JRC TECHNICAL REPORTS

LUCAS 2022 Soil Module

An overview

Jones, A.; Orgiazzi, A.; Panagos, P.; Scarpa S.; Havenga, C. & Van Eynde, E.

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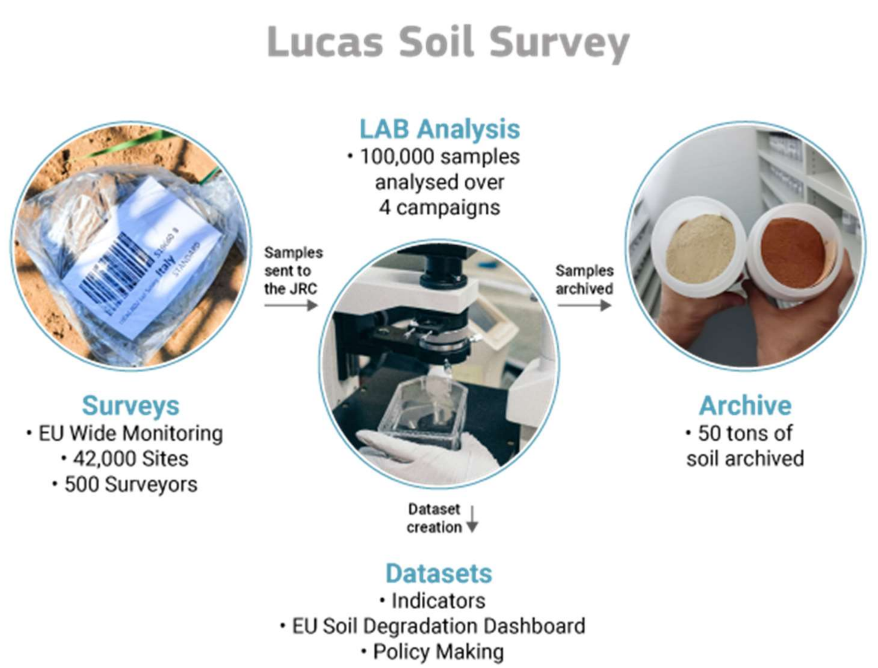

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Contents

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Finally, huge thanks to colleagues of the JRC Soil Team for their invaluable hands on support during the survey preparation, procurement and analysis.

Authors

Jones, A.; Orgiazzi, A.; Panagos, P.; Scarpa S.; Havenga, C. & Van Eynde, E.

Abstract

This report provides an overview of the soil dataset collected as part of the 2022 Land Use/Cover Area frame statistical Survey' (referred to as LUCAS Soil Module). It presents summary statistics of the collection of samples by Member States and land cover (LC) class, together with an overview of the laboratory analysis. The report relates to deliverable 2.1.

Regular monitoring provides a unique perspective on pressures affecting soils. In this respect, the soil module of LUCAS supports the specific needs of the European Commission by collecting data that characterises soil condition and health, which can be affected in relation to land use practices and other activities that are driven by specific policy instruments.

The LUCAS Soil module is the only mechanism that currently provides a harmonised and regular collection of soil data for the entire territory of the EU, addressing all major land cover types simultaneously, in a single sampling period (generally April – October).

At the same time, the LUCAS Soil module can support further policy needs through a flexibility that permits both the collection of new field data, if required, from new sampling sites. In turn, this can be complemented with additional laboratory analysis (e.g. micronutrients, specific pollutants). This capacity addresses the needs of a diverse policy user base and an evolving policy landscape.

New developments for the 2022 LUCAS Soil module survey included:

- An increase in the number of sampling points to c. 41,000 – this was to target statistically robust assessments of soil organic carbon content in arable soils at NUTS2 level, while at NUTS0 for grasslands and woodlands
- Revised sampling protocol for woodland sites and the collection of litter samples
- Collection of samples > 1 500 m
- Repeat assessment of bulk density for a subset of locations
- Sampling depth increased to 30 cm
- A doubling of the collection of fresh samples in order to extract DNA from the soil to assess soil biodiversity
- An assessment of gully erosion
- Increased measurements of metals and residues of plant protection products in a subset of samples.
- The involvement of organisations under the umbrella of EJP Soils in order to compare the LUCAS Soil approach with those of Member States

A set of descriptive environmental data for the new soil sampling locations is available to download from ESDAC.

Some takeaway messages:

- 4th iteration of soil sampling in LUCAS
- More than 41 000 locations were initially targeted for sampling
- 31 054 samples were collected covering all EU Member States, more than 11 000 were repeat visits to sites sampled in 2018.
- Bulk density measurements were made at various depths at 2 655 locations
- 1 410 fresh samples were collected to assess soil biodiversity
- 6 027 litter samples were collected from woodland sites

- More than 1 500 samples were collected from locations above 1 000 m, of which 202 will be assessed for soil biodiversity. The highest LUCAS sample was collected in France at an elevation of 2 260 m.
- Overall the collection of samples reached around 70% of expected, with BG, CY, CZ, EE, ES, HR, HU, LT, LV, PL and SI all returning more than 80% of planned samples. CZ collected 93% of samples.
- Access to land can be an issue, which resulted in a lower number of samples in some countries with both DE and DK returning less than 50% of standard samples. New developments for the 2022 LUCAS Soil module survey included:
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- Overall the collection of samples reached around 70% of expected, with BG, CY, CZ, EE, ES, HR, HU, LT, LV, PL and SI all returning more than 80% of planned samples. CZ collected 93% of samples.
- Access to land can be an issue, which resulted in a lower number of samples in some countries with both DE and DK returning less than 50% of standard samples. DE collected 39% of bulk density samples while BE only collected 29% of biodiversity samples. RO only returned 28% of litter samples.
- Surveyors were able to ascertain gully erosion features in around 399 591 locations (around 1% of the total surveyed).

1 Introduction

The aim of this report is two-fold:

(1) present an overview of the LUCAS 2022 Soil Module

(2) provide a description of the planned laboratory analysis

Soils deliver fundamental ecosystem services with environmental, economic, and social benefits for people. These services can be grouped into provisioning (food, feed, fuel, fibre and genetic resources), regulating (storage, filtration and cycling of nutrients and water), cultural (aesthetic, spiritual and recreational values) and supporting (essential for the provision of all other services). The provision of these ecosystem services depends on a sustainable management of soils aiming at maintaining/improving their health.

A sustainable soil management is a prerequisite to meet many of the objectives of the Green Transition([1]): preserving and restoring ecosystems and biodiversity, reducing nutrients losses and the use of pesticides and fertilisers, a zero pollution ambition, the mitigation of and adaptation to climate change, and the conservation of the rural landscape. In this context, a pan-European network of land and soil monitoring is fundamental. The topsoil assessment module of the LUCAS (Land Use and Cover Area Frame Survey) programme is currently the only mechanism for a harmonised monitoring (common sampling procedure and standard analysis methods) both in space and time of topsoils in the European Union (EU). It is worth noting that many of the principles of the LUCAS Soil Module are embodied into the proposed Soil Monitoring Law ([2]).

The LUCAS Programme is an area frame statistical survey organised and managed by Eurostat (the Statistical Office of the EU) to monitor changes in land use (LU) and land cover (LC) over time across the EU. Since 2006, Eurostat has carried out LUCAS surveys every three years. The surveys are based on the visual assessment of environmental and structural elements of the landscape in georeferenced control points. The points belong to the intersections of a 2 x 2 km regular grid covering the territory of the EU. This results in around 1,000,000 georeferenced points. In every survey, a subsample of these points is selected for the collection of field-based information. In LUCAS 2009, about 235,000 points were visited across 23 Member States (Bulgaria, Cyprus, Malta and Romania were not included – although the JRC arranged for a limited set of samples to be collected from Cyprus and Malta). In ten percent of these points, soil samples were taken from a depth of 20 cm and analysed for the following properties in a single laboratory: coarse fragments, clay, silt and sand, pH (in $CaCl_2$ and H_2O), organic carbon (OC), carbonates ($CaCO_3$), phosphorous (P), total nitrogen (N), extractable potassium (K), cation exchange capacity, multispectral properties, and heavy metals. The details and outcomes of the 2009 soil survey are fully documented in Tóth et al. (2013).

