European Commission

JRC TECHNICAL REPORTS

LUCAS Soil Component: proposal for analysing new physical, chemical and biological soil parameters

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2016

EUR 28038 EN

Joint Research Centre

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JRC Science Hub
https://ec.europa.eu/jrc

JRC102485

EUR 28038 EN

PDF ISBN 978-92-79-60683-0 ISSN 1831-9424 doi:10.2788/884940

Luxembourg: Publications Office of the European Union, 2016

How to cite: Fernández-Ugalde O., Jones A., Tóth G., Orgiazzi A., Panagos P., Eiselt B.; LUCAS Soil Component: proposal for analysing new physical, chemical and biological soil parametes; EUR 28038 EN; doi:10.2788/884940

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Acknowledgements

Sincere thanks are due to the past and present colleagues of SOIL Team of the Land Resources Unit in the Directorate for Sustainable Resources (DG JRC), especially Pasquale Borrelli, Luca Montanarella, Emanuele Lugato, Marc Van Liedekerke, Ana Paya Perez, Yusuf Yigini.

Our colleagues from DG ESTAT (Alessandra Palmieri), DG ENV (Josiane Masson and Jacques Delsalle), DG JRC (Javier Gallego), DG AGRI (Antonio De Angelis) and EEA (Geertrui Louwagie) also contribute to develop this proposal for LUCAS Soil Component. Thanks are due to all of them.

Abstract

The European Commission launched a soil assessment component to the periodic LUCAS Land Use/Land Cover Area Frame Survey in 2009. Physical and chemical parameters in topsoil (0-20 cm) were assessed in 23 Member States (EU-27 except Bulgaria, Romania, Malta and Cyprus). The aim of LUCAS Soil Component was to create a harmonised and comparable dataset of physical and chemical parameters of topsoil at the EU. The LUCAS Topsoil Survey was extended to Bulgaria and Romania in 2012. Overall, ca. 22,000 soil samples were collected and analysed. All samples were analysed for percentage of coarse fragments, particle-size distribution, pH, organic carbon, carbonates, phosphorous, total nitrogen, extractable potassium, cation exchange capacity, multispectral properties and heavy metals. In 2015, the Topsoil Survey was repeated in the same set of points of LUCAS 2009/2012 for monitoring changes in topsoil physical and chemical parameters across the EU. Furthermore, the topsoil survey was extended to Albania, Bosnia-Herzegovina, Croatia, Macedonia, Montenegro, Serbia and Switzerland. Approximately 27,000 samples we collected in 2015 and will be analysed over 2016 and 2017.

Currently, the European Commission is working on the organization of the upcoming LUCAS Soil Surveys. This technical report is a proposal for analysing new physical, chemical and biological soil parameters within the forthcoming LUCAS Soil Surveys. Soil biodiversity is a key parameter that needs to be added to LUCAS Soil Surveys, due to the contribution of the soil biological community to soil functions such as food and biomass production, genetic pool for developing novel pharmaceuticals, and climate regulation. Among physical properties, bulk density is necessary to assess soil compaction and to estimate soil organic carbon stock in the EU. Field measurements such as signs of soil erosion and thickness of organic layer in Histosols is also important to assess two critical soil degradation processes in the EU: soil erosion and organic carbon decline due to land use changes and land take of Histosols. Finally, it could be interesting to organize a survey of soil profiles to collect information that will help to understand soil-forming processes and to evaluate soil ability for carbon sequestration, nutrient cycling, water storage, and contaminant filtering.

1 Introduction

Soil has a role as a habitat and gene pool, serves as a platform for human activities, landscape and heritage and acts as a provider of raw materials. The Soil Thematic Strategy (COM(2006)231) showed that soil degradation is a serious problem in Europe [1]. This results in loss of soil fertility, carbon and biodiversity, lower water-retention capacity, disruption of gas and nutrient cycles and reduced degradation of contaminants. Soil degradation has negative impacts on natural ecosystems and climate, human health, as well as on our economy. It is difficult to extrapolate current trends into the future based on the limited existing data. However, the human-induced driving forces causing soil degradation are showing an upward trend. For instance, land use/land cover changes and climate change (in the form of global warming and extreme weather events) are exacerbating degradation processes such as erosion and landslides, organic carbon and biodiversity decline, compaction, and salinization. Currently, the Roadmap to a Resource Efficient Europe (COM(2011)571) provides a long-term framework for actions in many policy areas related to climate change, energy, raw materials, agriculture, biodiversity and regional development [2]. In all of them soil plays a key role. At this point, LUCAS Soil Component supplies the necessary soil data to develop future actions towards a sustainable growth in Europe.

Since 2006, Eurostat carries out a LUCAS survey on the land use/land cover situation and changes in the European Union [3]. The survey is conducted every three years for around 270,000 georeferenced points extracted from a regular 2 × 2 km grid across the EU. In 2009, a soil assessment component was added to the general LUCAS survey to evaluate physical and chemical parameters of topsoil in the EU. The aim of the LUCAS Soil Component was to create a harmonised and comparable dataset on topsoil at the EU level for supporting policymaking. Approximately 20,000 points across the EU[1] were selected from the LUCAS general survey for the LUCAS Soil Component. Selection of points was done according to the land use/land cover heterogeneity and topography of each country. Samples were collected from the topsoil (0-20 cm) following a standardized sampling procedure and analysed for several physical and chemical parameters in a central laboratory with standard methods. The same methodology was extended to Bulgaria and Romania in 2012, where topsoil samples were collected and analysed. See reference [4] for more details on the selection of points and the soil sampling methodology.

The Topsoil Survey was repeated in 2015 on the same set of points of LUCAS 2009/2012 for monitoring changes in topsoil physical and chemical parameters across the EU. This allows for controlling any variation in soil functions such as nutrient cycling, carbon sequestration and climate regulation, water retention capacity, and soil contaminant. Furthermore, the topsoil survey was extended to Albania, Bosnia-Herzegovina, Croatia, Macedonia, Montenegro, Serbia and Switzerland in 2015 following the same procedure of LUCAS 2009/2012. Overall, circa 27,000 topsoil samples were collected. The whole set of samples will be analysed in a central laboratory with standard methods in 2016.

[1] Twenty-three Member States (EU-27 except Bulgaria, Romania, Malta and Cyprus) participated in LUCAS Topsoil Survey 2009.

2 Interest of broadening LUCAS Soil Component

In LUCAS 2009/2012 and 2015 Topsoil Surveys, basic physical and chemical parameters of soil are measured. These parameters affect the ability of soil to perform its functions and they can be used as indicators of various soil degradation processes (Annex A). **For coming LUCAS Soil Surveys, we propose to measure additional physical, chemical and biological parameters that are also relevant to evaluate soil functioning** (Annex B): bulk density and soil moisture, electrical conductivity, organic pollutants, contents of (NO_2-NO_3)-N, (SO_4)-S and Na, soil biodiversity, specific measurements for Histosols, and soil erosion. The incorporation of these soil parameters to the current LUCAS soil analyses will improve our capacity for supporting policy-making towards a resource efficient, low-carbon economy to achieve sustainable growth in the EU (Roadmap to a Resource Efficient Europe, COM(2011)571).

