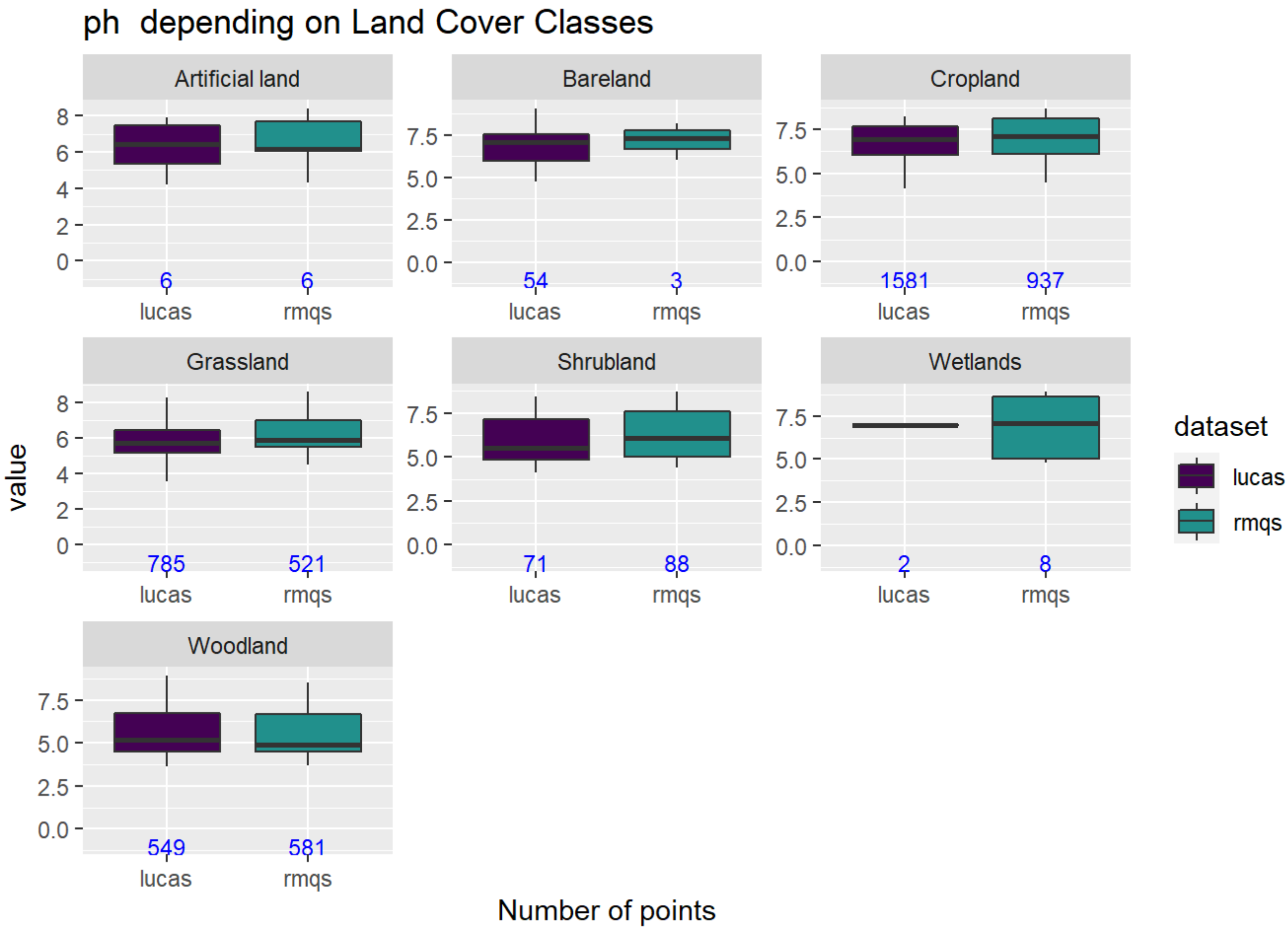
Boxplot by land cover classes



Statistics

Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	3.59	5.39	6.31	6.32	7.42	9.07	3050
rmqs	3.68	5.40	6.20	6.41	7.80	9.20	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	4.2	5.3	6.4	6.3	7.4	7.9	6
Bareland	4.8	6.0	7.1	6.8	7.6	9.1	54
Cropland	4.1	6.1	7.0	6.8	7.7	8.2	1581
Grassland	3.6	5.2	5.7	5.9	6.4	8.3	785
Shrubland	4.1	4.9	5.5	5.9	7.2	8.5	71
Water	8.1	8.2	8.4	8.4	8.6	8.8	2
Wetlands	6.9	6.9	7.0	7.0	7.0	7.0	2