In LUCAS 2012, the soil survey was conducted only for Romania and Bulgaria, whose samples were analysed for the same set of physical and chemical properties as in 2009. Altogether, the LUCAS topsoil dataset from 2009 and 2012 contains data of physical and chemical properties of 22,001 locations.

In 2015, the LUCAS survey was carried out in all EU-28 Member States (MS). In the countries sampled in 2009 and 2012, 90% of the soil locations were maintained while the remaining 10% of points were substituted by new sampling locations, including points above 1,000 m in elevation, which were out of scope of the LUCAS 2009 and LUCAS 2012 surveys. The 2015 survey was also extended through funding provided by the JRC's Enlargement and Integration Programme to Albania, Bosnia and Herzegovina, Croatia

[1] The European Green Deal: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[2] Proposal for a Soil Monitoring Law: https://www.consilium.europa.eu/en/press/press-releases/2024/06/17/soil-monitoring-law-eu-on-the-pathway-to-healthy-soils-by-2050/

(before it became a Member State), Montenegro, North Macedonia, and Serbia. Switzerland also participated in the survey. In total, 26 500 locations were targeted in 2015, of which 25 000 were in the EU-28.

As for LUCAS 2009 and 2012, soil samples in 2015 were collected from a depth of 20 cm following a common sampling procedure and were analysed for physical and chemical properties (except for heavy metals) in a single laboratory using the same analytical methods. In addition, electrical conductivity (EC) was included for the first time. The details and outcomes of the 2015 survey in the EU are documented in Jones et al. (2020). In total, the LUCAS topsoil dataset from 2015 contains data of physical and chemical properties of 21,859 locations in the EU-28 (out of 25,947 targeted).

A report on data produced for the Western Balkans from 2015 is due to be published by the JRC in early 2025.

In LUCAS 2018, the soil survey was carried out only in the all EU MS plus the UK (at that time still in the EU) using the same set of 25,947 locations that were targeted in 2015. In 65% of these locations, soil samples were to be taken from a depth of 20 cm following the standardised sampling procedure of the 2009/12 and 2015 surveys, in which a spade was used. In the remaining 35% of the locations (approximately 9,000 points), metallic rings were planned to be used instead, to collect soil cores to determine bulk density (BD), from a depth of 20 cm[3]. Finally, in 1,000 of the locations selected for bulk density determination, fresh soil samples were also targetted to assess biodiversity.

At the conclusion of the 2018 survey, samples were taken at various depths in 18,456 LUCAS points, out of the 25,947 locations targeted. In 18,216 locations, samples were taken from 0-20 cm depth i.e. 70.2 % of the targeted locations). In addition to these locations, there were 240 locations in which surveyors took samples from 0-10 cm depth or from 10-20 cm depth. For soil biodiversity assessment, samples were eventually taken in 885 points. The details and outcomes of the 2018 survey are documented in Fernandez-Ugalde et al. (2022).

Further details of the 2022 Survey are provided in the following sections.

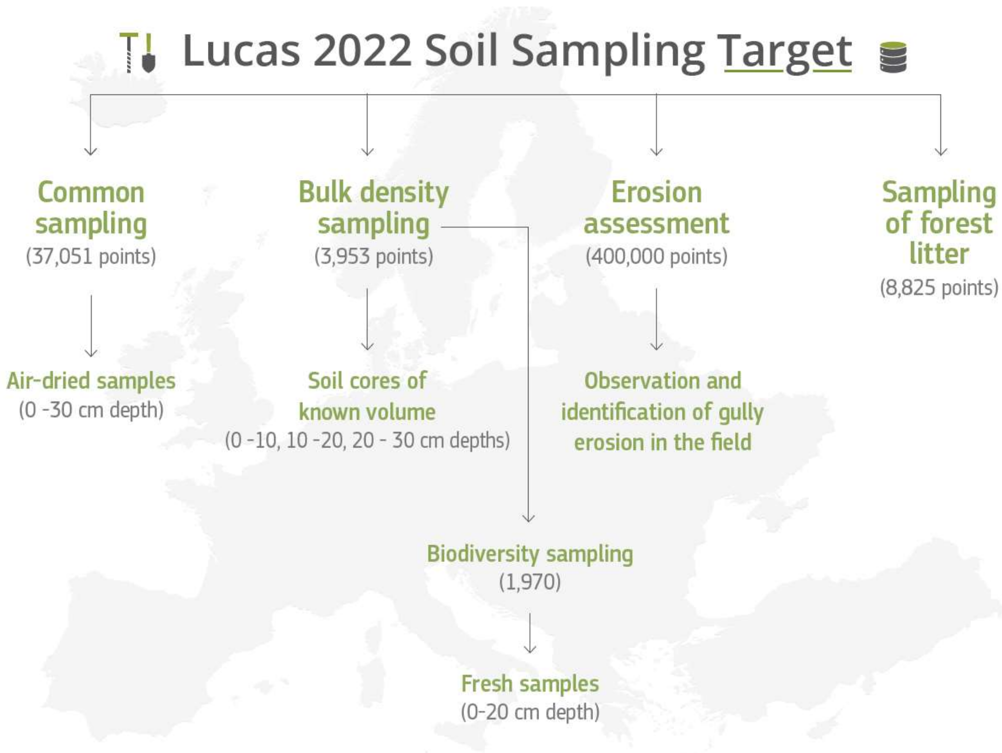
[3] In selected locations in Portugal (142 points), soil cores were taken also at a 20-30-cm depth.

2 LUCAS sampling methodology and laboratory analysis

The LUCAS 2022 Soil module was set for 41 000 points. Soil samples were taken following different sampling procedures: the majority of samples were collected using the 'standard' sampling procedure used in previous LUCAS. Bulk density and the sampling for biodiversity assessment follow a slightly different procedure. At biodiversity locations, separate standard and biodiversity samples are collected.

Bulk density sampling was planned for 4 000 points under different LC classes. In 2 000 out of these 4,000 points, samples were to be collected to assess soil biodiversity. In the remainder of the points, the common sampling procedure was carried out. Moreover, it included the following field-based assessments: the erosion assessment landscape features (Figure 1) ([4]).

Figure 1. Planned sampling schema for the LUCAS 2022 Soil Module



2.1 Sample collection

With the common sampling procedure, a composite sample of approximately 500 g was taken at each LUCAS point. The composite sample was consisted of five subsamples taken with the help of a spade.