Briefly, **bulk density** is a good indicator of soil compaction that can easily reduce crop yields due to restriction of root growth, available water capacity, plant nutrient availability, and microorganisms' activity. It can also lead to a diminution of soil quality due to increased runoff and degradation of soil structure. In addition, bulk density is necessary to calculate the stock of soil organic carbon in soils. When determining bulk density, **soil moisture** must also be determined to better assess hydropedological conditions. **Electrical conductivity** is a good indicator of salinity and fertility problems in soil. This is a critical problem in soils from southern EU. Analysis of **organic pollutants**, together with heavy metals, will give us a full picture of the status and risk of contamination of soils in the EU. Soil contamination can have a critical impact on the productivity of agricultural soils. Nitrogen and sulphur are essential elements for plant growth. However, an excessive accumulation of **(NO_2-NO_3)-N and (SO_4)-S** in soil, due to soil management practices, can result in gaseous emissions and leaching of N and S. This can negatively affect air and water qualities. Similarly, excess of **Na** can cause toxicity to plants, a breakdown of soil physical structure, and dispersion, which limits root growth, aeration, and water infiltration through the soil. **Soil biodiversity** is more and more under pressure because of the several potential threats (soil erosion, intensive human exploitation of soil, land degradation) acting on it. It has been estimated that soil biodiversity is under potential threats in more than half of EU-27 countries [5]. Decline of biodiversity can negatively influence soil functioning because soil organisms support soil functions such as food and biomass productivity, climate regulation, storage and filtering and preservation of pharmaceutical and genetic resources. **Histosols** are a key soil type for C sequestration; specifically cultivated Histosols are important because the continued reduction of their organic layers represents a significant decline of soil organic carbon stock. Finally, a visual assessment of soil conditions that can favour or hinder soil erosion will provide valuable information for improving erosion risk models in Europe.

LUCAS 2009/2012 and 2015 Topsoil Surveys only include information on the 0-20 cm depth, however characteristics of topsoil may be very different to those deeper in the soil profile. Many soil functions cannot be explained by topsoil properties alone and information of soil properties at various depth in the soil profile is needed to understand them; for instance, carbon sequestration, nutrient cycling, water storage, contaminant filtering (see Annex B). Conservation of these soil functions are crucial for developing a European model of sustainable agriculture. Soil management should begin with knowledge of the soil properties in the whole profile, not just in the topsoil. Thus, **we propose to establish a soil profile survey in the coming LUCAS Soil Surveys to collect information on physico-chemical parameters at different depths and evaluate the physico-chemical quality of soil in the EU.** The addition of a soil profile survey to LUCAS Soil Component would provide key data to support the Common Agricultural Policy in the EU.

Table 1 shows a proposal of a work-plan for LUCAS Soil Surveys in the coming years. According to the type of soil sample that shall be collected, soil parameters are grouped in six modules. Physico-chemical parameters in Module 1 shall be analysed in air-dried samples: coarse fragments, particle-size distribution, pH, electrical conductivity, organic carbon, carbonates, NPK, cation exchange capacity, (SO_4)-S, Na, heavy metals, and multispectral properties. All these parameters (except electrical conductivity, (SO_4)-S and Na) have already been analysed in LUCAS 2009/2012 Topsoil Survey. They will be analysed again, together with electrical conductivity, in soil samples collected in LUCAS 2015 Topsoil Survey. Heavy metals, (SO_4)-S and Na will not be measured in samples from LUCAS 2015 because of the cost of the analyses. Module 2 contains soil parameters that shall be analysed in samples were soil moisture is preserved (field-moist samples): $(NO_2$-$NO_3)$-N and organic pollutants. Nitrates and nitrites are primarily present in the soil solution because they are very soluble. Thus, moisture has to be preserved in soil samples. Organic pollutants have to be analysed in field-moist samples because this reduces the loss of the most volatile pollutants. In Module 3, field measurements such as soil erosion signs and thickness of organic layer in Histosols are grouped. There is no need to collect soil samples for these parameters. We recommend monitoring soil parameters from Modules 1, 2 and 3 every 6 years. This frequency of monitoring is based on likelihood of soil changes due to climate and land management changes. For instance, the interval of time needed to detect changes on soil organic carbon is of 5 to 10 years, depending on changes on vegetation, land use/land cover, and soil and climatic conditions [6-8]. Module 4 encloses collection of undisturbed soil samples for measuring bulk density. Soil moisture is closely related to bulk density. It can also be measured together with bulk density in undisturbed soil samples. Bulk density varies slowly over time, except for land use changes, thus its measuring frequency can be low (for instance, every 20 years). Module 5 refers to frozen soil samples for assessing soil biodiversity. Soil biodiversity is assessed by analysis of soil DNA in field-moist samples. If analysis of DNA cannot be done closely after sampling, field-moist samples must be frozen (at -20 $^{\circ}$C) in order to avoid damages of the genetic material before analysis. For assessing the variability over time linked to the climate and management sensitivity, initially soil biodiversity shall be analysed every 3 years. Depending on the results, the frequency of monitoring of soil biodiversity could be more spread afterwards. Finally, Module 6 is for evaluation of soil profiles. Air-dried samples are required at different depths for the evaluation of most common physico-chemical properties in soil profile (coarse fragments, particle-size distribution, pH, electrical conductivity, organic carbon, carbonates, NPK, cation exchange capacity, (SO_4)-S, Na, and heavy metals) and establishment of baseline values for monitoring of soil profiles. Soil profile survey shall be done every 6 years for the monitoring of changes due to climate and land use/land cover variations.

We propose to analyse bulk density (Module 4) and assess soil biodiversity (Module 5) in LUCAS 2018 Soil Survey. Performing a survey of soil profiles (Module 6) is costly and time consuming, and requires a great organization effort. Consequently, we propose to carry out a pilot exercise to study soil profiles in a reduced number of points in 2018. This will give us practical information to organize an extended survey of soil profiles in the future. Furthermore, we recommend analysing critical heavy metals (i.e. those showing great concentration in LUCAS 2009/2012 Topsoil Survey, Module 1) in 2018. Analysis of physico-chemical parameters in Module 1 (except heavy metals) and pollutants in Module 2, and field measurements in Module 3 shall be carried out together in LUCAS 2021 Soil Survey because sampling methodologies for these Modules are complementary and easy to carry out together.

Table 1. Work-plan for LUCAS Soil Surveys in the coming years.

MODULE/ Type of sample	Soil parameters	Year of survey											
		2009	2010-2014	**2015**	2016	2017	**2018**	2019	2020	**2021**	2022	2023	**2024**
MODULE 1/ Air-dried samples	*Coarse fragments*[1] *(2 mm)*	■		■									
	PSD[1] *: clay, silt, sand*	■		■									
	pH ($CaCl_2$, H_2O)	■		■						■			
	Organic C	■		■						■			
	Carbonate content	■		■						■			
	NPK	■		■						■			
	Cation exchange capacity	■		■						■			
	Electrical conductivity			■						■			
	(SO_4)-S, Na									■			
	Heavy metals[2]	■					▨						▨
	Multisprectral properties	■		■						■			
MODULE 2/ Field-moist samples	*(NO_2 - NO_3) -N*						▨			■			
	Organic pollutants						▨			■			
MODULE 3/ Field measurements	*Thickness of peat in Histosols*									■			
	Soil erosion[3] *by water / wind*									■			
MODULE 4/ Undisturbed samples	*Bulk density*						■			▨			
	Soil moisture						■			▨			
MODULE 5/ Frozen samples	*Soil biodiversity*[4]						■			■			▨
MODULE 6/ Soil profiles[5]	*Physico-chemical properties*[6]						▨						▨

[1] Percentage of coarse fragments and particle-size distribution (PSD) in LUCAS 2015 shall be determined only in new sampling points that were not sampled in LUCAS 2009/2012.

[2] Heavy metals: As, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Sb, V, and Zn.

[3] Depending on the variability of soil biodiversity observed between LUCAS 2018 and 2021, the frequency of monitoring of soil biodiversity over time could be 3 or 6 years.

[4] Coarse fragments, particle-size distribution, pH, electrical conductivity, organic carbon, carbonates, NPK, cation exchange capacity, (SO4)-S, Na, and heavy metals.

