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LUCAS Topsoil Survey

methodology, data and results

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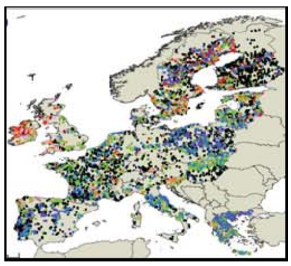

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LUCAS TOPSOIL SURVEY

methodology, data and results

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Sincere thanks are due to all of them.

SUMMARY

In 2009, the European Commission extended the periodic Land Use/Land Cover Area Frame Survey (LUCAS) to sample and analyse the main properties of topsoil in 23 Member States of the European Union (EU). This topsoil survey represents the first attempt to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures, with the analysis of all soil samples being carried out in a single laboratory.

Approximately 20,000 points were selected out of the main LUCAS grid for the collection of soil samples. A standardised sampling procedure was used to collect around 0.5 kg of topsoil (0-20 cm). The samples were dispatched to a central laboratory for physical and chemical analyses.

Subsequently, Malta and Cyprus provided soil samples even though the main LUCAS survey was not carried out on their territories. Cyprus has adapted the sampling methodology of LUCAS-Topsoil for (the southern part of the island) while Malta adjusted its national sampling grid to correspond to the LUCAS standards.

Bulgaria and Romania have been sampled in 2012. However, the analysis is ongoing and the results are not included in this report.

The final database contains 19,967 geo-referenced samples.

This report provides a detailed insight to the design and methodology of the data collection and laboratory analysis.

All samples have been analysed for the percentage of coarse fragments, particle size distribution (% clay, silt and sand content), pH (in $CaCl_2$ and H_2O), organic carbon (g/kg), carbonate content (g/kg), phosphorous content (mg/kg), total nitrogen content (g/kg), extractable potassium content (mg/kg), cation exchange capacity (cmol(+)/kg) and multispectral properties.

Subsequently, heavy metal content is being analysed but the result are not yet available and thus not included in this report.

Based on the results of the survey, the regional variability of topsoil properties within the EU has been assessed and a comparative soil assessment of European regions and countries is presented.

A series of predictive maps have been prepared using digital soil mapping methodologies that show the variation of individual parameters across the EU. In addition, the data have been used in studies to determine the SOC stock of the uppermost 20 cm of soil in the EU.

While the LUCAS approach is designed for monitoring land use/land cover change, potential bias in the sampling design may not necessarily capture all soil characteristics in a country.

Finally, a customised application has been developed for web browsers that allow users to view and query the LUCAS dataset in a variety of ways.

KEYWORDS : European Union – Topsoil – Land use - LUCAS – Land use change – Land cover – EU Soil Thematic Strategy – Digital soil mapping – Viewer

KEY MESSAGES

- In 2009, 19,967 topsoil samples with unique geo-referenced locations were collected in 23 Member States of the European Union under the periodic Land Use/Land Cover Area Frame Survey (LUCAS).
- Subsequently, Malta and Cyprus provided soil samples even though the main LUCAS survey was not carried on their territories.
- This topsoil survey represents the first attempt to build a consistent spatial database of the soil cover across the European Union based on standard sampling and analytical procedures.
- Around 0.5 kg of topsoil (0-20 cm) was collected at each soil sampling site.
- The samples were dispatched to a central laboratory for physical and chemical analyses.
- Bulgaria and Romania were sampled in 2012. The analysis of these data are not included in this report
- The survey provides an assessment of the regional variability of topsoil properties within the EU.
- Areas above 1000 m were not sampled.
- 43% of all samples were collected from croplands. The corresponding area of croplands for the EU-24[1] is approximately 34%.
- Limitations in the sampling design and possible limitations in the modelling process may mean that procedures to develop continuous mapping of soil parameters may not capture all spatial variation. Consequently, certain areas may be subject to high uncertainty.
- The characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body.
- There is an under sampling of peat soils in the Mediterranean region.
- Some soil types are likely to be under represented (e.g. saline, shallow, urban).
- The LUCAS database provides an excellent basis to assess changes in topsoil characteristics across the EU.