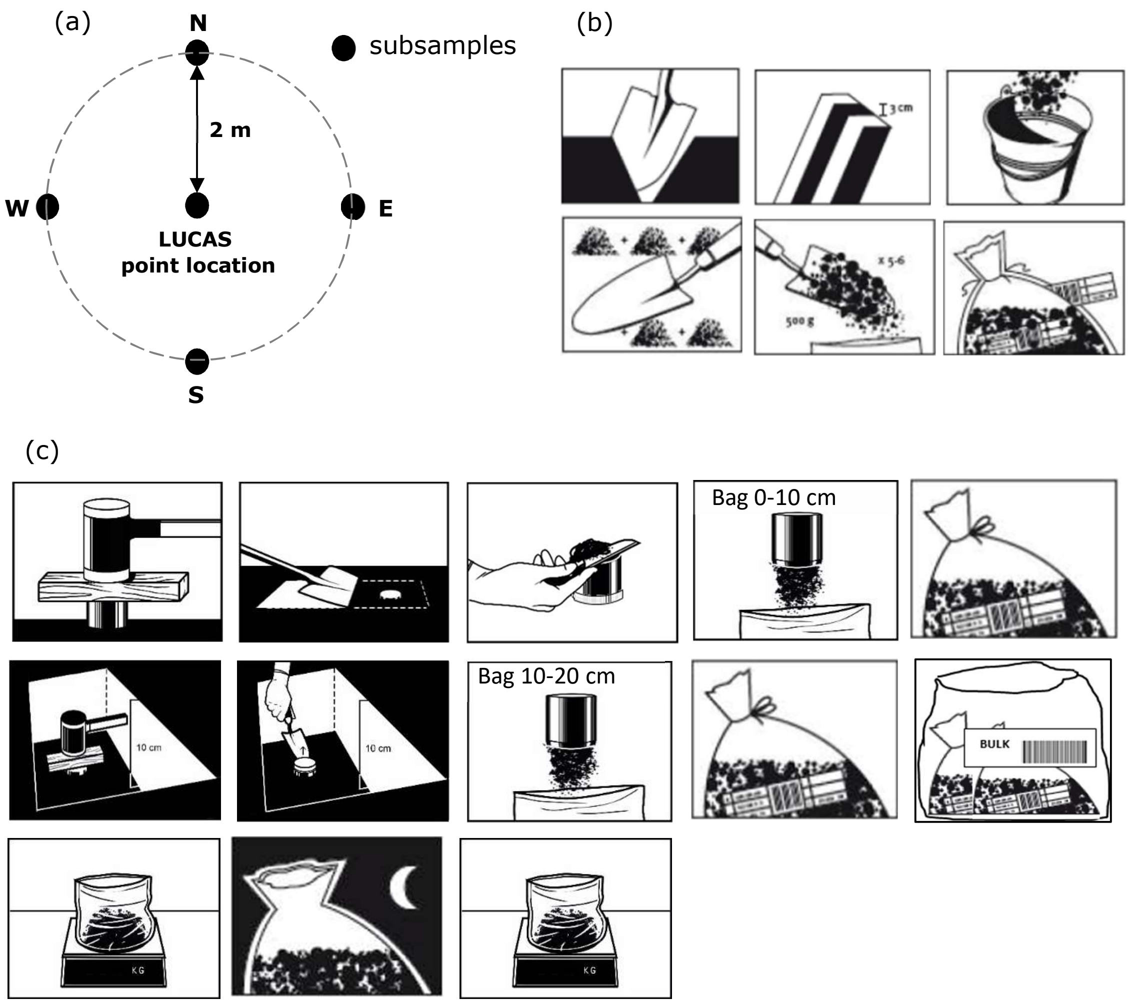
The first subsample was taken at the geo-referenced point location; the other four subsamples were collected at a distance of 2 m following the cardinal directions (North, East, South and West) (Figure 2a). Before taking the subsamples from cropland and grassland sites, stones (>6 cm) (FAO, 2006), vegetation residues, grass and litter were removed from soil surface by raking with the spade.

([4]) https://ec.europa.eu/eurostat/documents/205002/8072634/LUCAS2018-C1-Instructions.pdf

As shown by Figure 2b, a V-shaped hole was dug to a depth of 20 cm using the spade and a slice of soil (approximately 3-cm thick) was taken from the side of the hole with the spade. The slice was trimmed at the sides to give a 3-cm wide subsample. The subsample was placed in a bucket. The procedure was repeated at the other four subsample sites. Finally, the five subsamples in the bucket were mixed with a trowel. Vegetation residues and stones were removed.

Approximately 500 g of the mixed soil was taken with a trowel from the bucket, placed in a plastic bag, and labelled to derive the composite sample. Soil samples were allowed to air dry before the bags were sealed.

Figure 2. (a) LUCAS sampling schema, (b) summary of the common sampling procedure, and (c) summary of the bulk density sampling



For **determining bulk density**, soil cores were collected from 0 to 10, 10 to 20 and 20 to 30 cm depths.

Before taking the soil cores, stones (>6 cm) (FAO, 2006), vegetation residues, grass and litter were removed from soil surface in cropland and grassland sites by raking with the spade as in the common sampling procedure. After the cleaning of the soil surface, soil cores were taken from 0 to 10 cm depth with a metallic ring of 100 cm^3 at three LUCAS points. The first soil core was taken at the geo-referenced point location; the other two soil cores were taken at a distance of 2 m following the cardinal directions (a preference was indicated for North-South but the surveyor had the final choice) (Figure 2a).

As shown in Figure 3c, the metallic ring was gently driven into soil using a wooden block to push the ring with a mallet. This avoided the compaction of soil. The ring was removed from soil with the help of a spade placed underneath the ring. The excess soil around the ring was removed with a knife and the soil core was pushed into a labelled plastic bag. The procedure was repeated in the other points. The soil cores collected were placed in the same labelled plastic bag. In the end, three soil cores of known volume were taken at the 0-10 cm depth. After sampling the 0-10 cm depth was completed, the sampling of soil cores in the 10-20 cm and 20-30 cm depths were carried out following the same sampling procedure (Figures 2a and 2c).

At the end of each sampling day, the batch of soil cores of each depth were weighted (to provide the field-moist weight). The soil cores were then allowed to air-dry, and their weight was again recoded (air-dry weight). The plastic bags were then sealed for their transportation to the laboratory.

The **assessment of soil biodiversity** was carried out in field moist samples taken from 0-20 cm depth. A composite sample of approximately 500 g was taken at each LUCAS point. The composite sample consisted of five subsamples taken with the help of a spade. The first subsample was taken at the geo-referenced LUCAS point location; the other four subsamples were collected at a distance of 2 m following the cardinal directions (North, East, South and West) (Figure 2a). The common sampling procedure was used to take the subsamples. However, once the samples were mixed in the bucket, approximately 500 g of the mixed soil was placed in a plastic jar and labelled. The labelled jar was then stored in a polystyrene box cooled with freezer packs, sealed and sent to the JRC to control the condition of soil samples. Samples were then stored at JRC until their shipment to the laboratory for their analysis.

2.2 Sample analysis

Samples will be analysed in a single laboratory for each property listed in Table 1 according to standard ISO/CEN methods (unless indicated otherwise). Samples taken with the common procedure were analysed for physical and chemical properties (except for bulk density).

Bulk density will be determined with soil cores. Bulk density samples will also be subjected to the standard set of physical and chemical analysis. In field-moist samples, only DNA was analysed to assess soil biodiversity.

Before analyses, a subsample of the soil cores taken at each depth will be oven-dried and its weight recorded to determine bulk density from 0-10, 10-20 and 20-30 cm depths. The soil cores from the three depths will be mixed to derive a composite sample from 0 to 30 cm depth for its analysis.

More detail on laboratory analysis will be provided in D3.1.

Table 1. Planned analysis of physical, chemical and biological properties.

Soil properties	Method	Description
Water content		For bulk density calculation
Bulk density	Adapted ISO 11272:2017	Calculated from the mass and the volume of sole cores taken with rings of known volume
Coarse fragments	ISO 11464:2006	Sieving to separate coarse fragments (2-60 mm) from fine earth fraction
Clay, silt and sand	ISO 11277:1998 ISO 13320:2009	Laser diffraction
pH in $CaCl_2$ and in H_2O	ISO 10390:2005	Glass electrode in a 1:5 (V/V) suspension of soil in H_20 and $CaCl_2$
Electrical Conductivity	ISO 11265:1994	Metal electrodes in aqueous extract of soil
Organic carbon	ISO 10694:1995	Dry combustion (elementary analysis)
Carbonates	ISO 10693:1995	Volumetric method
Phosphorus	ISO 11263:1194	Spectrometric determination of P soluble in sodium hydrogen $CaCO_3$ solution
Total nitrogen	ISO 11261:1995	Modified Kjeldahl method
Extractable potassium	USDA−NRCS, 2004	Atomic absorption spectrometry after extraction with NH_4OAc
Oxalate extractable Fe, P, Al, As	ISO 12782-3:2012	Acid ammonium oxalate method
Effective cation exchange capacity	ISO 11260:2018	
Digestion of samples for metal analysis	ISO 11466: 1995 ISO 17586:2016 ISO 11260:2018	Aqua regia, dilute nitric acid and diluted salt solutions
Metals[5]	ISO 11466: 1995	Following extraction, the resulting solutions are analysed by inductively coupled plasma-optical emission spectrometry.
Biodiversity	DNA analysis	
Plant protection products	Various methodologies Non-targeted and targeted analysis	*Sample preparation:* - Multi-residue method QuEChERS - Srong alkaline/acid extractions - McIlvainbuffer/acetonitrile;SPE cleanup - MeOH/0.1 M HCl, 80°C; dilution *Instrumental analysis:* LC-MS/MS and GC-MS/MS
Visible and Near Infrared Spectra	Reflectance	350-2500 nanometer

[5] Al, Sb As, Ba, Be, B Cd Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg Mo Ni, P, K, Se Ag Na, Sr S, Te TI Sn Ti V, Zn

2.3 Field-based assessments

In addition to the soil sampling, gully erosion and landscape features were assessed in all 400 000 points of the main survey. Surveyors were trained and provided with a photographic guideline ([6]) to identify the signs of gullies and field boundaries. The field form ([7]) included a set of questions to describe and detail the conditions of any gullies identified signs.