This proposal has been prepared for the LUCAS Soil workshop held in Brussels on the 11th of November 2015. DGs ESTAT, ENV, AGRI, and JRC, and EEA participated in the workshop. Priority soil information needs for supporting policy-making were established and a work-plan for the coming LUCAS Soil Surveys was discussed. **In this proposal, we describe technical aspects of soil sampling and laboratory analyses for each Module proposed for coming LUCAS Soil Surveys. We also present a cost estimation of each activity in coming LUCAS Soil Surveys. Finally, the priorities for LUCAS 2018 are presented based on the users' needs**, as discussed on the meeting.

3 Sampling methods for proposed Modules

3.1 Air-dried and field-moist samples (Modules 1 and 2)

Soil sampling for air-dried and field-moist samples can be carried out together (Fig. 1). At each sampling point, five sub-samples from 0-20-cm depth shall be collected and mixed in a composite sample. Part of the composite sample (ca. 500 g) shall be air-dried, packed in plastic bags and sent to JRC following the procedure in LUCAS 2009/2012 and 2015 Topsoil Surveys [4]. Samples shall be controlled at JRC and sent to a central laboratory for analysis. After analyses, remaining material of air-dried samples shall be re-sent to JRC for storing at JRC Soil Archive.

A small part of the composite sample (ca. 100 g) shall be directly packed in a plastic bag and kept fresh in cool boxes. Field-moist samples shall be sent to JRC, where they shall be stored at 4 °C in a refrigerator. Sampling and delivery of field-moist samples from surveyors to JRC can be arranged on a weekly basis, according to characteristics of standard cool boxes in the market [2] and transport solutions offered by shipment companies[3]. Samples collected within a week can be kept fresh in cool boxes and sent to JRC at the end of each week using an appropriate packing solution. Overall, samples shall reach JRC within 8-9 days from sampling.

Surveyors will need the following material for sampling of air-dried and field-moist samples: a spade, a measuring type and a bucket to collect soil samples, and plastic bags and barcode labels to pack and identify samples at each point. In addition, for field-moist samples, cool boxes are needed to keep samples fresh during sampling and cold boxes are needed to transport samples at a suitable temperature. JRC shall provide a refrigerator to store samples before sending samples to laboratory (see cost estimation in Table 2).

We propose to carry out the sampling for air-dried and field-moist samples in the ca. 27,000 LUCAS points in LUCAS 2021 Soil Survey (Table 1), following the 6 years monitoring frequency established for LUCAS 2009 and 2015 Topsoil Surveys. If necessary, sampling for field-moist samples can be reduced to 50% of LUCAS points (ca. 13,500 points) in LUCAS 2021 because it will be the first time this sampling is done and its organization requires an extra effort. Sampling can be extended to more points in coming LUCAS surveys based on the experience gained and the results obtained in LUCAS 2021 Soil Survey.

Due to potentially negative effects of organic pollutants on soil biodiversity, it can be interesting to analysis organic pollutants (field-moist samples, Module 2) also in points where soil biodiversity will be analysed in LUCAS 2018 Soil Survey (see below for sampling method for soil biodiversity assessment (Table 1). Regarding threatening heavy metals (i.e. those that show notably high concentrations in LUCAS 2009/2012[4]),

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[2] For instance, Maxcold Igloo coolers are able to keep ice during 5 days (http://www.igloo-store.com/products/fullsize/maxcoldseries).
[3] Many shipment companies have specific packing solutions for cold transport of goods. For instance, TNT offers Medpack Thermo packing solution: samples can be transported at 2 °C to 8 °C in 72 h to 96 h (http://www.tnt.com/content/dam/tnt_express_media/en_gb/site/services/IndustrySolutions/4374_Healthcare_Inserts.pdf).
[4] The Land Resources Unit of the Directorate for Sustainable Resources (DG JRC) is preparing a report with the results of heavy metals from LUCAS 2009/2012.

we recommend collecting air-dried samples in LUCAS 2018 Soil Survey. Threatening heavy metals shall be identified and the density of sampling points shall be established for LUCAS 2018, based on the results of the analysis of heavy metals in samples from LUCAS 2009/2012 Topsoil Survey. This will allow us to check the repeatability and reliability of the applied analytical method and to identify potential threats of soil contamination in the EU.

3.2 Field measurements (Module 3)

Surveyors shall assess, based on visual field observations, soil conditions that can favour or hinder soil erosion by water and wind (Fig. 2, Annex B). The equipment needed for the visual assessment is simple and inexpensive: a camera to take pictures of the sampling site, a field guide to perform the visual assessment, and a field-form to record the visual observations (see cost estimation in Table 2). The field-form shall be prepared by the JRC and shall contain questions such as presence and percentage of stones, presence of plant residues in surface, signs of tillage (i.e. tillage type, direction, depth), and signs of erosion (for instance, soil accumulation along fence-lines and drifted appearance of the soil surface for wind erosion, and small rills and channels on the soil surface, soil deposited at the base of slopes for water erosion).

Histosols and organic-rich soils already account for circa 5% of the sampling points in LUCAS 2009/2012 and circa 7% of the points in LUCAS 2015 (Fig. 2, Annex B). These soils have a key role on carbon sequestration due to their high organic carbon content. Thus, we propose that surveyors measure the thickness of organic layer of Histosols and organic-rich soils and record whether these soils are cultivated or not. The thickness of organic layer is a necessary parameter to estimate the stock of organic C and it can be an indicator of the degradation of these soils.

Field measurements are easy to perform and shall be done in the whole set of LUCAS points (ca. 27,000 points) in LUCAS 2021 Soil Survey (Table 1).

3.3 Undisturbed soil samples (Module 4)

Undisturbed soil samples are collected in metallic rings of a known volume pressed into soil with a mallet. At each sampling point, 3-5 undisturbed samples shall be collected from 0-20 cm and used to calculate an average value of bulk density and soil moisture. Once samples are collected, they have to be weighed before dried (i.e. at field water content) and after dried. Bulk density and soil moisture can be calculated from these data (Fig. 3). Bulk density is the weight of dry soil in a given soil volume. Soil moisture is the mass of water compared to the mass of solid materials per unit volume of soil.

Surveyors will need the following material for collecting undisturbed soil samples: 3 to 5 numerated metallic rings with plastic caps per point, a mallet to press rings into the soil, plastic bags, barcode labels, and a portable scale to weight samples (see cost estimation in Table 2).

We recommend measuring bulk density in 1/3 of the LUCAS points (ca. 9,000 points) in LUCAS 2018 Soil Survey (Table 1). Based on this data of bulk density and other physico-chemical parameters such as particle-size distribution and organic carbon, pedotransfer functions can be developed to predict bulk density where missing. Selected LUCAS points for measuring bulk density shall be representative for the heterogeneity of soil texture and organic carbon content, land use/land cover, topography and soil type within each country. Depending on the accuracy of developed pedotransfer functions, the density of sampling points can be extended in LUCAS 2021 (Table 1) in order to get an overview of soil compaction status in the EU as real and complete as possible (Annex B). The data of bulk density and organic carbon concentration will also be used for estimating organic carbon stock in topsoil in the EU.

3.4 Frozen soil samples (Module 5)

Soil sampling can be carried out as for air-dried and field-moist samples. Briefly, at each sampling point, five sub-samples from 0-20-cm depth shall be collected and mixed in a composite sample (50-100 g). Field-moist samples shall be directly packed in a plastic bag and kept fresh (at 4 °C) in cool boxes until shipment to JRC. Note that field-moist samples can be kept at 4 °C for max. 10 days before freezing. As for field-moist samples, delivery of samples for soil biodiversity from surveyors to JRC can be arranged on a weekly basis, so that samples collected within a week can be kept fresh in cool boxes and sent to JRC using an appropriate packing solution5. At JRC, samples shall be placed in falcon tubes and stored at -20 °C in a freezer. Finally, frozen samples shall be sent to a central laboratory for analysis (Fig. 4).