Woodland	3.6	4.5	5.2	5.6	6.8	8.9	549

RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	4.3	6.0	6.2	6.5	7.7	8.4	6
Bareland	6.0	6.7	7.3	7.2	7.8	8.2	3
Cropland	4.5	6.1	7.1	7.0	8.1	8.7	937
Grassland	4.5	5.5	5.9	6.3	7.0	8.6	521
Shrubland	4.4	5.0	6.1	6.4	7.6	8.7	88
Wetlands	4.8	5.0	7.1	6.9	8.6	8.9	8
Woodland	3.7	4.5	4.9	5.6	6.7	8.5	581

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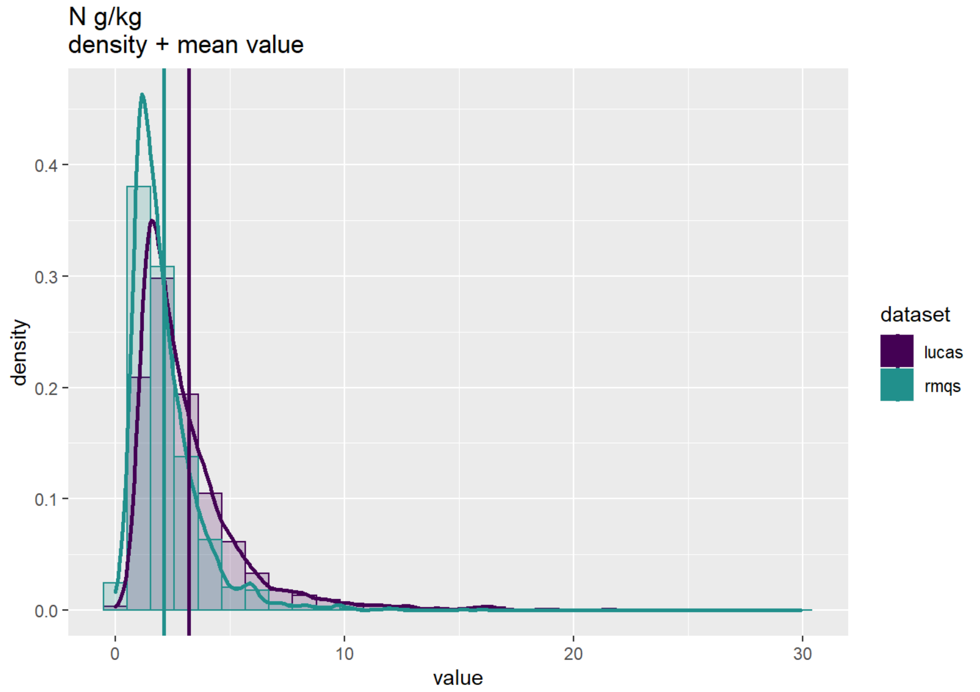
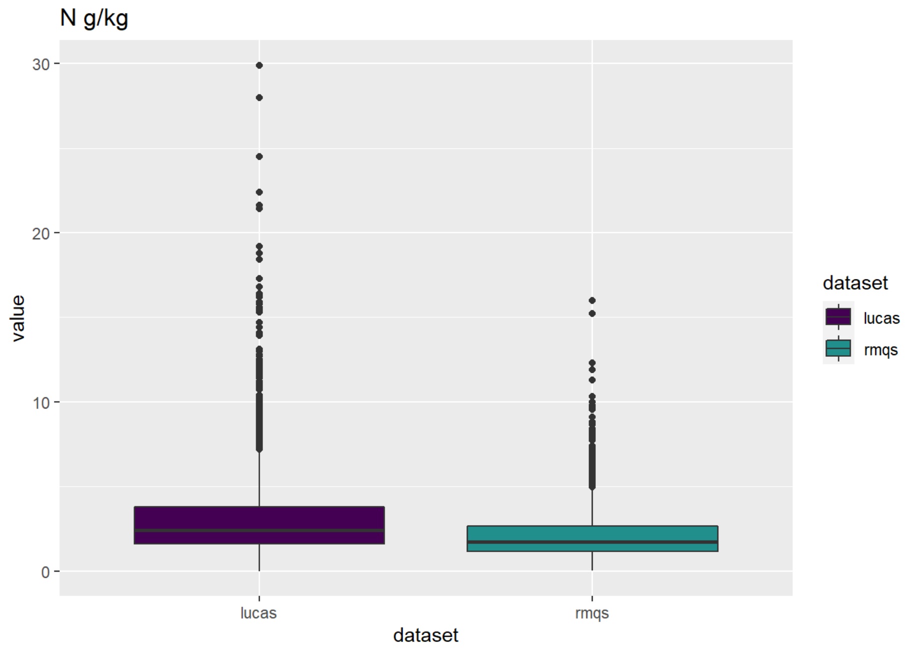
Comparison of variables - N