([6]) https://ec.europa.eu/eurostat/documents/205002/13686460/C1-LUCAS-2022.pdf
([7]) https://ec.europa.eu/eurostat/documents/205002/13686460/C2-LUCAS-2022.pdf

3 Sample collection

3.1 Identification and registration of samples during the field survey

Points in the LUCAS grid are identified by unique Point-IDs, which are used to record agro-environmental data related to each point in the Data Management Tool (DMT).

Furthermore, soil samples collected at LUCAS points are identified by an additional, unique Soil-ID, created by the JRC (Figure 3). The Soil-ID in 2022 is a six-digit code where the final digit confirms the type of sample. In this manner, Soil-IDs ending in 0 = standard, 1 = BD 0-10 cm, 2 = BD 10-20 cm, 3 = BD 20-30 cm (only five digits were used to identify the bag containing the three depths), 4 = Bio and 9 = Litter.

The first five digits of every Soil-ID were assigned in blocks for each MS.

Surveyors randomly assign Soil-IDs to the samples when collected. Each sample is double-packed with twin labels that have the same Soil-ID (A and B).

At each LUCAS point, surveyors document agro-environmental observations by filling in a field form and by taking photographs. Surveyors have to indicate the Point ID and the Soil ID in the field form. All the data is then stored in the DMT. Thus, every soil sample has a double identification: the Soil-ID and the Point-ID.

The Soil-ID is used to identify the samples in the laboratory and provides the soil data, while the Point-ID gives the field data and is used to link information from different LUCAS surveys.

Figure 3. Example of soil label with Soil-ID for a bulk density point in Finland.

Example of soil label with Soil-ID for a bulk density point in Finland. The core code 39917 is augmented by the characters 1, 2 and 3 to indicate the depth. Bulk density Soil-IDs for Finland ranged from 38624 -38828, 39917-39946, 80301-80300 and 81139-81150.

399171
BULK 0-10
LUCAS 2022 Soil Survey **Finland**

399172
BULK 10-20
LUCAS 2022 Soil Survey **Finland**

399173
BULK 20-30
LUCAS 2022 Soil Survey **Finland**

39917
BAG
LUCAS 2022 Soil Survey **Finland**

4 Overview of the 2022 survey

4.1 Soil samples

Soil samples were collected at a total of 31 054 locations by the end of the 2022 survey (Figure 4 - Figure 5 & Table 2 - Table 3).

Figure 4. Actual sampling results for the LUCAS 2022 Soil Module

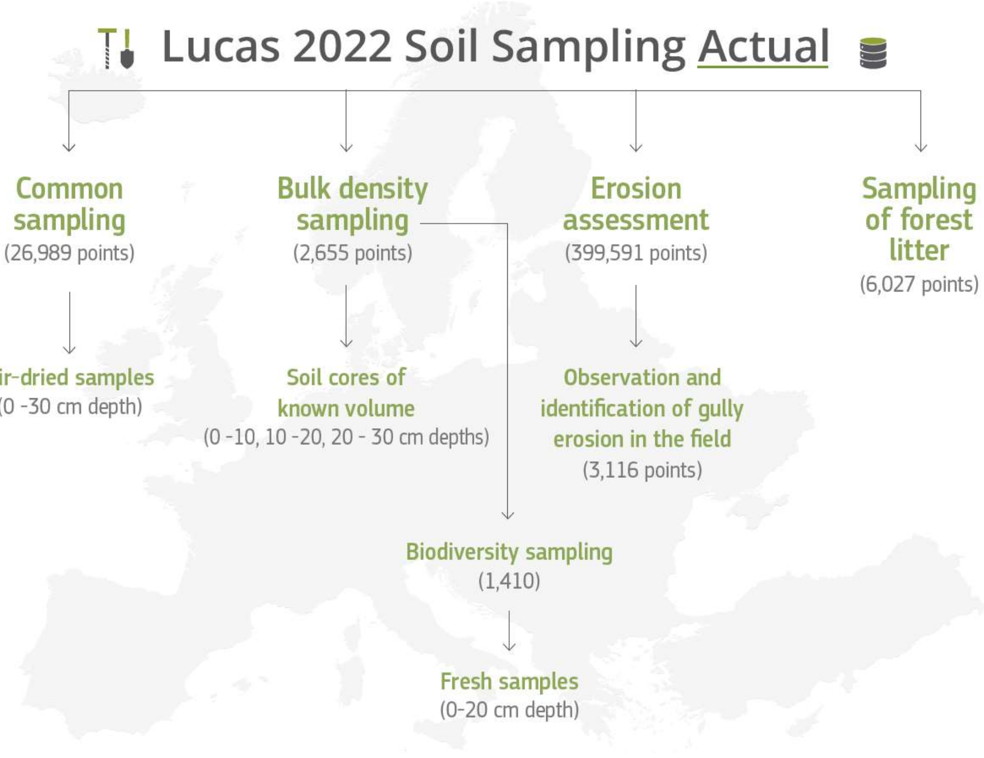


Table 2. Summary of planned and actual soil points visited in LUCAS 2022.

	***N* locations**			***N* samples**		
	Planned	**Sampled (1)**	**%**	**0-10 cm**	**10-20 cm**	**20-30 cm**
Basic soil properties	37 051	26 989	73	2 655	2 505	2 285
Bulk density	3 953	2 655	67	2 655	2 505	2 285
Biodiversity	1 970	1 410	72	1 410		
Litter	8 825	6 027	68			

(1) LUCAS points sampled and identified with unique Point IDs.

Figure 5. Map showing the location of LUCAS 2022 soil points.

