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LUCAS Soil 2022

ISSG Planning Document

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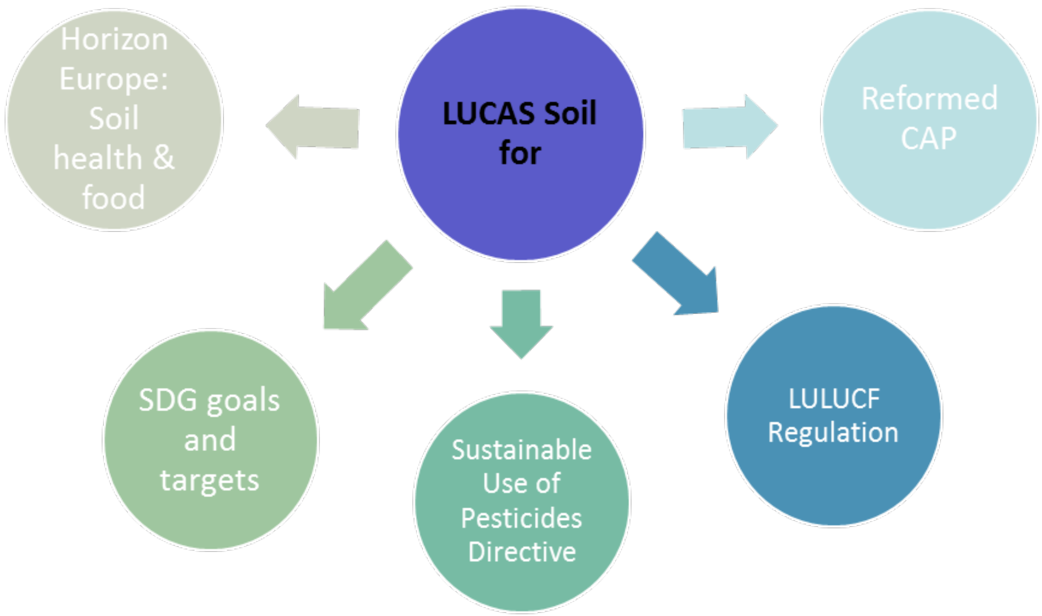

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Abstract

The purpose of this document, prepared by JRC (D3) and Eurostat (E4), is to:

- explain the underlying principles behind the LUCAS soil module,
- describe its subsequent development driven by the policy needs of the Commission, research, and lately, also by some countries, and
- present a proposal to adapt, adjust and improve the LUCAS Soil methodology for the 2022 Survey so that it serves the evolving policy needs of EC services, and beyond,
- identify mechanisms for increased involvement with Member States.

As a basis for discussion by the Inter-service Steering Group on Land Cover and Land Use (ISSG), and subsequently with representatives of Member States (e.g. EIONET-Soil, EJP Soil and EU Expert Group on Soil Protection), the document presents the following recommendations for the implementation of the 2022 survey:

- four sampling scenarios, reflecting different reporting units and thematic scopes
- to increase the sampling depth to 30 cm,
- to refine the sampling protocol and surveyor training for woodlands, especially for organic-rich soils,
- to simplify guidelines for the transport of soil biodiversity samples,
- to investigate the collection of soil samples during the spring and autumn, at least in the Mediterranean region,
- to maintain a single laboratory for sample analysis but reduce the timeframe for this stage,
- to assess the presence of gully erosion in all LUCAS field points,
- a timetable for 2018 and 2022 outputs
- a strategy for future LUCAS Surveys and possible integration with national soil monitoring initiatives.

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1. Background to the LUCAS Soil Module

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

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

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

This meant that harmonised geolocated information on soil characteristics at a plot level for the EU was lacking. As an example, an exercise carried by the JRC to collect harmonised data on soil organic carbon and erosion vulnerability through the European Environment Agency's (EEA) EIONET members showed that many Member States[2], in the absence of direct soil-related policy incentives, were reluctant to share data outside legal requirements.[2]. In this context, a mechanism was sought to collect data across the EU in a harmonised manner in order to derive assessments of the effects of land management practices on soil.

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

[1] http://www.fao.org/3/i3794en/I3794en.pdf

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

2. Policy needs

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

a. Initial policy considerations

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

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

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

As a consequence of the samples collected during the initial LUCAS Soil survey, the JRC has made the raw data available through the European Soil Data Centre while producing and distributing a series of novel pan-EU datasets[3,4] describing the physical and chemical characteristics of soil (e.g. particle size, pH & carbonates, organic carbon concentrations, nutrient status, drivers of soil fertility and metal content[5]).

In turn, these data were used to develop more elaborate datasets, assessments and research programmes. These include the modelling of soil erosion vulnerability[6,7], to improve assumptions underpinning carbon modelling[8]) and the impacts of land management scenarios (e.g. land use change, rotation practices, residue management, tillage, fertilizer applications and the use of cover crops – disaggregated from a range of

[3] https://esdac.jrc.ec.europa.eu/content/topsoil-physical-properties-europe-based-lucas-topsoil-data
[4] https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data
[5] https://esdac.jrc.ec.europa.eu/content/copper-distribution-topsoils
[6] https://esdac.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015
[7] https://www.sciencedirect.com/science/article/pii/S0264837715003257
[8] https://esdac.jrc.ec.europa.eu/content/soil-organic-matter-som-fractions

Eurostat and FAO databases, including the FSS) on fluxes of soil organic carbon[9,10] and nitrogen[11] from all agricultural LUCAS points.

Several of these products were used, or are being prepared, as formal policy indicators or as inputs into broader policy discussions. These include the:

EU SDG Core Indicator Set: Soil erosion vulnerability through the JRC's RUSLE 2015 model[12] - LUCAS provides key soil data (texture, OM) and anti-erosion management measures. In parallel, there are ongoing discussions on the suitability of LUCAS data to populate an EU soil carbon indicator showing changes from 2009-2015. Initial proposals were focused on using SOC concentrations for specific land cover classes and only for mineral soils. This raised a range of questions such as the validation of trends show, QA/QC of 2015 data (now completed), error detection and error management. Recent efforts by the JRC to develop and integrated soil carbon model based on LUCAS Soil data, biogeochemical modelling platform (based on Daycent), geostatistics and Machine Learning algorithms have recently produced soil carbon stock data for arable and managed grasslands of the EU for 2009 and 2015 (with related uncertainties). We propose to re-engage with Commission services and ESTAT as soon as possible to present these results.