Alternatively, a network of universities and laboratories that allow us using their freezers can be created in Europe thanks to networks of EcoFINDERS project and the Global Atlas of Soil Biodiversity. Surveyors can bring their field-moist samples to these centres, where samples can be stored in falcon tubes at -20 °C in freezers. Once all samples from a country are collected, they shall be sent to JRC for a control or directly to a central laboratory for analysis (Fig. 4).

During the sampling, contamination of samples (from one sample to another or from surveyors to samples) must be avoided. Thus, sampling material has to be cleaned from one sample to another and surveyors have to use gloves. The following material is required for the sampling: a spade, a measuring type, a bucket and gloves to collect soil samples, plastic bags and barcode labels to pack and identify samples in the field, and labelled falcon tubes to freeze soil samples. In addition, cool boxes are needed to keep samples fresh during sampling and cold boxes are needed to transport samples at a suitable temperature (see cost estimation in Table 2).

We propose to assess soil biodiversity in LUCAS 2018 Soil Survey in a selected set of points (500-1,000 points) due to the laborious and costly organization of the sampling (Table 1). This will be the first attempt to create a harmonized database of DNA sequence information about soil microbial community composition in the EU. In addition, soil biodiversity information can be linked to soil data and land use/land cover information in the database to enhance the understanding of the impact of soil physico-chemical conditions and characteristics of the landscape on soil biodiversity (Annex B).

3.5 Soil profiles (Module 6)

A soil profile is a historic record of all the soil forming processes and it forms the unit of study in pedological investigation. Many soil functions cannot be explained by topsoil properties alone, and information of soil properties at various depth in the soil profile is needed to understand them (Annex B). The analysis of physical and chemical properties, inspection of heavy metals and pollutants, and measurement of bulk density in topsoil

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[5] Many shipment companies have specific packing solutions for cold transport of goods. For instance, TNT offers Medpack Frozen packing solution: samples can be transported at less than -20 °C in 72 h to 96 h (http://www.tnt.com/content/dam/tnt_express_media/en_gb/site/services/IndustrySolutions/4374_Healthcare_Inserts.pdf).

and subsoil are valuable to assess conditions that affect soil functions such as carbon sequestration, nutrient cycling, water storage, contaminant filtering, and food and biomass productivity throughout the soil profile.

Two sampling approaches are possible for studying soil profiles. On one hand, **sampling can be done by horizons** (Fig. 5). Horizons are defined on the basis of observable features such as texture and colour which often are directly related to important measurable properties such as cation exchange capacity, organic carbon, nutrient status or water holding capacity. Furthermore, the presence or absence, thickness, depth and morphological characteristics of different soil horizons in a soil profile give important information about soil processes that are happening or not. Preparation of a detailed soil profile description requires the digging of a soil pit so that soil features can be observed laterally as well as vertically. We recommend digging a pit of 60-80 cm depth. Description and sampling of soil horizons present at the profile shall be done by an expert soil scientist. At each soil pit, expert surveyors shall identify and describe horizons, and take necessary samples. This approach is costly and time consuming, because it entails costs of excavation and hiring a qualified personnel.

On the other hand, **samples can be taken within fixed-depth intervals** without digging a soil pit (Fig. 5). Surveyors can take samples at least within three depth intervals, for instance 0-20, 20-40, and 40-80 cm. Besides the material detailed in Modules 1 and 4, surveyors will need an auger and a soil core sampler for collecting air-dried samples and undisturbed soil samples for bulk density, respectively (see cost estimation in Table 2). This approach is easier to apply: normal surveyors can carry it out and organization does not require a big effort as in the soil profile sampling by horizons. The soil profile sampling by fixed-depth intervals has advantages when conducting studies over time and across sites for detecting changes on soil properties, such as soil organic carbon [9]; however, it can give skew results, particularly in sites where erosion, deposition or compaction has occurred [10,11].

Points for the soil profile survey should be selected among those that have already been sampled in LUCAS 2009/2012 and 2015 Topsoil Surveys. The points shall be representative, as far as possible, for the heterogeneity of land use/land cover, soil heterogeneity and topography within each country. We can also focus the selection of points only within agricultural soils, since a soil profile survey for forest soil in the EU already exists (BioSoil project). It has to be noted that the selection of sampling points for soil profile survey using LUCAS grid (regular 2 × 2 km grid across the EU) might be problematic due to difficulties to select representative profiles as a result of the sampling design. Therefore, as alternative, we could extend LUCAS soil survey on supplementary sampling points, not on LUCAS grid, for the soil profile survey. Points can be selected among representative sites proposed by soil survey organizations of the Member States and sites of the International Network for Long-term Experiments. Soil survey organisations and managing institutions of long-term field experiments can be involved in the sampling and maintenance of the surveyed profiles. Sampling points should be selected based on pedological characteristics, land use/land cover heterogeneity and topography of each participating country.

In LUCAS 2018 Soil Survey, we propose to carry out a pilot exercise with a few number of points, for instance 1-2 profiles per Member State, to gain experience on organizing a soil profile survey (Table 1). In later LUCAS Soil Surveys, based on the experience gained in LUCAS 2018, a set of approximately 2,000 representative points could be selected from LUCAS points or from the International Network for Long-term Experiments for studying soil profiles in the EU.

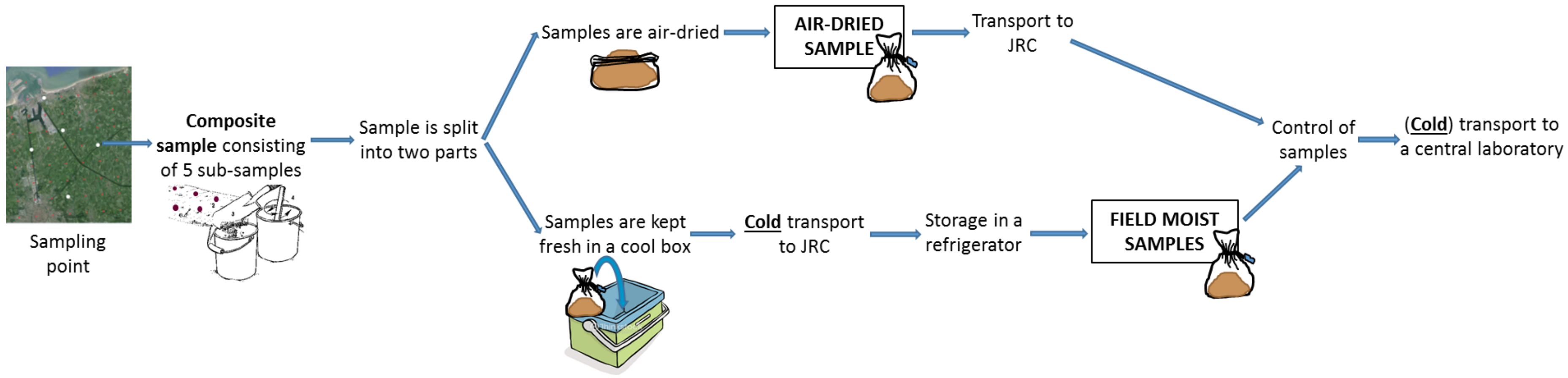

Fig. 1. Sampling plan for air-dried (Module 1) and field-moist samples (Module 2).