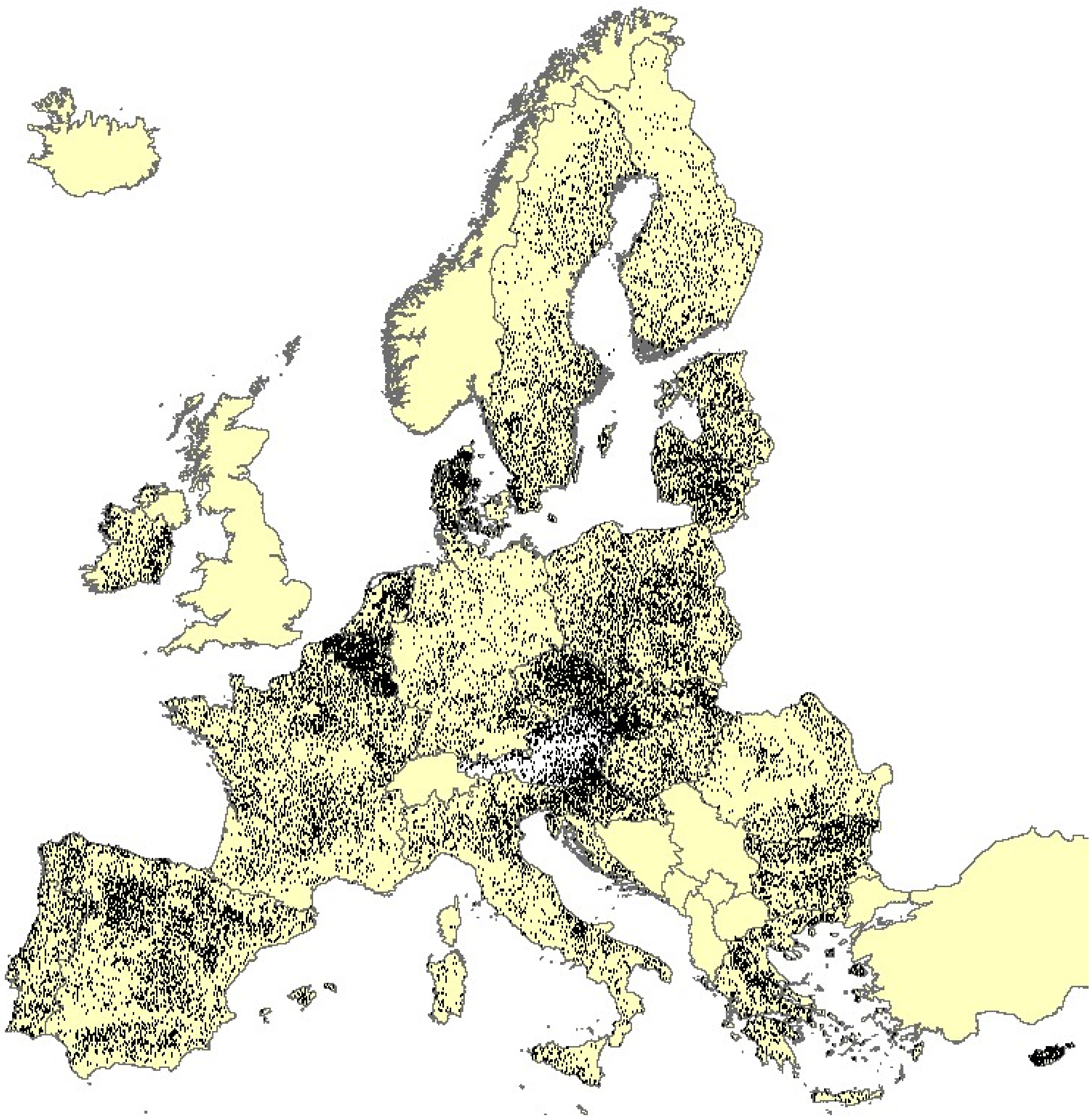


Figure 6 Location of standard sampling sites

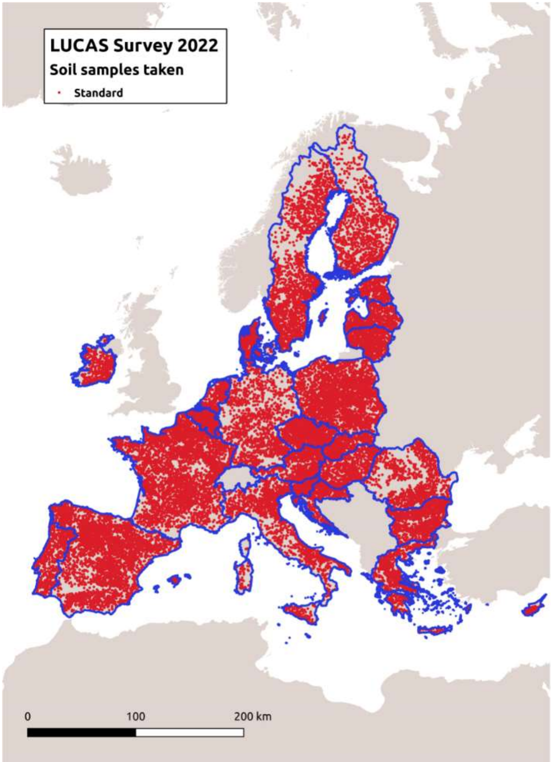


Figure 7 Location of bulk sampling sites

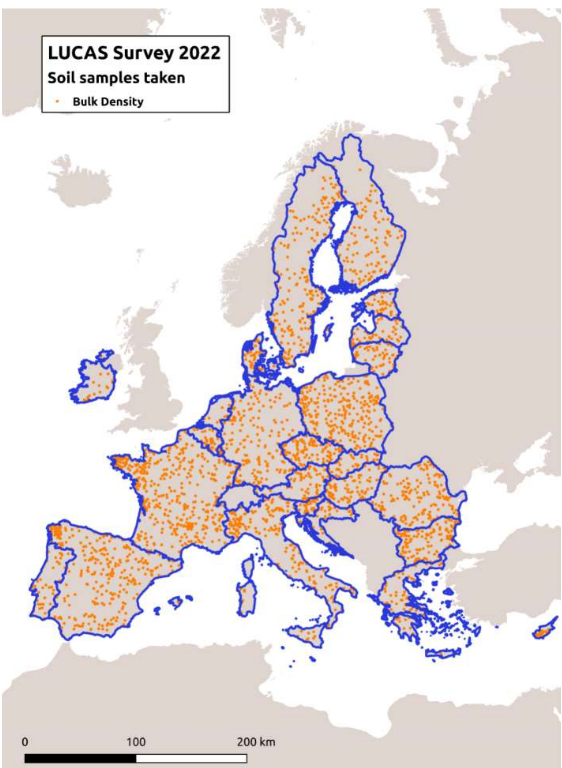


Figure 8 Location of biodiversity sampling sites

Figure 9 Location of forest litter sampling sites.

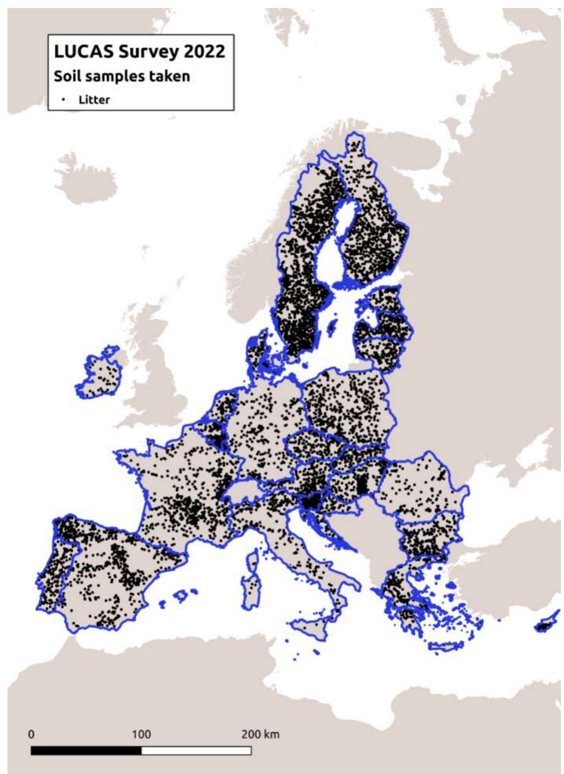


Table 3. Details of samples taken in the LUCAS 2022 soil survey in each MS.