Common Agricultural Policy: LUCAS Soil data have been used to produce AGRI-ENV soil erosion indicator[13], CAP Context Indicators[14] I.12: soil organic matter in arable land and I.13: soil erosion by water. In addition, LUCAS data contributed to soil erosion and carbon discussion on the Impact Assessment of the CAP (2018) and OECD Soil erosion Indicator for agricultural land[15]

Environmental assessments: LUCAS data have been used as inputs to 2015 and 2020 SOER Reports, while Cd concentration data were used for a note on the revision of the Fertilizer Directive. As support to the Nitrates Directive, LUCAS data underpinned a modelling excercice to assess environmental criteria for materials derived from advanced manure reprocessing technologies in nitrate vulnerable zones (SAFEMANURE Project – final report currently under review by ENV). Daycent model was run on all agricultural LUCAS points to assess changes to N cycle (N leaching, uptake by plants, N2O emiisions) and SOC stocks over 30 years.

Europe in the Wider World –the general approach behind the sampling framework and soil sample protocol used by the LUCAS Soil module for the EU is being applied to support the EU-Africa Partnership on Food and Nutrition Security and Sustainable Agriculture (FNSSA) through the establishment of soil condition baselines for Africa

In addition, the 2009 and 2015 data have contributed to the policy discussions on:

Climate – LUCAS 2009/2012 data have being used to model soil organic carbon stocks for EU territory – data can be downloaded from ESDAC[16]. See SDG bullet on discussion on 2015 data. Data will be refined in 2021 through the use of bulk density data collected

[9] https://esdac.jrc.ec.europa.eu/content/soil-ghg-fluxes-using-lucas-soil-daycent
[10] https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity
[11] https://esdac.jrc.ec.europa.eu/content/n2o-emissions-agricultural-soils
[12] https://ec.europa.eu/eurostat/documents/276524/10369740/SDG_indicator_2020.pdf
[13] https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion
[14] https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/impact-indicator-fiches_en.pdf
[15] https://stats.oecd.org/index.aspx?queryid=79113
[16] https://esdac.jrc.ec.europa.eu/themes/soil-organic-carbon-content

during LUCAS 2018 Survey. In addition, LUCAS data from 2009 (e.g. SOC, texture, N) have been used as inputs for models to assess carbon sequestration potentials under and N_2O fluxes as a result of diverse land management scenarios. Additional SOC data are required to both refine the model and validate outcomes.

Health: A pilot project was carried with Wageningen University to assess the potential of LUCAS to collect data on the residues of plant protection products in croplands. The subsequent peer review publications generated extensive discussion within Commission services and with the broader public[17][18] . The results clearly demonstrated the widespread use of specific active ingredients and showed that 83% of the sample set contained one or more residues while 58% contained mixtures (166 different mixtures were identified) and that predicted concentrations of individual residues were occasionally exceeded.

Biodiversity: the scope of LUCAS data to generate and populate a soil biodiversity indicator.

In addition, two audits from the European Court of Auditors (on desertification[19] and plant protection products[20]) made specific references to the value of LUCAS Soil in providing pertinent soil data and as inputs to monitoring while the ongoing audit on biodiversity in farming[21] highlights the importance of soil biodiversity and the need to improve the relevant knowledge base.

Finally, comparison of data from 2015 will allow **trends in soil conditions to be assessed**. Initial assessments on data quality for the 2009 and 2015 surveys[22][23] have been released while the formal report of the 2015 Survey and changes in soil parameters are ready for publication (as soon as Covid lockdown is released)

b. Policy drivers for 2022

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

In this context, the LUCAS Soil Module has evolved as an expandable resource that reflects the diverse policy needs of a range of Commission services through the addition of new

[17] https://www.sciencedirect.com/science/article/pii/S0048969717327973
[18] https://www.sciencedirect.com/science/article/pii/S0048969718343420
[19] https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=48393
[20] https://www.eca.europa.eu/en/Pages/DocItem.aspx?did={E798A9A6-8BD7-434D-AA04-65C50E9DF8C6}
[21] https://www.eca.europa.eu/en/Pages/DocItem.aspx?did={E798A9A6-8BD7-434D-AA04-65C50E9DF8C6}
[22] https://esdac.jrc.ec.europa.eu/public_path/shared_folder/JRC112711_lucas_oc_data_evaluation_final.pdf

properties (both by laboratory analysis and field investigations) and sampling locations during successive sampling campaigns. For the 2022 Survey, these could include:

• Support the implemention of Regulation on Monitoring-Reporting-Verification (MRV) of greenhouse gas emissions from land use, land use change and foresrtry (LULUCF): LUCAS Soil will provide an independent validation dataset of SOC stocks and changes at NUTS2 level for arable topsoils (and depending on budget availability, for managed grasslands at NUTS2/NUTS0) – to achieve this LUCAS will require additional sampling points as described in Section 4 to ensure the required statistical robustness.

• Priorities of the Green Deal I – LUCAS Soil data on soil biodiversity are highly relevant to the Biodiversity Strategy through the provision of novel indicators quantifying both the role of soil as a habitat (i.e. edaphic biodiversity – generally spatial distributions are not well understood) and assess the impact of human activity such as. agricultural land management practices (e.g. agrochemicals, tillage), industrial emissions or sewage sludge applications, on soil dwelling communities. There indicators (scheduled for mid 2021) will be based on metagenomic analysis carried out on LUCAS Samples that will provide an overview of the microbial soil communities persent. The characteristics of these communities data (richness, abundace, composition) will then be assessed against chemical and physical soil properties (e.g. pH, texture class, N levels, Carbonates, SOC) and measures of human activity (e.g. pollution levels, erosion, compaction, crop types/rotation, etc.) to understand how soil biodiversity is affected by land use and pollution. In addition, the publication of the genetic database from the LUCAS 2018 Survey will be a major resource to Horizon Europe research programmes on soil biodiversity, microbiome and medicine (e.g. antibiotics, antibiotic resistance genes,…).

• Priorities of the Green Deal II – both the Zero Pollution Strategy and the Farm2Fork Strategy highlight the importance of reducing soil pollution to ensure an environmentally friendly and healthy food system. In this respect, LUCAS Soil has already provided a baseline of heavy metals in soil and is currently developing the largest harmonised assessment of plant protection residues (around 100 active ingerdients and metabolities in over 3,000 locations – approximately one-third of all LUCAS agricultural points) and selected antibiotics from across the EU .These observed data will be assessed against agricultural practices (e.g. from LUCAS, FSS, IACS, erosion models, etc.). The eventual outcomes will provide a unique perspective on the use (i.e. types, concentrations) and eventually risks, associated with the use of pesticide and veterinary products, by highlighting the key drivers and the validity of risk assessment procedures. In addition, data will be used to validate models of pesticide flows to water bodies and plant uptake scenarions (public health). Data from the 2018 Survey will beging to become available from the autumn of 2020 (full dataset 2022), LUCAS Soil has also the flexibility to investigate other substances of concern such as plastic, POP, PFAS, etc. Other policy areas of relevance are the Sustainable Use of Pesticide Directive, Fertilizer Directive, the Antimicrobial Action Plan and the EU Plastic Strategy

• Priorities of the Green Deal III – healthy functional soils are at the heart of the Climate Law and the Circular Economy Action Plan. LUCAS can provide independent validation and scenario analysis of soil organic carbon stocks within the carbon removal actions and measure the impact of measures to ensure soil resouce efficiency. These could include the application of composts and sludges, safe resuse of manures, efficient use of phosphorous, reuse of extraction materials, loss of fertile soils from land take.