[1] Figures for 2000 - excluding Greece, Malta & UK

Contents

SUMMARY i

KEY MESSAGES ii

1. Introduction 1

1.1 Principles of the LUCAS Topsoil Survey 1

2. Soil sampling methodology 3

2.1 Methodology for the selection of soil sampling sites 3

2.2 The triplet concept in survey design 5

2.3 Soil sampling 5

2.4 Spatial representativity of the data 6

3. The LUCAS Topsoil Database version 1.0 9

3.1 Database properties 9

3.2 Methods of laboratory analysis of samples 11

3.3 Quality assurance in data preparation 13

4. Quality control of data against pedological criteria 15

5. Spatial representation of soil properties of LUCAS soil samples 25

6. Land-use specific comparative analysis of soil characteristics in the EU 35

6.1 Croplands 37

6.1.1 Regional variability of topsoil texture of croplands 38

6.1.2 Regional variability of topsoil organic carbon of croplands 40

6.1.3 Regional variability of topsoil pH of croplands 41

6.1.4 Regional variability of topsoil cation exchange capacity of croplands 42

6.1.5 Regional variability of topsoil calcium carbonate content of croplands 43

6.1.6 Regional variability of topsoil total nitrogen content of croplands 45

6.1.7 Regional variability of topsoil phosphorus content of croplands 46

6.1.8 Regional variability of topsoil potassium content of croplands 47

6.2 Grasslands ... 49
6.2.1 Regional variability of topsoil texture of grasslands ... 50
6.2.2 Regional variability of topsoil organic carbon of grasslands ... 51
6.2.3 Regional variability of topsoil pH of grasslands ... 52
6.2.4 Regional variability of topsoil cation exchange capacity of grasslands ... 53
6.2.5 Regional variability of topsoil calcium carbonate content of grasslands ... 54
6.2.6 Regional variability of topsoil total nitrogen content of grasslands ... 55
6.2.7 Regional variability of topsoil phosphorus content of grasslands ... 56
6.2.8 Regional variability of topsoil potassium content of grasslands ... 57
6.3 Shrublands ... 59
6.3.1 Regional variability of topsoil texture of shrublands ... 60
6.3.2 Regional variability of topsoil organic carbon of shrublands ... 61
6.3.3 Regional variability of topsoil pH of shrublands ... 62
6.3.4 Regional variability of topsoil cation exchange capacity of shrublands ... 63
6.3.5 Regional variability of topsoil calcium carbonate content of shrublands ... 64
6.3.6 Regional variability of topsoil total nitrogen content of shrublands ... 65
6.3.7 Regional variability of topsoil phosphorus content of shrublands ... 66
6.3.8 Regional variability of topsoil potassium content of shrublands ... 67
6.4 Woodlands ... 69
6.4.1 Regional variability of topsoil texture of woodlands ... 70
6.4.2 Regional variability of topsoil organic carbon of woodlands ... 71
6.4.3 Regional variability of topsoil pH of woodlands ... 72
6.4.4 Regional variability of topsoil cation exchange capacity of woodlands ... 73
6.4.5 Regional variability of topsoil calcium carbonate content of woodlands ... 74
6.4.6 Regional variability of topsoil total nitrogen content of woodlands ... 75
6.4.7 Regional variability of topsoil phosphorus content of woodlands ... 76
6.4.8 Regional variability of topsoil potassium content of woodlands ... 77
6.5 Peat ... 79
6.5.1 Regional variability of topsoil organic carbon of peat soils ... 80
6.5.2 Regional variability of topsoil pH of peat soils ... 81
6.5.3 Regional variability of topsoil cation exchange capacity of peat soils ... 83
6.6 Organic-rich mineral soils ... 85
6.7 C:N elemental ratio in topsoils of the European Union ... 87
6.8 Conclusions ... 88

7. Interim results of continuous mapping topsoil properties of the European Union on a continental scale using LUCAS Soil data 89

7.1 Generating continuous soil maps from point observation and auxiliary information 89

7.2 Topsoil organic carbon content map 91

7.3 Topsoil pH maps 95

7.4 Topsoil sand-, silt- and clay maps 97

7.5 Topsoil nitrogen content and C:N ratio maps 101

7.6 Topsoil calcium carbonate map 105

8. Spatial analysis of soil properties of the European Union 107

8.1 Estimation of topsoil organic carbon stock of the European Union and its Member States for the reference year of 2009 107

8.2 Applicability of LUCAS Soil data to improve predictions of soil water retention in the EU 113

8.3 Soil erodibility estimation of the EU using LUCAS point survey data 119

9. Prediction of SOC content by Vis-NIR spectroscopy at European scale 125

10. LUCAS soil data in the ESDAC Web-Tool for Soil Point Data 131

11. Overall conclusions and implications for future LUCAS Topsoil Surveys 141

1. Introduction

Gergely Tóth and Luca Montanarella

Soil information is essential for agricultural and environmental planning and monitoring. The availability of soil information in the Member States of the European Union (EU) varies greatly in many regards, including their scope, spatial representativity, date of collection sampling designs and analytical methods (Jones et al., 2005; Morvan et al., 2008). The variability of this information makes any pan-European comparative assessment difficult. However, there is an increasingly strong demand for soil data and information from policy makers to assess the state of soils at European level (COM(2006) 231, COM(2011) 571, COM(2012) 46; Panagos et al. 2012). To serve this demand, the European Commission has extended the periodic Land Use/Land Cover Area Frame Survey (LUCAS) of the territory of the EU to sample and analyse the main properties of topsoil across the Union. This topsoil survey - although limited to the upper layer of soil cover (usually regarded as the uppermost 20-30 cm) - represents the first effort to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures, with the analysis of all soil samples being carried out in a single laboratory. In addition, the LUCAS Topsoil Survey has the potential to be the basis for an EU wide harmonised soil monitoring.