MS	TOTAL Planned	STD Points			BD points			Bio points			Litter		
		Target	Actual	%	Target	Actual	%	Target	Actual	%	Target	Actual	%
AT	1512	1375	902	65.6	137	66	48.2	87	47	54.0	283	200	70.7
BE	1158	1108	842	76.0	50	29	58.0	11	3	27.3	171	98	57.3
BG	1356	1217	1115	91.6	139	135	97.1	63	62	98.4	256	206	80.5
CY	290	257	220	85.6	33	29	87.9	13	12	92.3	67	51	76.1
CZ	1414	1306	1215	93.0	108	101	93.5	42	38	90.5	196	169	86.2
DE	2845	2440	1138	46.6	405	158	39.0	150	69	46.0	390	197	50.5
DK	1348	1263	618	48.9	85	48	56.5	25	15	60.0	124	63	50.8
EE	461	417	356	85.4	44	37	84.1	19	16	84.2	150	109	72.7
EL	1605	1487	1073	72.2	118	77	65.3	52	42	80.8	332	205	61.7
ES	4362	4020	3455	85.9	342	284	83.0	228	198	86.8	777	554	71.3
FI	1818	1623	899	55.4	195	111	56.9	134	90	67.2	964	543	56.3
FR	4776	4190	3034	72.4	586	378	64.5	286	191	66.8	794	557	70.2
HR	607	557	478	85.8	50	41	82.0	25	20	80.0	163	98	60.1
HU	911	807	666	82.5	104	80	76.9	31	26	83.9	201	147	73.1
IE	740	690	456	66.1	50	21	42.0	22	9	40.9	71	28	39.4
IT	2579	2279	1412	62.0	300	189	63.0	156	101	64.7	471	203	43.1
LT	1110	1035	829	80.1	75	57	76.0	36	32	88.9	195	137	70.3
LU	201	176	139	79.0	25	18	72.0	7	5	71.4	72	58	80.6
LV	717	661	593	89.7	56	48	85.7	30	26	86.7	250	221	88.4
MT	20	2			18	12	66.7	7	3	42.9	2	1	50.0
NL	895	851	476	55.9	44	13	29.5	18	9	50.0	115	67	58.3
PL	3230	2907	2440	83.9	323	269	83.3	135	117	86.7	445	341	76.6
PT	998	932	614	65.9	66	42	63.6	42	27	64.3	292	166	56.8
RO	1614	1360	839	61.7	254	155	61.0	113	68	60.2	143	41	28.7
SE	2845	2587	1952	75.5	258	189	73.3	197	152	77.2	1513	1286	85.0
SI	512	475	407	85.7	37	30	81.1	19	15	78.9	202	167	82.7
SK	1080	1029	821	79.8	51	38	74.5	22	17	77.3	186	114	61.3
TOTAL	41004	37051	26989	72.8	3953	2655	67.2	1970	1410	71.6	8825	6027	68.3

Of the 41 000 locations that were initially targeted, 31 054 samples were collected in total with more than 11 000 being repeat visits to sites sampled in 2018 (almost 73% of planned). BG, CY, CZ, EE, ES, HR, HU, LT, LV, PL and SI all returning more than 80% of planned samples. CZ collected 93% of samples.

Bulk density measurements were made at various depths at 2 655 locations, with 2 505 and 2 285 reporting samples for two and three depths, respectively (67% of planned).

From these bulk density samples, 1 410 fresh samples were also collected to assess soil biodiversity (almost 72% of planned).

In total, 6 027 litter samples were collected from woodland sites (almost 68% of planned).

Access to land is an increasing issue, which resulted in a lower number of samples in some countries. Both DE and DK returned less than 50% of standard samples while DE collected only 39% of bulk density samples, BE only collected 29% of biodiversity samples and RO only returned 28% of litter samples.

Tables 4-7 show the breakdown of sample type by land cover in each MS. Despite instructions that litter samples were only to be taken in Woodland sites (Land cover Code C), a number of sites with different classifications have been considered as woodland.

Table 4. Standard sampling sites by MS and land cover

MS	ARTIFICIAL	CROPLAND	WOODLAND	SHRUBLAND	GRASSLAND	BARE	WATER	WETLANDS
AT	4	428	180	5	277	7		1
BE	2	551	94		128	63		4
BG	1	678	192	28	197	16		3
CY	1	124	42	12	32	8		1
CZ	3	753	147	2	262	42		6
DE	6	688	178	4	218	40		4
DK		443	67	3	94	8		3
EE	2	154	98	4	91	6		1
EL	3	547	185	33	234	59	1	11
ES	9	1918	630	44	526	321	2	5
FI	2	162	568	15	124	23		5
FR	13	1848	489	15	560	104		5
HR	2	179	87	24	163	22		1
HU	2	305	164	13	147	24	1	10
IE	2	171	26	9	177	2		69
IT	6	852	202	14	301	34	1	2
LT		494	130	4	175	21		5
LU	1	44	53	1	37	3		
LV	1	249	204	4	117	17		1
NL	3	309	71	2	81	6		4
PL	6	1536	356	7	454	74		7
PT	1	232	160	34	163	23		1
RO	3	541	40	16	219	13		7
SE	6	370	1146	38	274	38	1	79
SI		108	156	1	136	6		
SK	5	465	118	14	176	40		3
Totals	84	14149	5783	346	5363	1020	6	238

Table 5. Bulk density sampling sites by MS and land cover

MS	ARTIFICIAL	CROPLAND	WOODLAND	SHRUBLAND	GRASSLAND	BARE	WETLANDS
AT		24	21	1	19		1
BE		14	8		6	1	
BG	1	72	29	1	26	5	1
CY	1	12	8	5	3		
CZ		57	16	1	24	3	
DE	1	98	19		34	6	
DK		35	4	1	8		
EE		17	12	1	6	1	
EL		36	23	4	10	2	2
ES	1	159	40	10	51	23	
FI	1	14	79	1	15	1	
FR	1	242	53	4	73	4	1
HR		17	11	5	8		
HU	2	40	11	3	20	3	1
IE		2	5	1	12	1	
IT		94	34	2	56	3	
LT		31	12		12	1	1
LU	2	7	6		3		
LV		21	16		10		1
MT		5	1		4	2	
NL		5	4	1	3		
PL		166	41		57	5	
PT	1	11	14	2	14		
RO		84	12	2	54	2	1
SE	1	24	125	5	26	4	4
SI		5	12	1	12		
SK		23	6	1	7	1	
Totals	12	1315	622	52	573	68	13

Table 6. BIO sampling sites by MS and land cover

MS	ARTIFICIAL	CROPLAND	WOODLAND	SHRUBLAND	GRASSLAND	BARE	WETLANDS
AT		14	15	1	17		
BE		2	1				
BG	1	23	25		12	1	
CY	1	5	2	4			
CZ		17	12		9		
DE	1	33	17		16	2	
DK		12	2		1		
EE		5	9		2		
EL		18	19	3	2		
ES		101	38	11	29	19	
FI	1	8	71	1	9	9	
FR		94	48	4	43	1	1
HR		7	8	3	2		
HU		13	4	1	6	2	
IE			3		5	1	
IT		34	29	1	37		
LT		13	10		9		
LU	1	1	2		1		
LV		9	11		6		
MT		1	1		1		
NL		3	2	1	3		
PL		57	33		27		
PT		6	13	1	7		
RO		22	11	1	33	1	
SE	1	9	120	4	14	3	1
SI		1	7	1	6		
SK		7	5		5		
Totals	6	515	518	37	302	39	2

Table 7. Litter sampling sites by MS and land cover

MS	ARTIFICIAL	CROPLAND	WOODLAND	SHRUBLAND	GRASSLAND	BARE	WETLANDS
AT			196	1	3		
BE			97				1
BG			204	1	1		
CY			50	1			
CZ		1	165		3		
DE		2	193	1	1		
DK		1	62				
EE			109				
EL		1	202	2			
ES	1	1	551		1		
FI		1	531	6	4		1
FR		1	554		2		
HR			96	2			
HU			146		1		
IE			28				
IT			203				
LT			367	1			
LU			58				
LV			215	1	3	1	1
MT			1				
NL		1	65	1			
PL	1	1	335		4		
PT			166				
RO		1	40				
SE	5		1250	11	11	4	5
SI			167				
SK			113	1			
Totals	7	11	6164	29	34	5	8