• Common Agricultural Policy – LUCAS can provide independent verification of CAP Impact Indicators (at NUTS 2) on soil erosion and soil carbon while contributing to those on biodiversity and pesticide use. 2022 Survey will establish a baseline, with subsequent surveys providing inputs for mid-term and final review. In paralllel, increased integration with national initiatives will allow LUCAS data to support MS reporting obligations set out under National Strategic Plans.

- The National Emission Ceilings (NEC) Directive sets reduction commitments for a set of airborne pollutants, which in turn, can give cause soil acidification and pollution. LUCAS Soil data may help countries to udertake their reporting on metal concentration in soils (i.e. Cd, Pb, Hg and, if available, As, Cr, Cu, Ni, Se and Zn – all available in LUCAS) together with a set of persistent organic pollutants (POPs), including selected polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB).

- LUCAS Soil data have high potential to support the EU's implementation of the UN Sustainable Development Goals. Currently, in the context of EU-SDG and OECD, LUCAS Soil and ICP Forests are the only Europe-wide data sources involving soil sampling and analysis, which are used to populate soil-related indicators (ICP Forests soil data are mostly applied nationally, while LUCAS Soils currently solely populates the Europe-wide indicators on SOC and soil erosion). Depending on the further discussion of soil-related indicators, LUCAS Soil offers potential for various SDGs on zero hunger, health, clean water and sanitation, climate action, life in water and life on land. It can be expected that closer connection with national monitoring and reporting can improve the availability of soil information for these additional SDG targets (see section 7). These needs can be summarised in Table 1:

Table 1. Soil data for EU policy needs

EU Policy areas	Activities
CAP and Farm2Fork Circular Economy Action Plan	Support to Common Agricultural Policy(CAP): • Production / validation of agri-environmental indicators • Input for the development of an agricultural nutrient management tool • CAP Impact Indicators (erosion, carbon, pesticides, biodiversity) • Case study for IACS data sharing
Climate Law	Support to EU regulations and International actions (e.g. Paris Agreement): • Calculation of soil organic carbon stocks • Input to produce GHG emission inventory
Biodiversity and land degradation neutrality	Assessment of the state of soil and trends of soil degradation due to land-use changes at EU level: • Trends of soil erosion and soil organic carbon • State of soil biodiversity and antibiotic resistance • Strategic approach to pharmaceuticals • HM in fertilizers • Plant protection product residues
SDG	• Erosion • Soil organic carbon (for 2021)
Europe in a wider world	LUCAS Survey as example for drafting a H2020 proposal in Africa to develop a topsoil and land-use/land-cover monitoring system (proposal for 2018)
Green Agenda for WB	• New harmonised soil data for Western Balkans

c. Supporting the needs of external users

LUCAS Soil Data and derived products are also available to the scientific community and decision makers through the European Soil Data Centre (ESDAC). In fact, LUCAS Soil Core and derived data from the 2009/2012 Surveys are among the most downloaded datasets of those made available by the JRC[24]. This broad pool of users and applications contributes to both research and the development of policies with a focus on the use of land. Analysis carried out by the JRC show a diverse range of applications of the use of LUCAS Soil datasets by external users ranging from research including H2020 Projects, Masters or

[24] Datadownloads as of 31.12.2019

PhD projects, validation of modelling outputs, input parameters for modelling of soil processes, in particular soil carbon dynamics, erosion, fertility studies, land-use evaluation, remote sensing analysis and ecosystem service assessments.

Interestingly, the majority of the users apply LUCAS Soil data to studies at national scales, potentially reflecting the lack of operational soil monitoring systems and timely data in many Member States. The release of new datasets (on salinity, sulphur, plant protection products and soil genetics) will ensure a continuous development of applications.

It should be noted that for around half of Member States, LUCAS Soil is the only recent source of soil condition derived from large-scale field observations. While other MS use data from their own surveys or monitoring, as indicated in the introduction, national baselines are not harmonised or the results from the last monitoring exercise are outdated.

When requested, LUCAS Soil has attempted to incorporate specific demands from MS (as represented through the LUCAS WG). PT requested extending the sampling depth to 30 cm to support IPCC report requirements. This was successfully trialled in the 2018 LUCAS Survey. In addition, several MS and organisations (e.g. Slovakia, 2020 State of Forests Report) have used preliminary versions of the 2015 dataset to report on progress in the implementation of the current CAP in absence of ongoing national inventories. Additional sampling sites were identified for Luxembourg and Lithuania for the 2018 exercise.

3. The current design of the LUCAS Soil module

a. How did the soil sampling framework evolve?

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

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

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

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

As the LUCAS Soil module was meant to acquire soil data to support mapping purposes and at the same time provide the basis for a possible future EU soil monitoring system, a multi-stage stratified random sampling approach (e.g. using soil type, land use and terrain information) was chosen (following McKenzie et al. 2008). This approach had been applied in other established soil monitoring systems (e.g. France, Hungary, Poland)[25].

Land cover type was obtained by aggregating classes from the CORINE LANDCOVER 2000 dataset (CLC2000, 100 m resolution). Six broad land cover classes were distinguished: arable land with annual crops, arable land with permanent crops, grassland, woodland, shrub land and bare. The amalgamated CLC2000 dataset was then used to calculate the area of each land cover type in each MS that participated in the survey. The number of selected points should then be proportional to the percentage of land cover for each country[26].

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

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

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

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

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

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

Restrictions in access (e.g. not possible at any of the triplet points) and weather conditions subsequently reduced the number of actual samples collected to just under 20,000 (see Table 2).