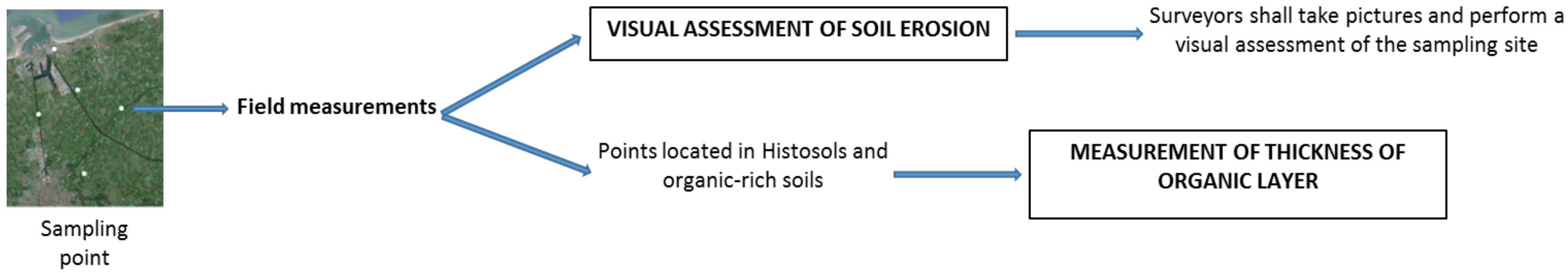

Fig. 2. Field measurements in Module 3.

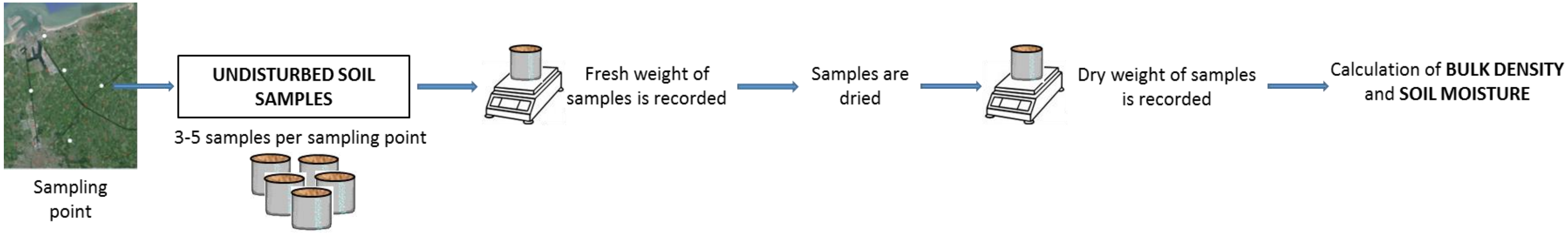

Fig. 3. Sampling plan for undisturbed soil samples (Module 4).

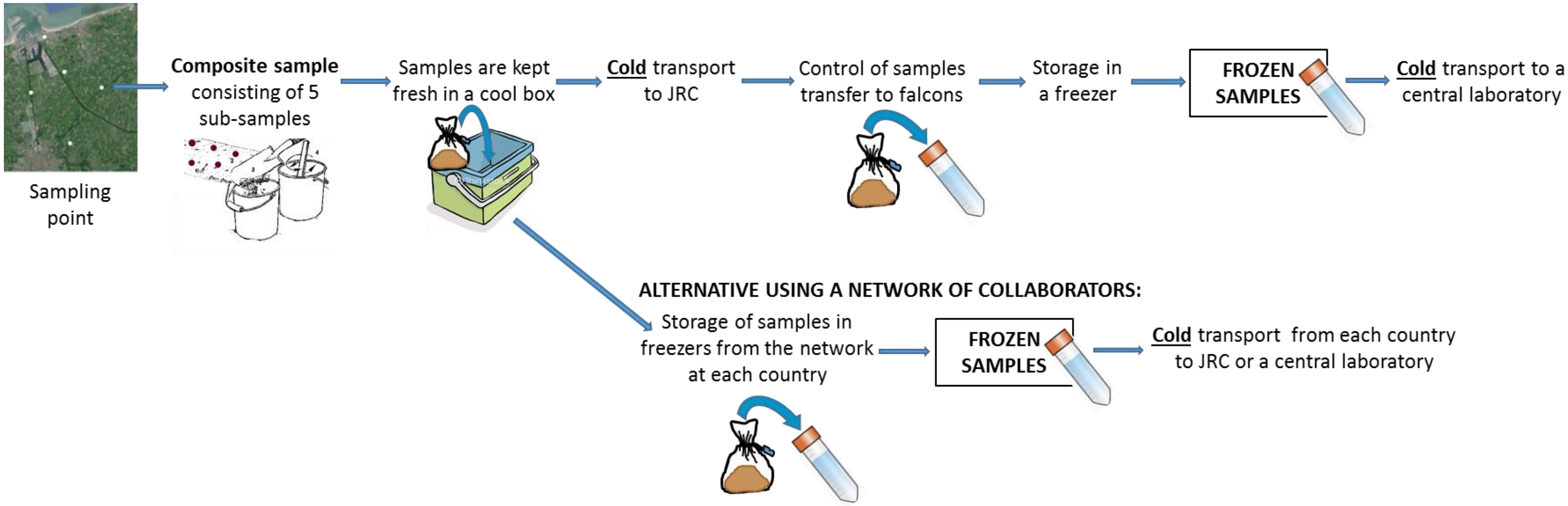

Fig. 4. Sampling plan for frozen samples (Module 5).

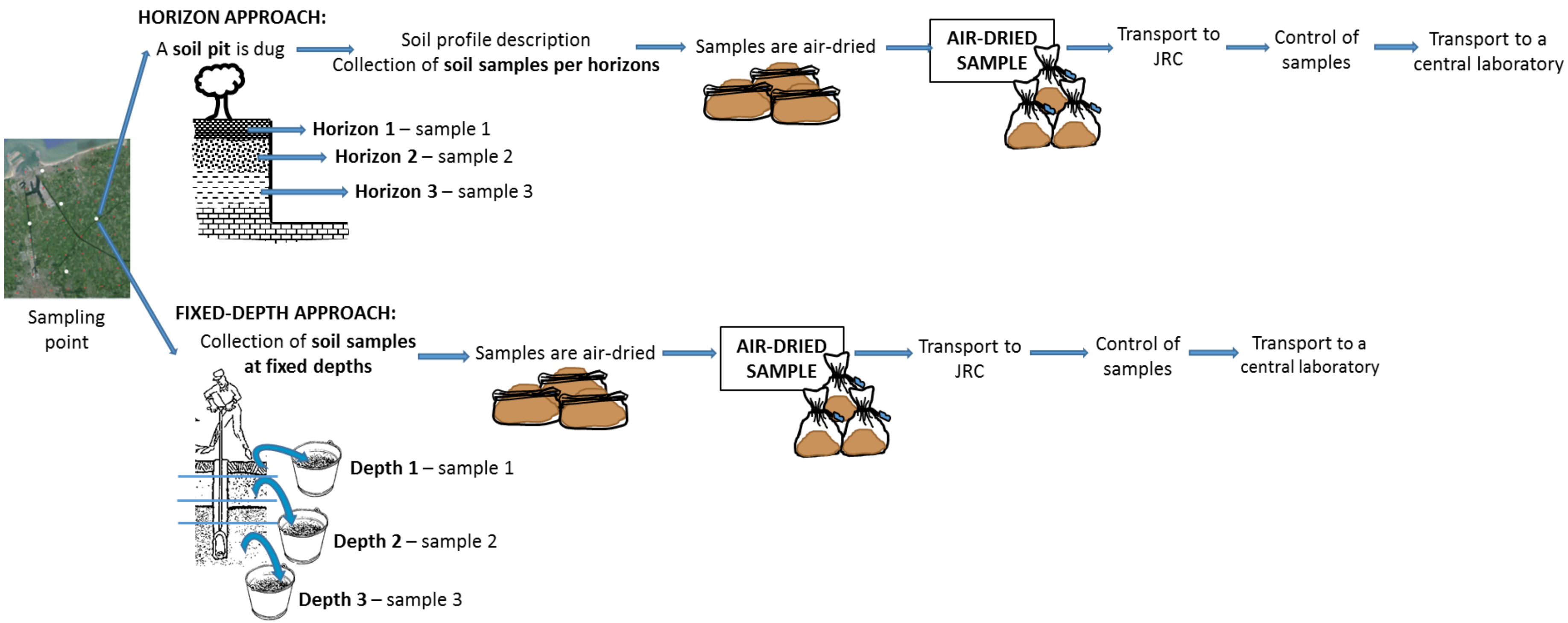

Fig. 5. Sampling plan for soil profiles (Module 6).