Histogramme

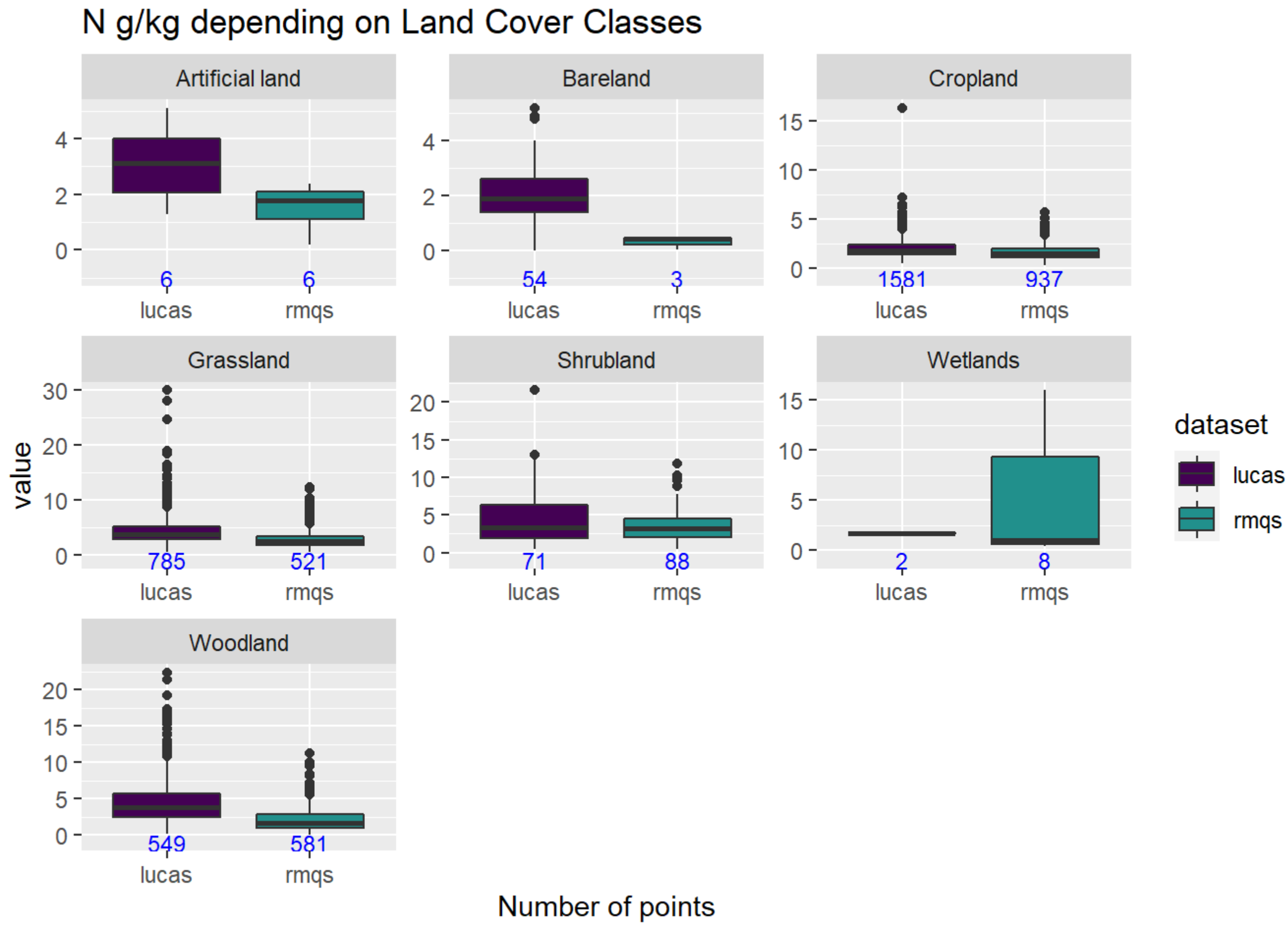


Boxplot



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Boxplot by land cover classes



Statistics

Global

dataset	min	Q1	median	mean	Q3	max	number
lucas	0.00	1.60	2.40	3.17	3.80	29.9	3050
rmqs	0.03	1.15	1.73	2.14	2.66	16.0	2145

LUCAS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	1.3	2.0	3.1	3.1	4.0	5.1	6
Bareland	0.0	1.4	1.9	2.1	2.6	5.2	54
Cropland	0.5	1.4	1.8	2.0	2.4	16.3	1581
Grassland	0.4	2.8	3.7	4.4	5.1	29.9	785
Shrubland	0.5	2.0	3.4	4.5	6.3	21.6	71
Water	0.8	1.0	1.2	1.2	1.4	1.6	2
Wetlands	1.7	1.7	1.7	1.7	1.7	1.7	2
Woodland	0.2	2.5	3.9	4.7	5.7	22.4	549

RMQS

LandCover	min	Q1	median	mean	Q3	max	number
Artificial land	0.2	1.1	1.8	1.5	2.1	2.4	6
Bareland	0.0	0.2	0.4	0.3	0.4	0.5	3
Cropland	0.3	1.1	1.4	1.6	2.0	5.7	937
Grassland	0.5	1.7	2.4	2.8	3.3	12.3	521
Shrubland	0.5	2.0	3.2	3.6	4.5	11.9	88
Wetlands	0.4	0.6	1.0	5.3	9.4	16.0	8
Woodland	0.0	1.1	1.7	2.2	2.9	11.3	581

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7.3. SMS dedicated to forest land

Two countries (Latvia and Sweden) answered the questionnaire to describe their SMS dedicated to forests. Other SMS dedicated to forests exist (e.g. in Germany, France…) but were not declared.

Latvia has a soil monitoring system called *Forest soil monitoring system (former Biosoil)* and managed by Latvia State Forest Research Institute "Silava". It started in 2004 to monitor SOC, soil nutritional regime and activity data for remote sensing studies on 95 sites. It is still running and next campaign is planned by 2024 (meaning an interval of 10 between 2 sampling campaigns). The system was designed to investigate forest land uses and based on a grid design (16 x 16 km). All sampling sites are treated the same.

All sites are georeferenced (precision 5 m) and a composite sample is taken on an area of 500 m² (circle, radius of 12,61 m) at fixed depths (0-10, 10-20, 20-40, 40-80 cm) ending with approximately 50-150 g for volume samples and 100-500 g for mixed samples. Sampling for bulk density is also made. Before preparation the samples are stores at 4°C. Then before analysis the samples are first air dried, then oven dried at 105°C, crushed (mineral soils - by hand, peat soil - by mill) and sieved to 2 m. Litter is removed (fine root are left in sample, other roots are removed). Litter is collected as a separate layer.