[25] http://www.fao.org/3/a-x7585e.pdf

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

Table 2. Number of samples collected per land cover class for LUCAS Soil 2009

Country	Total number of samples	Cropland annual crops	Cropland permanent crops	Woodland	Shrubland	Grassland
Austria	420	145	3	121	6	134
Belgium	71	35	1	15	-	18
Cyprus	90	25	9	14	14	25
Czech Republic	431	227	6	88	2	95
Denmark	232	166	1	25	2	34
Estonia	220	54	-	103	5	54
Finland	1716	314	1	1261	22	94
France	2952	1525	88	380	53	830
Germany	1947	928	27	410	3	549
Greece	491	150	100	64	60	88
Hungary	497	314	6	60	4	104
Ireland	233	11	-	19	9	174
Italy	1333	549	268	127	39	285
Latvia	349	78	-	126	8	132
Lithuania	356	137	1	69	2	141
Luxembourg	3	1	-	2	-	-
Malta	19	1	1	-	-	9
Netherlands	211	88	-	22	-	88
Poland	1648	829	21	304	11	446
Portugal	476	45	71	193	52	99
Slovakia	268	111	2	83	7	64
Slovenia	112	8	1	68	3	32
Spain	2696	1321	419	215	105	350
Sweden	2256	185	-	1802	47	146
UK	942	354	-	72	21	458
Total	19967	7601	1026	5643	475	4449

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

For the soil survey of 2015, 26,000 points were initially targeted, slightly less than the 10% targeting. The increase in number compared to the 2009/2012 survey reflected the addition of Malta, Cyprus and Croatia, the need to include sites above 1000 m in elevation and a 3% increase in overall points in all MS. All points visited during the 2009 and 2012 surveys were revisited while the additional sites were selected by the procedure used in 2009. No triplets were used in the 2015 (or 2018) survey. In addition, the JRC arranged the bilateral collection of samples from five Western Balkan countries[27].

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

The sampling locations used in the 2018 survey were to all intents the same as 2015[28]. In 2018, the Austrian Agency for Health and Food Safety (AGES) received a duplicate sample to carry out laboratory analysis on parameters not measured under LUCAS SOIL (e.g. available nutrients, additional cations, different analytical methodologies - results are due mid-2020).

[27] Albania, Bosnia and Herzogovina, Montenegro, North Macedonia and Serbia,

[28] https://onlinelibrary.wiley.com/doi/full/10.1111/ejss.12862

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

In summary:

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

b. What has been measured?

Overview

The current evolution of LUCAS Soil has led to sub-modules, which are continuously under refinement based on a) stakeholder needs (EU COM, statistics, reporting, impact assessment), b) involvement of countries, and c) research needs (which partially helps to improve the monitoring, and address stakeholder needs, e.g. through modelling). These are summarised in Table 3.

Table 3. Breakdown of LUCAS Soil measurements and policy context

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

All measurement components are essential elements of the EU Soil Thematic Strategy, and impact assessments of various policies related to land use.

Each module has its own characteristics:

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

Each parameter and module requires an evaluation scheme: thresholds.

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

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

Details

The initial surveys (2009/2012 and 2015) targeted physical and chemical properties, such as particle size distribution (texture), pH, organic carbon concentrations, nutrient concentrations (N, P, K, S), metal content (only 2009/2012), salinity (only 2015 onwards) and cation exchange capacity. In addition, visible and near-infrared spectra data were collected on both the 2009/2012[29] and 2015 samples (see Castaldi et al 2018 for application of LUCAS Soil spectral data for airborne imaging spectrometry assessment of soil carbon levels).

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

Experiences with data collected under the BIOSOIL Forest Focus programme highlighted inconsistencies between Member States as a result of unknown systematic errors and inter-laboratory bias between countries. Consequently a decision was taken to only use a single laboratory for all soil analysis for the LUCAS 2009 samples. A similar approach was also adopted by the German Agricultural Soil Inventory for the same reasons (Bach et al, 2011), while the German forest soil sampling successfully adopted the ICP Forests scheme, using regional inventory teams and laboratories.

In order to speed up analysis, the possibility was made in during the procurement processes that laboratories could outsource the analysis of all samples for individual parameters.

c. Sampling depth

Mineral topsoils

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

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

Organic topsoils

For organic soils in wetlands (including wetlands under forest, grassland and shrubs), the default depth of 20 cm can present problems. The organic horizon in these soils can be

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29

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

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

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

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

d. Field sampling protocol

A key goal of the LUCAS SOIL approach is the standardised collection of soil samples. The initial LUCAS Soil field sampling protocol[31] was adapted from standard FAO Guideline for Soil Profile Description[32] and the 2006 BIOSOIL sampling manual[33]. Guidelines for sample collection were amended slightly to provide further clarification in subsequent surveysbased on the feedback from surveyors.

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

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

[31] https://esdac.jrc.ec.europa.eu/content/lucas-2018-soil-component-sampling-instructions-surveyors
[32] http://www.fao.org/3/a-a0541e.pdf
[33] https://www.icp-forests.org/pdf/manual/2000/Chapt_3a_2006(1).pdf

4. Proposals for 2022 LUCAS Soil module

a. Technical considerations for 2022 survey.

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

In essence, they address:

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

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

Reflecting the user needs defined in the preceding sections, the following modifications are proposed for the soil module under the 2022 survey.

b. Optimum sampling framework

As outlined in Section 3, the current design of the LUCAS SOIL module is, in simple terms, a stratified random selection of points selected for LUCAS 2009 field visits. This has been increased over time to reflect the increasing geographical focus of the survey. As a result of discussions within the ISSG, the JRC has undertaken the following analysis to ascertain the necessary sample population to assess soil organic carbon stocks for a range of reporting units, at defined levels of confidence.

LANDMARK investigations

As part of the LANDMARK H2020 Project[34], the JRC collaborated with researchers from the University of Wageningen to determine the number of sites required for a representative soil monitoring system for the EU to assess soil functions (i.e. biomass production, carbon sequestration, nutrient cycling, water quality and quantity regulation, provision of habitat).

For this exercise, the following covariate layers were used:

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

[34] http://landmark2020.eu/

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

the scale of the 1:1 million pan-European soil dataset was too restrictive to predict diagnostic criteria of sites at field level. This constraint had been identified in the original sampling design in LUCAS 2009.

- *As a result,* ***soil characteristics were not considered*** *as a covariate for the representativity exercise* ***and the reporting areas were defined as combinations of land use classes and climatic zones at national levels.***

To assess the possible sample designs for LUCAS 2022, the Wageningen team used a pure nugget model-based approach to predict the variance of the estimated mean of various reporting units within a simple random sampling survey (i.e. assuming that the data are independent). On this basis, the sample variances are model-unbiased estimates of population variances (spatial variances) within reporting units. These variances can then be used to compute the required sample sizes for simple random sampling given a requirement on the precision of the estimated populations mean of reporting units. Given the broad policy interest, a specific assessment was made of the sample numbers required to be representative of soil organic carbon for Member State in any given Climate Zone x Land-cover reporting unit with a probability of 90%, while the error should not be larger than 10% of the mean. A further consideration was that all reporting units should contain at least 20 sampling locations.

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

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

Total: 56,788

- **The conclusions of the LANDMARK study shows that at a NUTS0 level, the current LUCAS Soil sampling design for soil organic carbon is under representative of croplands but broadly in line for the numbers required for grasslands and woodland.**

JRC evaluation of fixed grid approach

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

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

c. Cost-efficient improvement of the effective sampling design

In light of budgetary recent discussions during ISSG meetings, it is unlikely that funding will be made available to collect and analyse the scale of sampling proposed by the LANDMARK study (and earlier, by the ENVASSO project 2008). In the near-future, other considerations can be explored to see how the LUCAS Soil can be properly aligned with national monitoring and reporting schemes (see also Section 7).