Figure 10 Standard sampling points in croplands

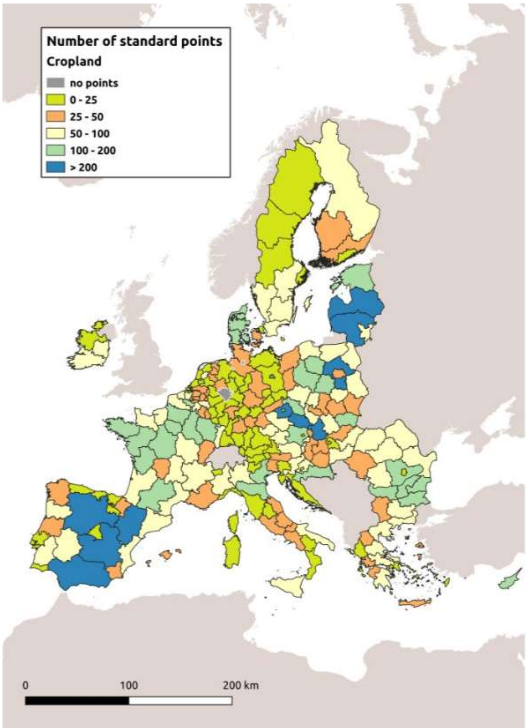


Figure 11 Standard sampling points in woodlands

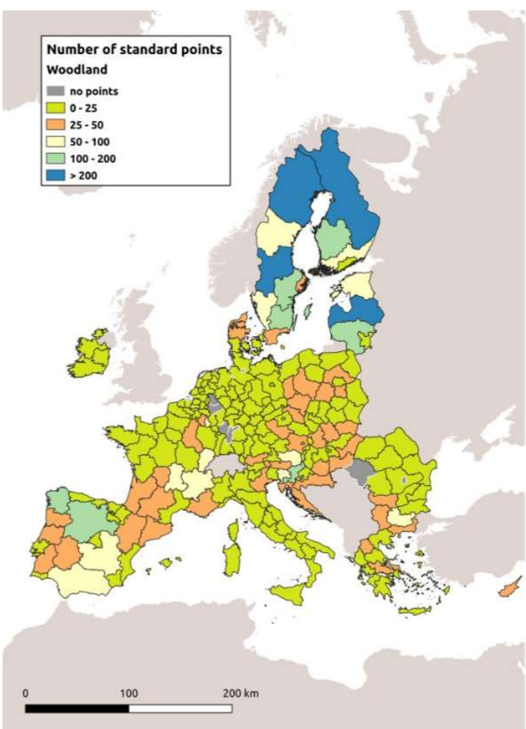


Figure 12 Bulk density sampling points in cropland

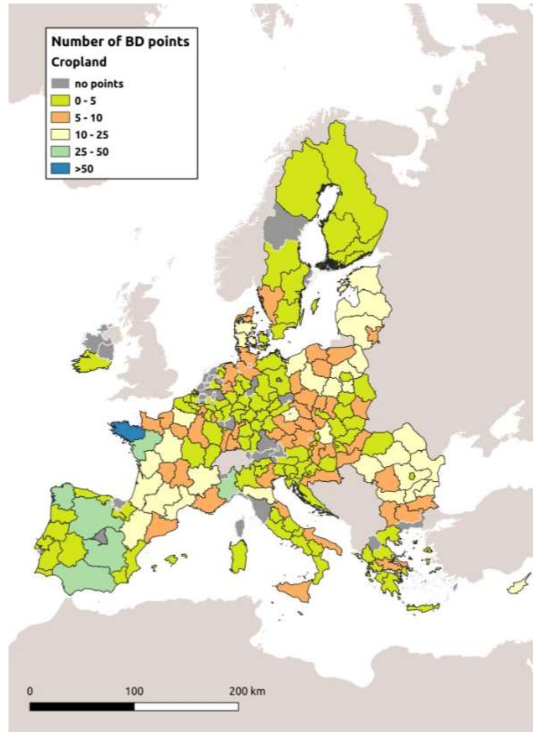


Figure 13 Bulk density sampling points in woodland

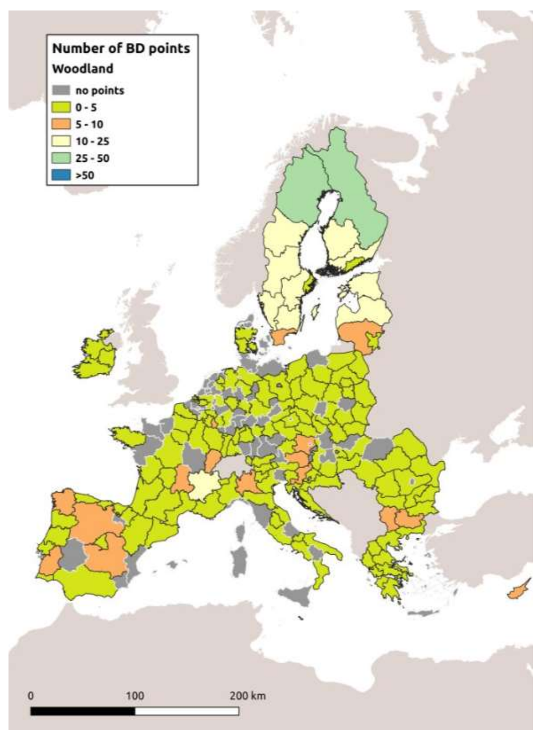


Figure 14 Sampling density: standard

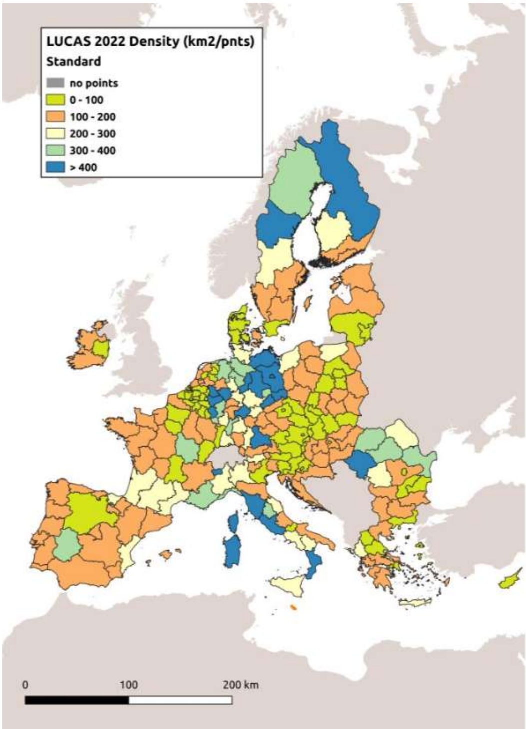
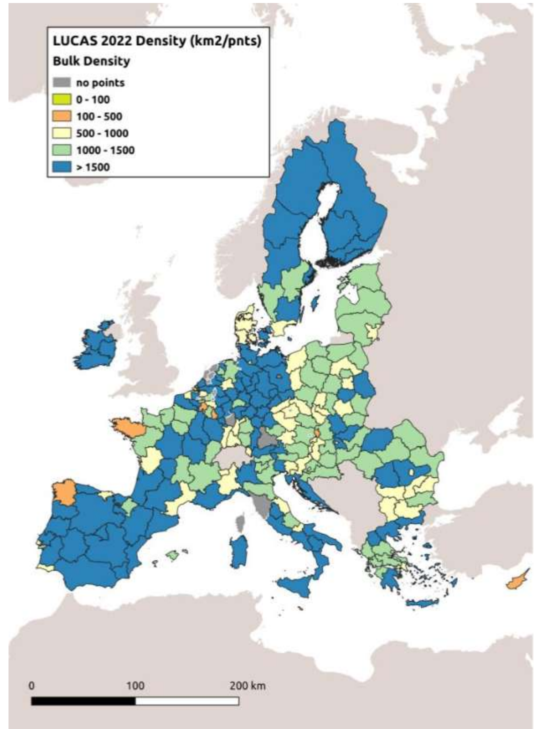


Figure 15 Sampling density: bulk density



A novel aspect of the 2022 LUCAS was to remove the elevation limits and target soils at higher elevations as these special environments are generally understudied and may be highly vulnerable to pressures from climate change.