Soil is described (ICP forests guidelines) and classified (FAO). Additional information on the sites is available on:

- elevation,
- soil data management is available (eg. thinning, regenerative felling, soil scarification, planting, stand characteristics)
- slope, exposition, erosion features
- vegetation
- pictures are taken

Considering harmonization options:

- the design of the monitoring can be changed as new points can be added in forests and other land uses, soil microorganisms can be analysed
- It is possible to collect new information on the monitoring sites and the soil description can be improved if there is additional funding. Soil microorganisms, GHG fluxes in selected sites may also be measured.
- The sampling area can be increased
- The sampling depths may be changed by using additional depths or split existing layers, but so that they can be compared with earlier data, not less than 10 cm layer.
- The soil sample preparation cannot be changed
- New parameters can be added and analyses may be changed. Some adaptations can be made if they are reasonable and additional work including certification of methods is funded.

Considering collaboration with LUCAS campaigns, **Latvia** didn't yet collaborate. LUCAS data were already used to compare topsoil properties (e.g. C and N content comparison at EU level). However, data quality is not consistent with other soil monitoring systems sometimes, so we are using them carefully, as a backup option if better sources are not available.

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Sweden has a soil monitoring system called *Swedish Forest Soil Inventory* and managed by Johan Stendahl. It started in 1983 to monitor the status of soils (acidification, SOC, nutrients, soil biodiversity) in forest land, mountainous forests, mires, sub-alpine areas and grazed land. The inventory is carried out in collaboration with the Swedish National Forest Inventory, on In total 20 000 plot where c. 10 000 are sampled in topsoil and c. 5000 with deeper sampling.

The monitoring program is running continuously. The system was designed to investigate natural, forest, grazed land, mires and sub-alpine areas land uses and designed on a grid basis (triangular grid of sampling clusters (average c. 1 plot per 15 km²)).

All sites are georeferenced (precision C. 2 meters m) and a composite sample is taken on an area of 3.14 m² (circle of 1 m radius) at fixed depths (0-10, 10-20, 55-65 cm) ending with approximately 1.5 litre of organic topsoils, 0.75 litre of mineral subsoil. Weight will depend on moisture content.
Before preparation the samples are stored at room temperature before delivery to the lab (within 1 week).. Then before analysis the samples are air dried at 35°C, crushed (organic topsoils are milled and separated by fraction) and mineral soils are sieved to 2 mm.. Litter is integrated in the sample.
A soil description is also available and is obtained by opening a soil pit. Soil is described (National standard) and classified (WRB) (see also https://www.slu.se/en/markinventeringen).
Additional information on the sites is available on: elevation, soil surroundings (e.g. road, factory, city…), lithology and vegetation.

Are all sampling sites are treated the same as:

- for c. 20 000 plot field observations are available of soil characteristics, landuse, vegetation incl. tree layer
- for c. 10 000 samples are collected from topsoil for c. 5000 plots from the subsoil as well.
- soil chemistry analyses differs slightly between plots with/without subsoil sampling.

Considering harmonization options:

- the design of the monitoring cannot be changed as the sampling plots are permanent and have been used since the 1980ies.
- It is nevertheless possible to collect new information on the monitoring sites and the soil description can be improved. From 2023 modifications of soil description for harmonization purposes could be introduced. Additional data on specific landuse types, e.g. grazing land could be of interest.
- The sampling area cannot be changed as previous data rely on the current protocol.
- The sampling depths can be changed in order to increase precision. Note that comparative sampling to previous inventory periods must be guaranteed.
- The soil sample preparation and analyses cannot be changed
- New parameters can be added

Considering collaboration with LUCAS campaigns, **Sweden** didn't yet collaborate. No contacts have been made between LUCAS and our inventory. LUCAS data were not used.