Given the primary scope of the LUCAS Survey is to generate data aggregations at MS or Regional level, an exercise was carried out to determine the optimum sample size for all land cover types in MS and at NUTS 2 level (i.e. no consideration of climate zones or farm types) which could function as a minimum expanded baseline for 2022. The Raosoft calculator[35] was used to determine the recommended sample size for a given level of precision (i.e. confidence level and margin of error).

Table 4. Number of samples for various representative scenarios[36]

Class	NUTS0	Targeted NUTS0	NUTS2 x Cropland	Standard Survey	Repeat points only
Cropland	10,200	12,800	26,000	10,200	8,280
Grassland	5,400	6,000	6000	5,460	3,780
Woodland	8,100	8,100	8,100	8,320	4,860
Wetland	2,100	2,100	1,000	1,000	540
Shrubland	2,100	500		1,020	270
Bareland	2,100	500		0	270
Total	**30,000**	**30,000**	**32,000 / 41,000**	**26,000**	**18,000**

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

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

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

[35] http://www.raosoft.com/samplesize.html

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

In conclusion:

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

These conclusions are summarised by Table 5.

Table 5. Scenarios for optimum sampling points

	Scenario 1	Scenario 2	Scenario 3	Scenario 4		
Land cover	**NUTS0**	**Targeted NUTS0**	**Cropland-NUTS2**	**Climatic zones**	**Standard survey**	**Repeat points only**
Cropland	10,200	12,800 (+)	26,000	39,000	10,200	8,280
Grassland	5,400	6,000 (+)	6,000	6,500	5,460	3,780
Woodland	8,100	8,100	8,100	9,500	8,320	4,860
Wetland	2,100	2,100	1,000	2,500	1,000	540
Shrubland	2,100	500		..2,500	1,020	270
Bareland	2,100	500			0	270
Total	**30,000**	**30,000**	**41,000**	**60,000**	**26,000**	**18,000**

Three options are proposed:

- **increase the number of sampling locations to 30,000 data points that guarantees representativity at NUTS0 (an increase of 4,000 over the planning of the 2018 survey).**
- **increase the number of sampling locations for agricultural land to 32,000 (26,000 from cropland and 6,000 for grassland) to guarantee representativity at NUTS2 and NUTS0, respectively.**
- **increase the number of sampling locations to 41,000 to guarantee representativity for major land cover types at NUTS2.**

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

- **Maintain the repeated core points from the past three surveys** (c. 18,000 points).
- **Reallocate the remainder** of the eventual total on the basis of stratified random allocations to land cover classes that are under represented on the basis of latest statistical data (e.g. FSS 2016).

- In the event that access to a specific location is not possible, a **set of backup sampling sites will be generated to ensure sample size** and representativity.
- **Sample all MS** to ensure consistency of results between all countries.

At this moment in time, no attempts have been made to assign precise geographic locations to additional points. This will be done once the total sampling population has been agreed.

As a possible consideration, the JRC has developed a spatial dataset of estimated soil carbon sequestration capacity for Europe[37], based on the integration of LUCAS 2009 points and Century biogeochemical modelling. This capacity, expressed as the ratio between the actual SOC stock and the potential (equilibrium) SOC stock could be considered as a factor in the selection of new points.

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

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

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

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

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

[37] https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity

Table 6. Cropland LUCAS SOIL Points under CAP

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

Table 7. Grassland LUCAS SOIL Points under CAP

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

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

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

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

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

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

e. Field sampling protocol – depth

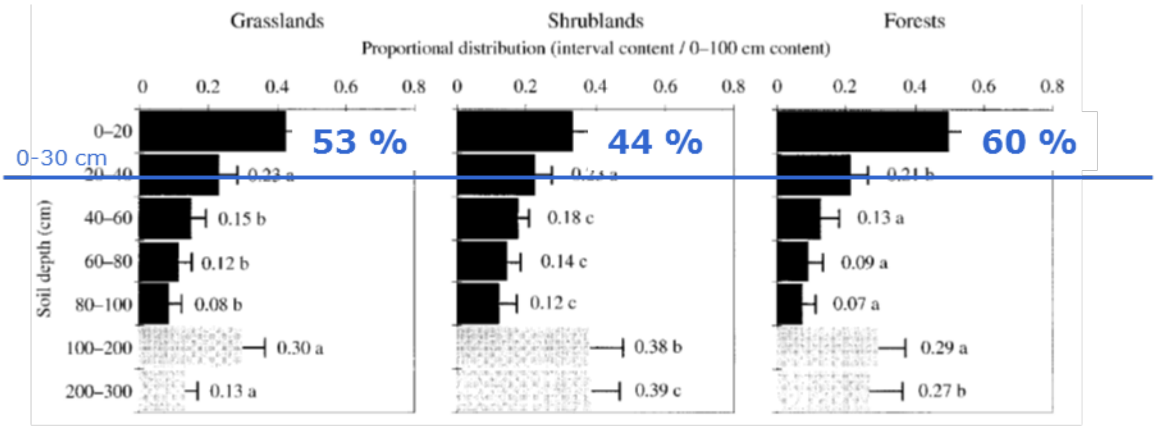
Soil profiles

Where existing, national soil monitoring programmes investigate deeper soil horizons (e.g. Germany, 0-10, 10-30, 30-50, 50-70 & 70-100 cm). The reasons is that some change in the topsoil may be simple re-allocation down the soil profile, rather than loss into the groundwater, or uptake by plants and soil animals, or lateral translocation processes (sedimentation). There are different ways to investigate deeper soil layers, such as machine or manual augers, or soil pits. Such sampling requires experts to carry out site preparation, excavation and the collection of sub-samples, thus there is an impact on capacity and time. In the case of the German survey[38], the fieldwork for 2,631 final locations lasted seven years. Additionally, the total number of samples analysed is approximately 120,000 compared to around 30,000 for LUCAS.

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

Extended topsoil sampling

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



Jobbágy & Jackson (2000) in Ecological Applications

Based on this scientific evidence and experiences presented above, together with surveyor feedback on the pilot exercise carried out in Portugal in 2018 (at the invitation of PT), we **propose to increase the sampling depth in the 2022 soil survey to 30 cm**[39].

It is proposed that the majority of samples would be collected as a single sample to a depth of 30cm. For the 4,000 bulk density samples), which would act as a control set, two

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[38] https://www.thuenen.de/media/institute/ak/Allgemein/news/Thuenen_Report_64_final.pdf

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

samples would be collected, corresponding to 0-20 cm depth and 20-30 cm, to allow comparison with data collected from previous surveys. Further design options can be scientifically developed and tested at national level through the European Joint Progamming on Soils (EJP Soils) and other initiatives (see section 7)

f. Field sampling protocol – collection of sample

Collection of sample – access to LUCAS Point

Sampling quality – systematic errors

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

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

Accessibility issues.