4 Laboratory analyses for new soil parameters

For coming LUCAS Soil Surveys, we propose to analyse additional soil parameters that affect the ability of soil to perform its functions and can be used as indicators of various soil degradation processes.

Electrical conductivity (Module 1, air-dried samples) can be measured in a 1:5 soil-to-water extract (EC1:5), which it is also used to measure the pH. The EC1:5 is a variant of the saturation paste extract method. The 1:5 soil-to-water extraction ratio generates a large volume of solution for analysis; but this produce a great dilution of salts, much greater than would occur in the field. Despite this drawback, for routine soil measurements the EC1:5 is a convenient approach to assess salinity and it has the advantage of simplicity, reduced time and low cost. The saturation-paste extraction method reflects better the field moisture contents and it is well related to plant response to soil salinity and leaching of soil. However, it is a tedious method and it has the difficulty of determining the appropriate water saturation point when preparing a saturated paste extract.

Determination of **(SO_4)-S and Na** (Module 1, air-dried samples), and **$(NO_2$-$NO_3)$-N and organic pollutants** (Module 1, field-moist samples) can be done following standardized methods. **$(NO_2$-$NO_3)$-N** can be analysed by extraction with potassium chloride solution. (SO_4)-S can be analysed in water and acid extracts of soil by a gravimetric method in which barium chloride is use to precipitate sulphate. Determination of Na can be done together with heavy metals using techniques such as inductively coupled plasma mass spectrometry (ICP-MS) and X-ray fluorescence. These analyses will entail additional laboratory costs.

Soil biodiversity (Module 2, frozen samples) can be assessed by means of DNA tools (also known as metabarcoding approach, [13]). This methodology consists of the extraction of DNA from soil for the identification of the main groups of soil organisms: bacteria, protists, fungi, nematodes, insects and earthworms. The DNA analysis will allow to (i) get an overview of the species present in each soil sample, and (ii) to have an approximate idea of the relative abundance of the considered soil organisms. Field-moist samples are needed for soil DNA analysis. Since samples cannot be analysed immediately after sampling, they have to be frozen to avoid damages of genetic material. In addition to the specific conditions of storage, DNA analysis requires a great laboratory work. Consequently, we propose to conduct DNA analysis in a reduced number of samples, for instance around 1,000 soil samples. Soil biodiversity has to be assessed during the Spring-Summer active period for most soil organisms, in particular meso- and micro-fauna, to obtain an accurate community structure of the soil biodiversity.

5 Impact of proposed Modules on the organization of LUCAS Soil Component

Module 1 contains physico-chemical parameters already analysed in LUCAS 2009/2012 and 2015 Topsoil Surveys. The sampling method in Module 1 follows the procedure in LUCAS 2009/2012 and 2015 [4], thus its performance has no implications on the organizational aspects of coming LUCAS Soil Surveys. However, analysis and measurement of soil parameters in Modules 2, 3, 4, 5, and 6 require to carry out new sampling methods in LUCAS Soil Surveys (see section 3). Consequently, the organization of coming LUCAS Soil Surveys has to be adapted to take on these Modules. Below we detail some of the organizational aspects that have to be readjusted.

5.1 Surveyors' expertise and training

Normal surveyors can conduct soil sampling for all Modules following an appropriate training. If the horizon approach is used for studying soil profiles (Module 6), it is mandatory to hire expert surveyors, for instance soil scientists.

5.2 Arrangement of transport of samples

Transport of samples to JRC and/or a central laboratory for analysis have to be readjusted for field-moist samples in Module 2 and frozen samples in Module 5. The transport of these samples requires special conditions of temperature. Field-moist samples in Module 2 have to be transported at maximum 4 $^{\circ}$C to ensure that their humidity is preserved. Frozen samples in Module 5 shall be transported at -20 $^{\circ}$C to maintain the cold chain and avoid damages of biological material of samples. Specific cold boxes and refrigerator trucks will be needed for the transportation of these samples, as described in the above sections.

5.3 The data management tool

The existing schema of data management tool (DMT) can be used for coming LUCAS Soil Surveys. Analysis of additional soil parameters in LUCAS Soil Surveys will not have big implications on the DMT. For the soil profile survey, the schema of the existing DMT shall be adapted to deal with horizons or fixed-depth layers within soil profiles.

5.4 Quality assurance of the data

Following the LUCAS 2009/2012 and 2015 Topsoil Surveys, we recommend applying a uniform sampling design, standardized methodologies and nomenclature to secure the internal coherence of the data. The surveyors shall follow precisely described quality procedures during field measurements and collection of samples. Furthermore, samples shall be analysed in an accredited central laboratory using standard methods to provide coherent and comparable data.

If necessary, quality controls of laboratory analyses and data storage can be conducted according to the procedures established in the LUCAS 2009/2012 Topsoil Survey [4]. For instance, internal control and external peer review process of the DMT, control of laboratory analyses by repeated analyses of randomly selected samples and control of registration of samples, and assessment of data against pedological criteria by soil experts.

5.5 Dissemination strategy for LUCAS soil data

The analytical data of the Soil Profile Survey in 2018 will be available for the public through the European Soil Data Centre. The data from LUCAS 2009/2012 Topsoil Survey is already available in the European Soil Data Centre. For LUCAS 2015 Topsoil Survey, the analyses are in progress and the data will be available in the future.

The samples of all LUCAS Soil Surveys will be stored in the JRC’s European Soil Repository for future research purposes. Currently, the repository contains soil samples from LUCAS 2009/2012 Topsoil Survey.

6 Cost estimation of LUCAS Soil component

Table 2. Cost estimation of each Module proposed in this proposal, based on data from LUCAS 2015 Soil Survey and market research.