In total, 1 566 samples were collected from elevations greater than 1 000 m (Table 8), of which around 35 locations in the Alpine region > 1 500 m. Over 200 of these samples will be analysed for soil biodiversity, which will give novel insights to these soils. The highest LUCAS sample was collected in France at an elevation of 2 260 m (Point ID 40782404).

Table 8 LUCAS 2022 samples > 1 000 m

MS	Standard	Bulk	Bio	Litter	Alps ?
AT	140	9	9	79	9
BG	50	14	11	53	
CY	3	1	1	3	
CZ	2	3	3	3	
DE	5	3	3	5	3
EL	71	10	10	59	
ES	761	66	62	347	
FR	176	53	52	119	52
HR	2	1	1	2	
IT	104	43	41	77	41
PL	1				
PT	6	1	1	1	
RO	6	2	2	6	
SI	19	6	5	21	5
SK	7	1	1	6	1
Total	1353	213	202	781	111

Figure 16 Locations of sampling points > 1 000 m

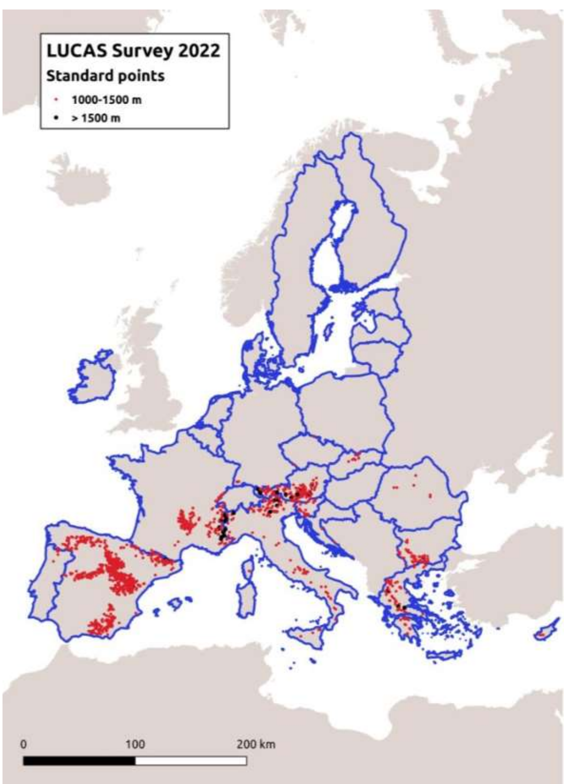
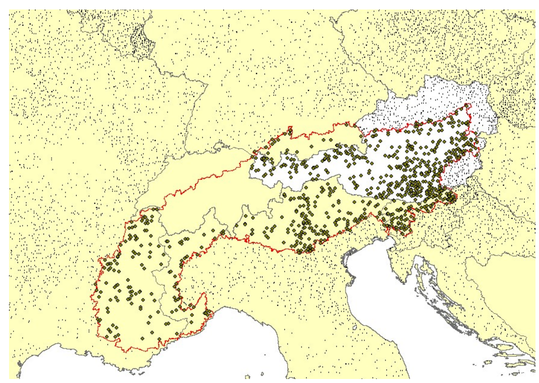


Figure 17 845 LUCAS 2022 points located within the region of the Alpine Convention



Finally, in relation to soil biodiversity, 50 samples were collected from soils within the capital cities of EU Member States in order to provide novel perspectives on urban soils, which were absent in the 2018 exercise.

4.2 Evaluation of field-based data

In addition to the soil sampling, the 2022 LUCAS also considered two soil-related aspects: gully erosion and landscape features in relation to erosion control. These included the presence of grass margins in croplands and different types of field boundaries (e.g. stone walls, etc).

Evaluation of gully erosion

Gully erosion occurs when running water is channelled across land and washes away soil where it passes. Gullies are classified depending on their permanent or ephemeral (temporary or seasonal) nature.

Permanent gullies are deep channels that cannot be eliminate by tillage. They can range from 0.5 to 30 m depth on deep soils.

Ephemeral gullies are shallower (< 0.5 m deep) channels formed in cropland that can be relatively easily obliterated by tillage. They form repeatedly at or near the same location on a yearly basis.

Badlands are heavily gullied landscapes, generally found in drylands. They are characterized by steep sided gullies, steep bottoms and a high drainage density. Badlands often develop on soft or unconsolidated geological materials with low permeability (e.g. marls), which reduces infiltration. Badlands account for some of the highest erosion rates worldwide and are associated with poor soil development and scarce vegetation cover.

Gully erosion in general can cause serious difficulties of land management and loss of productivity, reduction of surface water quality, sedimentation in drainage networks and the release of greenhouse gases.

Surveyors were asked to record evidence of gully erosion within a distance of 500 m from almost 400 000 LUCAS points. For positive sightings, surveyors had to take a picture of the area affected and indicate the distance from the LUCAS point.

The successful implementation of the visual assessment of gully erosion channels in the 2018 LUCAS prompted its repetition in a more comprehensive manner in 2022. The assessment was made in all 399 591 locations that were visited by surveyors. The primary objective is to enhance understanding of the geography of gully erosion throughout the EU and develop forecasting techniques for supporting the soil health indicators proposed under the Soil Monitoring and Resilience Directive (COM(2023)416).

From the assessment, gullies were identified 3 116 locations (~0.8% of all monitored locations). Further work will be published on this in due course.

Evaluation of land management features

Different land management activities can have an impact on erosion. Relevant land features were assessed for for all points in the field survey. Crop residues and standing vegetation were assessed only in case the land cover was cropland. The main elements include:

- Stone walls: These are masonry constructions, often built without the use of mortar from local rocks, generally excavated from the ground nearby. As a general guide, well maintained stone walls would act as a barrier to the passage of livestock.
- Hedgerows: These are lines of closely spaced shrubs and sometimes trees, planted and managed to form a barrier or to mark the boundary of an area (such as between neighbouring properties or roads and fields).
- Grass margins: These are herbaceous areas (generally 0.5 - 3 m wide) between the main crop and the field boundary. They are deliberately managed to (a) provide habitat for wild flora and fauna, (b) support biodiversity and ecosystem services,

(c) protect water quality, and (d), provide weed control. If present, the average width in the field containing the LUCAS point should be recorded.

- Soil surface cover: Standing vegetation and crop residues following harvest.

Further assessments on these elements will be provided in due course.

5 Spatial representation of soil properties

Due to the delay in the assignment of the laboratory services, this section will be covered by a dedicated report in 2026.

6 Conclusions

Regular monitoring provides a unique perspective on pressures affecting soils. In this respect, the soil module of the Land Use/Cover Area frame statistical Survey (generally referred to as LUCAS Soil) collects data that characterises soil conditions and health in relation to land use practices and other activities that are driven by specific policy instruments.

In 2022, the survey was carried out for the continental extent of all twenty-seven EU MS.

This marked the 4th iteration of soil sampling in LUCAS.

More than 41 000 locations were initially targeted for sampling, a significant increase over previous LUCAS.

31 054 samples were collected covering all EU Member States - more than 11 000 were repeat visits to sites sampled in 2018. In all points, the sampling depth was increased to 30 cm.

Bulk density measurements were made at various depths at 2 655 locations while 1 410 fresh samples were collected to assess soil biodiversity.

6 027 litter samples were collected from woodland sites to supplement the soil analysis with the view to provide total carbon estimates for woodland sites.

More than 1 500 samples were collected from locations above 1 000 m, with 35 locations > 1 500 m.

Overall the collection of samples reached around 70% of expected, with BG, CY, CZ, EE, ES, HR, HU, LT, LV, PL and SI all returning more than 80% of planned samples. CZ collected 93% of samples.

Access to land can be an issue, which resulted in a lower number of samples in some countries with both DE and DK returning less than 50% of standard samples. DE collected 39% of bulk density samples while BE only collected 29% of biodiversity samples. RO only returned 28% of litter samples.

Surveyors were able to ascertain gully erosion features in around 4 000 locations (around 1% of the total surveyed).

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List of figures

List of tables