A general comment is that the majority of countries manage to collect more than 85% of the target samples (some even higher). So in reality, surveyors in most countries appear to be able to collect soil samples without (too many) access problems.

It is worth reflecting on terminology. Illegal normally describes a criminal act while unlawful, it means it is against the law, but not necessarily a criminal act. The latter include issues such as trespass (more on this later) or libel, for which somebody may be sued in a civil action but without criminal prosecution.

In the context of LUCAS, this means that to be illegal, there must exist a national or regional law that explicitly forbids either the taking of soil samples or access on to land without permission. For the former, it appears that such a law exists in Germany but not in most other countries.

In the latter cases, access to land is treated in most countries under trespass law (if the concept exists) which is civil matter (unless you enter military or special government zones). For example, in the UK it is not illegal to enter private land but the landowner may take you to court (but at a cost - so actions are relatively rare). Definitions vary significantly from country to country. In Italy or France, it appears that there is no legal concept of trespass so people (e.g. hunters and mushroom pickers) can go anywhere apart from gardens of private houses. In other countries it depends if the land is enclosed or fenced or where access will cause damage at certain times of the year (e.g. when crops are growing). In addition, there are generally no restrictions to unenclosed public land (e.g. forests in Austria or Germany, open land across Scandinavia and Baltics, Common Land in the UK, etc.).

It is clear, it would be much better to have the permission of the owner or manager agricultural areas. In some countries, this is relatively easily done. In others, it's more challenging as the necessary cadastral data is lacking. In this case, clearly the support of national entities would be very helpful.

In this respect, for LUCAS 2022, a concerted effort will be made to discover land ownership as an obligatory task in the LUCAS call for tender. Perhaps one element could be a statement in the call for surveyors that the soil component should be planned in conjunction with the national institution responsible for soil survey who could then help in addressing access issues.

Sample transport

The JRC proposes to maintain the collection of two types of samples. Air dried (for core analysis, bulk density, salinity, metals, etc.) and samples that maintain soil moisture from time of collection (e.g. organic pollutants) that eventually will be frozen. In this respect, the instructions for surveyors from 2018 will be valid.

In addition, the JRC will look to **simplify guidelines for the transport of the chilled soil samples.**

Import/Export of soil samples

After three rounds of LUCAS Soil surveys, there has never been an issue with customs in any country either in respect of exporting samples to the JRC or from the JRC to other places. It should be noted that all the LUCAS soil samples **must pass through Italian customs** to enter and leave the JRC. No objection has ever been raised.

Seasonality of sampling

Together with Eurostat, the JRC will **investigate whether the collection of soil samples can be scheduled for spring and autumn**, thus avoiding full crop development and in the Mediterranean region, hard, dry soils during the summer months. It is interesting to note that the FAO suggest that a soil sampling campaign should take no longer than 60 days within the same season[40].

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

g. Laboratory analysis

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

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

Revisited points:

- **Subset of core analysis**
    - Organic Carbon & total nitrogen

[40] http://www.fao.org/3/CA2934EN/ca2934en.pdf

- P, K, S and pH, only in cropland and managed grassland (possibility to also consider Ca, Na, Mg, Na, Mg, H)
- Electrical conductivity (EC) only in regions with salinity problems (predominantly southern EU MS, but also regions with irrigation, where likely saline aquifers are concerned, as well as coastal agricultural plots)
- Particle size and coarse fragments for 600 points (quality control with previous surveys on 3% of sample)

o **Bulk density**

- 2000 new points to complete the 9000 points planned in 2018
- Repeat measurements in soils where 2018 data suggest compaction problems (BD > 1.6 g/cm3)

o **Biodiversity and genetic assessments** (for the same 1,000 points of LUCAS 2018)

- Repeat DNA analyses for biodiversity index
- Identification of key genes for a functional assessment of biodiversity (e.g. ecosystem services, such as nitrogen cycle, decomposition, etc.)
- Presence of antibiotics resistance genes

o **Soil pollution module**[41] (budgetary restrictions allowing, at least same 3,000 locations from 2018, to understand better temporal change dynamics)

- Metals
- Antibiotics (more substances?)
- PPP[42] (more samples?)
- Plastic (to be decided following ongoing pilots)
- Industrial chemicals (e.g. POPs, PFAS, PAHs, dioxins and furans, PCBs,…?)

New points

o Standard core analysis (to be compatible with past surveys)

o 2000 locations will be selected for bulk density (in cultivated or grassland soils.)

o 1,000 additional points will be selected for biodiversity - attention to locations with high pressures on biodiversity (reflecting agricultural intensity, low OC, compaction, erosion, contamination) to understand better temporal change dynamics.

o Subset for pollution (as above) – PPP and metals in all new points

[41] Dependent on policy priorities and budget availaibility
[42] i.e. the c. 90 active ingredients sampled in 2018

Table 8.Policy relevance for laboratory analysis.

Policy Area	Indicator	Existing LUCAS until 2018	New LUCAS 2022
AGRI	Soil nutrient status Soil fertility	N, P, K, CEC, BS, pH, OC, CO_3	Ca, Na, Mg,
	Erosion (water, wind, harvest)	Particle size distribution, Coarse fragments, OC	
	Compaction	OC, Bulk density, Clay content	Texture, Bulk Density
AGRI/CLIMA	Soil organic C content Soil organic C stocks	OC, CaCO3, Bulk Density, Particle size distribution	More points in cropland and grassland
	C-Sequestration Pot	OC, Particle size distribution	
	N-Cycle, C:N ratio	N, OC, Particle size distribution	
	Salinity/Sodicity	EC	Na
Biodiversity	Species richness/diversity	DNA/metagenomics	Rna, meso and macrofauna analysis?, microbial respiration?
	Pressures	N, P, K, metals, pH, salts	
	Peatlands	OC, depth,	Classification
Ecosystem Service	Biomass, Climate Regulation, Nutrient Cycling, Habitat, Water Regulation	OC, particle sis	Models/pedo-transfer functions
Soil sealing			Loss of point
Zero Pollution	Acidity Critical loads exceedance	pH, S, N,	H^+
	Metal	12 elements	Measure new points and above national thresholds
	Pesticides	90 active ingredients and metabolites, Cu & S	Increase sample size
	Industrial/Organics		POPs, PFAS, PAHs, dioxins, furans, PCBs
	Veterinary	2 antibiotics	More compounds
Contaminated sites	Metals and industrial pollutants	Not assessed	Need reallocation of points
Land degradation		All data	

Outlook

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

h. Laboratory analysis

It should be noted that unlike the other elements of the LUCAS Survey, the soil component involves three logistic phases, each of which requires a distinct period of time. These entail:

- the physical collection of the sample in the field (which is relatively straightforward from a time perspective) – usually completed with five to six months from the start of the survey,
- laboratory analysis (currently in the order of 12-24 months, depending on the scope) and
- quality control and value-added assessments of the results from the laboratory by the JRC (also requiring 6-12 months).