Module	Recurrence (years)	Number of points	Surveyors' profile	Number of surveyors	Cost per hour surveyor (€)	Time per point (min)	Points per day	Special needs	Equipement	Unit cost of equipement (€)	Total cost of transport (€)	Total cost of analysis (€)	Training needs
Module 1: Air-dried samples													
Sampling	6	ca. 27,000	normal	700	normal	10	10	n.a.	Spade, measuring tape, bucket Plastic bags	80 4,390 (cost for 27,000 samples)	n.a.	n.a.	3 h (2 theory + 1 practice)
Transport of samples	6	ca. 27,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	15,000	n.a.	n.a.
Analysis (all except heavy metals) *Analysis of heavy metals*	6	ca. 27,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	700,000 1,000,000	n.a.
Storage of samples at JRC Soil Archive	n.a.	ca. 27,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Module 2: Field-moist samples													
Sampling	6	ca. 27,000	normal	700	normal	5	10	cooling	Spade, measuring tape, bucket Plastic bags Cool boxes, reusable cool packs	Equipment for air-dried samples is used 4,390 (cost for 27,000 samples) 300	n.a.	n.a.	No additional training needed
Transport of samples at 4 ˚C	6	ca. 27,000	n.a.	n.a.	n.a.	n.a.	n.a.	cooling	Positive cold boxes	583	15,000	n.a.	n.a.
Storage of samples at 4 ˚C, before sending samples to laboratory	6	ca. 27,000	n.a.	n.a.	n.a.	n.a.	n.a.	cooling	Refrigerator	10,474	n.a.	n.a.	n.a.
Analysis	6	ca. 27,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.d.	n.a.
Module 3: Field measurements													
Thickness of peat in Histosols	6	ca. 2,000	normal	700	normal	3	10	n.a.	Spade, measuring tape	Equipment for air-dried samples is used	n.a.	n.a.	20-30 min. theory
Evaluation of soil erosion	6	ca. 27,000	normal	700	normal	5	10	n.a.	Camera	100	n.a.	n.a.	
Module 4: Undisturbed samples													
Sampling	n.a.	ca. 9,000	normal	200	normal	15	6	n.a.	Metallic ring Mallet Plastic bags	17 15 4390	n.a.	n.a.	10 min. practice
Weighing	n.a.	ca. 9,000	normal	200	normal	n.a.	n.a.	n.a.	Scale	80-300	n.a.	n.a.	
Module 5: Frozen samples													
Sampling	3	500-1,000	normal	2 per country	normal	10	4	cooling	Spade, measuring tape, bucket Plastic bags Gloves Cool boxes, reusable cool packs	80 150 274 300	n.a.	n.a.	3 h (2 theory + 1 practice)
Transport of samples	3	500-1,000	n.a.	n.a.	n.a.	n.a.	n.a.	cooling freezing	Positive cold boxes (surveyors to JRC) Negative cold boxes (JRC to laboratory)	58 44	75,000	n.a.	n.a.
Storage of samples at -20 ˚C at JRC, before sending samples to laboratory	3	500-1,000	n.a.	n.a.	n.a.	n.a.	n.a.	freezing	Ultra Low Freezer Falcon tubes	10,000-15,000 26	n.a.	n.a.	n.a.
Analysis	3	500-1,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	90	n.a.
Module 6: Soil profiles													
Sampling	6	ca. 2,000	normal/ expert	5 per country	normal/ n.d.	20/45	5/2	n.a.	Spade, measuring tape, bucket Plastic bags Auger Soil core sampler, metallic rings	80 1,500 70 2,000	n.a.	n.a.	2 h (1 theory + 1 practice)
Transport of samples	6	ca. 2,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	15,000	n.a.	n.a.
Analysis	6	ca. 2,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	700,000	n.a.
Storage of samples at JRC Soil Archive	n.a.	ca. 2,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

7 Conclusion: evaluation of priorities for LUCAS 2018

Based on the users' needs collected, the following priorities have been set for LUCAS 2018 Soil Component:

Assessing **soil biodiversity** is critical due to its influence on soil quality. Soil organisms support soil functions such as food and biomass productivity, climate regulation, transport and storage of substances, and preservation of pharmaceutical and genetic resources. Thus, a decline of soil biodiversity can negatively influence soil functioning and quality. However, currently there is no detailed survey of soil biodiversity in the EU. EcoFINDERS project (ended in December 2014) is the most recent project assessing soil biodiversity in the EU soil, with about 80 points of control [14]. We propose to launch a soil biodiversity survey with 1,000 points of control in LUCAS 2018 Soil Survey. This will allow assessing the status of biodiversity regarding land use/land cover and physico-chemical properties of soil in the EU. This information will help the European Commission to develop and implement strategies for a sustainable use of the soils. Such an assessment will be of key relevance to the achievement of the EU2020 Biodiversity Strategy.

Measuring **bulk density** is also a top priority for assessing soil compaction and estimating organic carbon stock. Soil compaction negatively affects soil functions such as food and biomass production, storage and transport of water and habitat and gene pool. Since it is inversely related to porosity, bulk density is a key indicator of soil compaction (i.e. soil compaction increases bulk density as decreases porosity). Bulk density is also necessary to calculate organic carbon stock in soil, which is key data for developing future actions towards a sustainable growth in the EU and it will be very useful information for supporting the Roadmap to a Resource Efficient Europe (COM(2011)571). We propose to measure bulk density at least in 1/3 of the points in LUCAS 2018 Soil Survey in order to assess soil compaction and carry out estimations of soil organic carbon stocks. Since *s*oil compaction can negatively affect soil biodiversity, we recommend including the points where soil biodiversity will be assessed on the set of 1/3 points for bulk density.

Heavy metals have only been analysed in soil samples collected in LUCAS 2009/2012 Topsoil Survey. Based on this data, the Land Resource Management Unit of JRC is currently preparing a report of results of heavy metals in topsoil in the EU. The goal of the report is to show regional and land use/land cover specific trends on the distribution of heavy metals and to identify potential threats of soil contamination by heavy metals in topsoil in the EU. This report will allow us to identify critical heavy metals that shall be analysed in coming LUCAS Soil Surveys. We recommend repeating soil sampling to analyse critical heavy metals in LUCAS 2018, in order to check the repeatability and reliability of the applied analytical method. Density of sampling points for this purpose can be adapted, i.e. focused in specific regions of the EU and specific land uses/land covers, based on the results of heavy metals in LUCAS 2009/2012 Topsoil Survey.

For EU policies on agriculture, climate and environment, 2018 is an important reference year. As a result, there is an increasing demand for up-to-date information on soils for 2018. This information will be used to support EU policies in the following years. Thus, **a topsoil sampling** will have to be included in the LUCAS 2018 Survey in order **to analyse physical and chemical parameters already examined in the LUCAS 2009/2012 and the LUCAS 2015**. **Field measurements** such as signs of **soil erosion** and **thickness of organic layer in Histosols** will be also analysed in LUCAS 2018 to assess two critical soil degradation processes in the EU: soil erosion and organic carbon decline due to land use changes and land take of Histosols.

Studying **soil profiles** provides extremely rich information on the soil system for environmental and agricultural applications. Thus, a soil profile survey is important for implementing a sustainable soil management plan in the EU. However, organizing such a survey has several difficulties as explained before: selection of representative (land use/land cover and soil heterogeneity) sampling points using LUCAS grid might be problematic, and expert surveyors might be also needed for the profile description. Consequently, a survey of soil profiles might be costly and time-consuming. We consider that a survey of soil profiles is not feasible with the available budget and technical resources for the LUCAS 2018. The capacity of performing a soil profile survey within LUCAS Soil Component might be studied for coming LUCAS Surveys.