This means that there is an inevitable time lag between the collection of the samples and release of results of at least 2-3 years. It should be noted that this is still quicker than comparable surveys carried out by some member states (e.g. France and Germany).

One approach for shortening the time between sample collection and reporting to Commission services is to **allocate less time for laboratory analysis** (e.g. 12 months). This can be done by:

- a single laboratory requesting less parameters (e.g. only measuring OC, metal content or DNA),
- a consortium of laboratories: criteria and procedures for the separation of samples and/or parameters for analysis need to be developed; implementation via central lab (subcontracting of other labs). Will cause additional costs due to additional overheads.
- the use of tendering lots for parallel analysis: could speed up results but will incur additional costs and time through the production and transport of subsamples),
- insisting on a shorter timeframe for analysis.

In 2018, separate tendering lots were prepared for the analysis of (a) core parameters, (b) biodiversity & antibiotic resistance genes, and (c) pesticide & antibiotic residues, so that the analysis could run in parallel.

In general, the advice from JRC Procurement Officers is that shortening the operational window for laboratory analysis may restrict an already limited market to offers. Preliminary market analysis has indicated that reducing the time period would result in higher laboratory costs due to the need to dedicate additional personnel and equipment to meet shorter deadlines. Both these issues could be overcome by clear and strong statements of the importance of rapid delivery of results and offering more budget so that operators could invest in additional personal or equipment, with implications on the budget of the overall soil module.

Given the complexities and overheads (both financial and in terms of human resources) to develop an inter-calibration process prior to the 2022, survey, the proposal is **to maintain the single laboratory model but to assign less time for laboratory analysis** (e.g. 12 months) through increased use of tendering lots to run in parallel, resulting in an increase of costs.

i. Data release timetable

As indicated in the previous point, there is an interval between the collection of the physical sample and the release of the quality checked laboratory data and any eventual analysis of the results. The JRC will **provide a detailed planning and coordination document** (supplemented by the field sample protocol and a procurement planning document

In summary, we could foresee the following timetable LUCAS Soil over the next four years:

- 2020 Q2: Release of the 2015 LUCAS Soil dataset through ESDAC with overview report and report on changes 2009-2015
- 2020 Q3: LUCAS Soil Archive operational after relocation (2009 + 2015),
- 2020 Q4: Initial report on soil genetics analysis and antibiotic resistance genes from 2018 Survey, Interim report on pesticide and microplastic analysis,
- 2021 Q1 Unvalidated SOC data
- 2021 Q2 Unvalidated LUCAS Soil Data
- 2021 Q4 Release of 2018 Soil data together with supporting reports and datasets (raw points, interpolated rasters, input to modelling platforms)
- 2022 Q1 Report and data on pesticide analysis from 2018
- 2024 Q2* (budget allowing) Unvalidated LUCAS Soil 2022 Data

- 2024 Q3* (budget allowing) Release of LUCAS Soil 2022 Data with supporting reports and datasets (raw points, interpolated rasters, input to modelling platforms)

5. Future surveys after 2022

Determining **sampling frequency** is an important element of soil monitoring programme. It is well recognised that some soil parameters, such as nutrients applied as fertilizers (and pollutants via composts and sludges), can respond relatively rapidly (i.e. in a few years) to changes in drivers, while others, such as SOC stock changes are generally much slower and also reflect inherent variation in their measurement. As an indication, the '4 per 1000' initiative[43] targets an increase of 0.4% per year in organic carbon stocks of agricultural topsoil, which would amount to 4% change over a decade. This is comparable to the findings of Post et al (1991) who noted that rates of change in temperate climates are typically less than 0.5 Mg C ha^{-1} year, compared to stock levels around 100 Mg C ha^{-1}. The Commission's Mapping and Assessment of Ecosystems and their Services (MAES) has set a threshold of 5% change over a 10 year period to be statistically significant.

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

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

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

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

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

[43] https://www.4p1000.org/

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

In conclusion, the following proposals are made:

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

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

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

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

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

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

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

Table 9. Proposal for post-2022 Soil Module

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

6. Use of LUCAS data for derived products and modelling / research

An important secondary benefit of LUCAS Soil data is their use in research activities. One aspect is the need for and the benefit from research where the JRC and others have invested efforts to improve the range of information that is available to stakeholders beyond what is captured by surveyors, and to improve the quality of the survey in the future.

While this section reports on work undertaken by the JRC, Orgiazzi et al (2017) reports on applications in the broader scientific community.

Primary LUCAS data have been used by the JRC to derive a range of datasets and research products describing physical and chemical characteristics of soil (integral to many indicators and models), key nutrient fluxes (predominantly carbon and nitrogen, including carbon fractions and black carbon) and a range of pollutants (e.g. metals and pesticides levels, the presence of antibiotics, antibiotic resistance genes and plastics). Each output is supported by peer-review publication that describes the methodology and uncertainties associated with geostatistics, modelling or analytical approach utilised (see references in main report).

In relation to physical attributes, spatial datasets on clay content, silt content, presence of coarse fragments, bulk density, texture class and available water capacityfor the topsoil fine earth fraction through a range of geostatistical methods (e.g. Multivariate Additive Regression Splines) at a range of spatial resolutions (1 km – 100 m). The spatial interpolation model showed a good performance (cross validation R2 = 0.65, 0.62, and 0.60 corresponding to the clay, silt and sand prediction) while high prediction uncertainty was limited to relatively few areas. Maps of model uncertainties were also published.

In relation to chemical attributes, spatial datasets (also at 500 m resolution) were developed fo pH (measured in H2O and CaCl2 0.01 M solution), Cation Exchange Capacity (CEC), calcium carbonates content (CaCO3), C:N ratio, Nitrogen (N), Phosphorus (P) and Potassium (K), using Gaussian Process Regression technique that allows the estimation of prediction uncertainty. The best performing prediction was obtained for the C:N ratio (R2=0.91), followed by phosphorus and potassium (R2=0.75). The performance prediction of the rest of chemical properties in terms of R2 is higher than 0.60 with the exception of CEC (R2= 0.35). It should be noted that comparisons of CEC from 2009 and 2015 is problematic and further studies are ongoing to understand better the issues.

LUCAS 2009/2012 data have also been used to assess metal content in soils. For example, Generalized Linear Models (GLM) were used to investigate the factors driving copper distribution in EU soils. A full description of model development is provided in the supporting paper[44]. A set of LUCAS 2015 samples were analysed for pesticide residues but no spatial dataset was produced due to the limited number of samples. The analysis of more than 3,000 samples from the 2018 survey will be used to explore the development of spatial products for pesticides and antibiotic residues.

LUCAS Soil SOC data have also been used as inputs for several EU Member States by FAO in the production of the Global Soil Organic Carbon Map (FAO, 2017)

Data have also been used as by processes-based biogeochemical models as input parameters (e.g. carbon sequestration potential, N2O fluxes from soil, soil erodability, N

[44] https://www.sciencedirect.com/science/article/pii/S0048969718314451?via%3Dihub

leaching) and as validation data for outputs. The uncertainties associated with the modelling outcomes were derived using a Monte Carlo approach and are expressed as the ratio between the standard deviation and mean (Coefficient of Variation, CoV). Generally, the majority of CoV values are between 0-0.5 and presented as maps for all scenarios. A full discussion of modelling uncertaintiy analsysis and validation is presented here[45]. Analysis of modelling outcomes have also been shown to be in line with peer-reviewed metadata analysis and able to replicate the results from benchmark sites.

Modelling outcomes from the JRC are available at a range of spatial scales ranging from 1 km to 100 m cells (the latter, under development is based on the application of machine learning algorithms to LUCAS Soil points and outputs of biogeochemical models). All data are available on European Soil Data Centre

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

In addition:

o The analysis of more than 3,000 samples from the 2018 survey are the basis of the largest ever assessment of pesticides and antibiotic residues in soil across the EU. LUCAS Soil data will be used to validate and calibrate JRC pesticide fate models.

o Soil genetic analysis is being used to develop a novel soil biodiversity indicator, assess the impact of land management practices on soil communities and associated ecosystem services, and identify genomic functionality.

o A soil health pilot is being developed under the IACS data sharing to identify the feature types in IACS that could contain information on land management practices not collected by LUCAS (e.g. crop rotation, pesticide application).

o LUCAS Soil Module will be tested under the umbrella of ENV's EMBAL initiative.

o LANDMARK H2020 methodology will be applied to LUCAS Soil points to predict synergies and trade-offs in the supply of key soil functions (climate and water regulation, nutrient cycling, habitat, …).

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

That said, it should be noted that a combination of remote and in situ or point data will still be necessary to derive high resolution and accurate SOC maps, with known

[45] https://static-content.springer.com/esm/art%3A10.1038%2Fs41558-018-0087-z/MediaObjects/41558_2018_87_MOESM1_ESM.pdf

uncertainties. Earth observation systems are also problematic for deriving soil properties. These include:

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

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

7. Collaboration with Member States

An eventual goal for the LUCAS Soil Module, as highlighted in the preceding chapters, is to develop systematic links with Member States, specifically to:

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

These tasks are currently under discussion by the EEA/Eionet Task Force Soil Monitoring, which intends to report to the EU Soil Expert Group (see following points). This governance is important so that the proper policy-relevant decisions about soil monitoring can be taken in the near future. In addition, the Eionet Task Force foresees that recommendatins are made so that closer **links between national soil information institutions and statistical offices can be established**.

The work of these two policy networks and experts will be supplemented by research (e.g. JRC, EJP Soils).

EU Soil Expert Group

The Commission has established an Expert Group to implement the soil protection provisions of the 7th Environmental Action Programme (referred to as EU Soil Expert Group). The scope of the group is to exchange views between the Commission and Member States on soil related issues. At the Autumn 2020 meeting, we propose to initiate a discussion as to how LUCAS Soil and Member States soil monitoring initiatives could be fully integrated. This would consist of a review of MS soil monitoring systems (from the Soil Monitoring Task Force), the current LUCAS Soil proposal and how to maximise mutual benefits (for both the EU and individual MS).

EIONET Soil Monitoring Task Force

Recent discussions with MS (EIONET SOIL) have shown that while all MS have national soil mapping surveys, repeated soil sampling and monitoring is still restricted to fewer countries. Usually, national programmes have different scope, design, representativity and timeline. Important exceptions are the national contributions to the ICP Forests soil monitoring, in which all European countries participate applying agreed protocols with national capacities. Some national programmes show similarities to the LUCAS Soil design, while others focus on less samples but target additional parameters (such as subsoil).

To address these issues, the Task Force Soil Monitoring has been established by the EEA/Eionet National Reference Centres Soil. Besides JRC (lead), and a representative of the ICP Forests soil expert panel, the task force consists of six MS mandated by the NRC Soil. The task force will eventually propose a concept for an integrated soil monitoring system to all NRC Soil members (38 countries incl. EU), for review and recommendations, before it is forwarded to the political decision making community (i.e. the EU Soil Expert Group). The expected product of this task force is a technical document about harmonised soil monitoring in Europe, using LUCAS Soil as a broad-scale Europe-wide monitoring level. Among others, the task force attempts to define the national entry points to LUCAS Soil. This document will be an important contribution to the work of the Task Force. A draft final paper is due for early 2021, which will be shared with both the EIONET-Soil and the LUCAS ISSG so that feedback can be solicited. As stated above, the work of the Task Force will contribute to the discussion with EU Soil Expert Group in the autumn and expanded with the final report in the spring of 2021.

EJP SOIL

The European Joint Programming on Soil (EJP SOIL) is a co-funded programme (by the European Commission and participating organisations from the field of soil science, agricultural soil management and policy development from 24 countries) that aims to create an integrated European research community on agricultural soil management, while contributing to food security, climate change mitigation and adaptation, and ecosystem services. EJP Soil will be closely aligned with the Horizon Europe Mission on "Soil health and food", and it is expected to contribute to the EU Green Deal and the Farm to Fork Strategy.[46]

One key research area of the EJP is to support the development of harmonised soil information through methods for soil sampling, analysis and mapping, including the further development of LUCAS Soil component and how to ensure that soil data compilation in Member States and LUCAS Soil can be fully integrated. The final version of this document will be made available to EJP Soil to facilitate this discussion.

It is clear that the outcomes of the EJP SOIL will benefit the operation of LUCAS SOIL and foster increased data integration. EJP SOIL formally started its programme in February 2020. As a formal beneficiary of the outputs of EJP Soil, the JRC will look to build on, and benefit from its actions.

<u>Some specific research issues that could already be targeted</u> include:

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

As the first reporting period of EJP Soil is set for 2021, it is not possible to incorporate any input from EJP to planning for LUCAS 2020 at this point in time. However, it should be stressed that practical advice in relation to the sample collection is welcome and there is high potential for the subsequent surveys (e.g. 2026 and beyond).

[46] https://dca.au.dk/fileadmin/user_upload/EJP_SOIL_roadmap_final-23-01.pdf

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