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Annex 1: Soil properties analysed in LUCAS 2009/2012 and LUCAS 2015

Soil information /Potentially interested DGs, Agencies	Related soil functions	Related soil degradation processes	Related legislations
Organic carbon / AGRI, ENV, CLIMA, JRC, EEA	Food and other biomass production Storage, filtration, transformation - carbon sequestration - nutrient cycling - water storage, filtration Climate regulation *Other soil properties related to OC:* - Buffering ability - Hydraulic conductivity	Organic C and other nutrients decline Biodiversity decline Erosion	***Agricultural Policies*** Common Agricultural Policy Nitrates Directive Sustainable Pesticide Use Directive Use of Sewage in Agriculture ***Environmental and Climate Policies*** Environmental Impact Assessment Directive Water Framework Directive Floods Directive Air Quality Framework Directive Habitat Directive LULUCF Decision EU Strategy on Adaptation to Climate Change ***Industrial Policies*** Landfill of Waste Directive Waste Framework Directive ***Others*** Roadmap to a Resource Efficient Europe EU2020 Biodiversity Strategy Horizon 2020: Research and Innovation 7th Environmental Action Programme
Coarse fragments, Clay, silt, and sand / AGRI, ENV, JRC	Storage, filtration, transformation - water storage, filtration - filtering: contaminants, excess nutrients - nutrient cycling - carbon sequestration Food and other biomass production Source of raw material Habitat and gene pool	Erosion Landslides Compaction Contamination	
pH / AGRI, ENV, JRC	Storage, filtration, transformation - nutrient cycling - filtering: contaminants, excess nutrients	Salinization Contamination *Other problems* : Nutrient imbalance	
Cation exchange capacity / AGRI, ENV, JRC	Storage, filtration, transformation - nutrient cycling - filtering: contaminants, excess nutrients *Other soil properties related to CEC:* - Buffering ability	*Other problems* : Nutrient imbalance	
NPK / AGRI, ENV, JRC, EEA	Food and other biomass production	*Other problems:* Nutrient depletion Nutrient imbalance	
Electrical conductivity / AGRI, ENV, JRC	Storage, filtration, transformation - nutrient cycling - filtering: contaminants, excess nutrients	Salinization Contamination *Other problems:* Nutrient imbalance	

Annex 1 (continuation)

<table>
<tr><th>Soil information
/Potentially interested DGs, Agencies</th><th>Related soil functions</th><th>Related soil degradation processes</th><th>Related legislations</th></tr>
<tr><td>Calcium carbonate
/ AGRI, ENV, JRC</td><td colspan="2">Lithogenic and/or secondary carbonates are important components of the mineral fraction in many semi-arid and arid soils, such as Calcisols. Calcium carbonate is:
▪ key agent of cementation (affects formation of stable aggregates)
▪ part of the C cyle (formation of pedogenic carbonates can result in the incorporation of C of biological origin into the soil mineral fraction, participating in the long-term C sequestration)
▪ regulating soil pH</td><td rowspan="2"><u>Agricultural Policies</u>
Common Agricultural Policy
Sustainable Pesticide Use Directive
Use of Sewage in Agriculture
<u>Environmental and Climate Policies</u>
Environmental Impact Assessment Directive
Water Framework Directive
Habitat Directive
LULUCF Decision
<u>Industrial Policies</u>
Landfill of Waste Directive
Waste Framework Directive
<u>Others</u>
Roadmap to a Resource Efficient Europe
EU2020 Biodiversity Strategy
Horizon 2020: Research and Innovation
7th Environmental Action Programme</td></tr>
<tr><td>Heavy metals
/ AGRI, ENV, SANTE, REGIO, JRC, EEA</td><td>——</td><td>Contamination</td></tr>
<tr><td>Multispectral properties
/ AGRI, ENV, CLIMA, JRC, EEA</td><td colspan="3">The near-infrared reflectance spectroscopy (NIRS) is a rapid, non-destructive, reproducible and cost-effective analytical technique for characterization and quantification of properties of materials.
The NIRS can be a good tool of assessment and monitoring of soil quality. Its potential use has been widely recognized for soil science. Indeed, it has been use to predict chemical, physical and biological properties of soil (such as C and N content, CEC and clay content). However, these studies are limited to a small number of samples analysed, lack of diversity of soil types and/or a small number of soil properties tested. The LUCAS Soil Survey provides the opportunity to apply this technology in a wide variety of soil types and conditions to (i) validate the ability of the NIRS to measure a wide variety of soil properties, and (ii) collect a large amount of NIRS soil data across EU required for monitoring and assessing soil quality.</td></tr>
</table>

Annex 2: Proposal for analysing new soil parameters in the LUCAS

Soil information /Potentially interested DGs, Agencies	Related soil functions	Related soil degradation processes	Related legislations
Bulk density, Soil moisture / AGRI, ENV, JRC, EEA	Food and other biomass production Storage, filtration and transport: water, nutrients Habitat and gene pool	Compaction Erosion Landslides	***Agricultural Policies*** Common Agricultural Policy ***Environmental and Climate Policies*** Environmental Impact Assessment Directive Water Framework Directive Floods Directive Habitat Directive LULUCF Decision EU Strategy on Adaptation to Climate Change ***Others*** Roadmap to a Resource Efficient Europe Horizon 2020: Research and Innovation EU2020 Biodiversity Strategy
Soil Biodiversity / AGRI, ENV, CLIMA, SANTE, JRC, EEA	▪ *Nutrient cycling and plant growth* . The importance soil biodiversity to support a more sustainable plant growth is well known. However, its capability to impact agricultural management at large scale is still missing. ▪ *Climate regulation* . The role of soil biodiversity in climate regulation at large scale needs to be better understood in order to assess how soil life may be targeted by climate regulation policies. ▪ *Source of pharmaceutical and genetic resources* . The World Health Organisation recognises that the increasing diffusion of antimicrobial resistance threatens the effective prevention and treatment of an ever-increasing range of infections caused by bacteria, parasites, viruses and fungi. As soil is extremely rich in unknown soil organisms, it can also represent a source of new antibiotics, as recently assessed.		
Cultivated Histosols / AGRI, ENV, CLIMA, JRC, EEA	▪ Histosols are organic soils, formed through the accumulation of partially decomposed plant residues. ▪ Histosols are increasingly seen as a key soil type in relation to carbon sequestration, habitat directive and water cycle management. ▪ With respect to cultivated histosols, the key issue is the continual reduction in thickness of the organic layer through shrinkage, oxidation and wind erosion. This causes an important reduction of organic carbon sequestered in this soils and has important implications for climate change.		
Soil erosion by water and wind / AGRI, ENV, JRC, EEA	— —	Erosion Landslides	

Annex 2 (continuation)

Soil information /Potentially interested DGs, Agencies	Related soil functions	Related soil degradation processes	Related legislations
Soil profiles / AGRI, ENV, CLIMA, JRC, EEA	A soil profile is a historic record of all the soil forming processes and it forms the unit of study in pedological investigation. Many soil functions cannot be explained by topsoil properties alone, and information of soil properties at various depth in the soil profile is needed to understand them: ▪ *Carbon sequestration* . Subsoil horizons contribute to more than a half of the total soil carbon stocks. In fact, the response of the subsoil C to land-use and/or management changes can equal that from the topsoil (20-30 cm). ▪ *Nutrient cycling* . Subsoils can be an important nutrient reservoir for plants, and roots have a key role on accessing these nutrients. For instance, subsoils can contribute to more than two-third of the plant nutrition of NPK in some crops, especially when the topsoil is dry or nutrient depleted. ▪ *Water storage, filtration and flood regulation* . Soil absorbs and stores water from precipitation. When the topsoil is very wet, water moves downward through the soil profile and accumulates in the subsoil. This creates a pool of available water for plants and soil organisms to live. When water is supplied to the soil at a rate that exceeds the soil's infiltration capacity, it moves downslope as runoff on sloping land or ponds on the surface of level land. When runoff occurs on bare or poorly vegetated soil, erosion takes place. ▪ *Contaminant filtering* . Soil absorbs contaminants from both water and air. Some of these compounds are degraded by microorganisms in the soil profile and others are held safely in place in the soil, especially in subsoil, preventing contamination of air and water.		***Agricultural Policies*** Common Agricultural Policy Nitrates Directive ***Industrial Policies*** Landfill of Waste Directive Waste Framework Directive ***Environmental and Climate Policies*** Environmental Impact Assessment Directive Water Framework Directive Floods Directive EU Strategy on Adaptation to Climate Change ***Others*** Roadmap to a Resource Efficient Europe Horizon 2020: Research and Innovation

LB-NA-28038-EN-N

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doi:10.2788/884940

ISBN 978-92-79-60683-0