It is important to emphasise that the purpose of the LUCAS Topsoil Survey is to allow the production of statistics on soil characteristics with a harmonised methodology at EU level. It is underlined that the collected information will be used only for the production of EU or regional scale statistics and will not contain any information of personal or land properties character. The survey is not designed for compliance controls. Furthermore, given the relatively limited number of points analysed and their spatial distribution, results cannot be considered representative of local conditions and certainly not of field conditions.

In this report, a detailed insight to the design and methodology of the LUCAS topsoil sampling and laboratory analysis is provided. Based on the results of the survey, the regional variability of topsoil properties within the EU is assessed. In this report, the differences in characteristics by soil attributes by main climatic regions, and by major land use/cover types, were evaluated. In addition to the introduction to the LUCAS survey, the results of a comparative soil assessment of European regions is presented.

1.1 Principles of the LUCAS Topsoil Survey

The LUCAS Programme started in 2001 as an area frame survey organised and managed by Eurostat (the statistical office of the European Union). The survey is based on the visual assessment of parameters that are deemed relevant for agricultural policy. Since 2006 the sampling design is based on the intersection of a regular 2 km x 2 km grid covering the territory of the EU. This results in around 1,000,000 geo-referenced points. Each point has been classified according to seven land cover classes using orthophotographs or satellite images (Eurostat 2012). A sub-sample of around 200,000 points were selected for twenty-three Member States (EU-27 except Bulgaria, Romania, Malta and Cyprus) as a representative sample for the LUCAS 2009 survey as control points for the survey.

With the scope of creating the first harmonised and comparable data on soil at European level to support policymaking, Eurostat, together with the European Commission's Directorates-General for Environment (DG ENV) and the Joint Research Centre (JRC) designed a topsoil assessment component ('LUCAS-Topsoil') within the 2009 LUCAS survey.

From the subset of 200,000 points of the general LUCAS survey, some 20,000 points were selected for the collection of soil samples using a standardised sampling procedure. These soil samples, weighting about 0.5 kg each, were dispatched to a central laboratory for physical and chemical analyses.

Subsequently, Malta and Cyprus provided soil samples even though the main LUCAS survey was not carried on their territories. Cyprus has adapted the sampling methodology of LUCAS-Topsoil for (the southern part of the island) while Malta adjusted its national sampling grid to correspond to the LUCAS standards.

The total number of soil samples collected in the frame of the LUCAS-Topsoil 2009 Survey for twenty-five Member States of the EU (EU-27 except Bulgaria and Romania) with exact geographical coordinates is 19,967.

The Soil Action of the JRC's Institute for Environment and Sustainability was entrusted with the training of surveyors, management of sample logistics and execution of the analytical process of the 20,000 soil samples from the survey. All samples were registered and visually checked; mineral soils were air-dried and properly re-packed. After this registration and pre-treatment process, the samples were shipped for laboratory analysis. The samples analysed for particle size distribution and coarse fragments content, organic carbon, pH, multispectral reflectance, exchangeable acidity, carbonates content, total nitrogen, soluble phosphorus and potassium, cation exchange capacity and heavy metals content.

The portion of the soil samples remaining after the completion of the laboratory analysis will be stored in the JRC's European Soil Repository.

2. Soil sampling methodology

Florence Carre, Ezio Rusco, Gergely Tóth, Arwyn Jones, Ciro Gardi and Vladimir Stolbovoy

2.1 Methodology for the selection of soil sampling sites

During the preparatory phase of the LUCAS-Topsoil Survey, the main issue was to design the most meaningful method for site selection. An appropriate survey design will allow the most diverse utilisation of the results without compromising their scientific merit.

Two options seemed to be appropriate to follow. The first option was similar to the approach of the general LUCAS survey by taking the soil samples along a regular grid by systematically selecting 10% of the general LUCAS points according to a geometrically even distribution. This approach is applied in many national soil monitoring schemes (e.g. Denmark, UK, see Van Camp et al. 2004). The second option, which is also applied in established soil monitoring systems (e.g. France, Hungary, Poland, see Van Camp et al., 2004), was to establish a stratified sampling scheme based on land use and terrain information. The LUCAS Topsoil Survey, apart from providing a basis for possible future soil monitoring, was also meant to build soil data to support mapping purposes. Since soil mapping, even topsoil mapping is best performed if design-based, a multi-stage stratified random sampling approach (McKenzie et al. 2008) was chosen.

The following land use and terrain data (called covariates in the following text) were available on the European scale for the stratification of sampling location: elevation, slope, aspect (orientation of the slope), slope curvature and land use.

The CORINE LANDCOVER 2000 dataset (CLC2000; 100 m resolution) was used for calculating the percentage area of each land use type. Since one of the aims of the LUCAS Topsoil Survey was to collect information that will allow both pan-European and interregional comparisons of soil status, land use percentages were calculated for each country that participated in the survey. The number of selected points was proportional to the percentage of land use coverage for each country. Due to the availability of soil data for forest land from the BIOSOIL exercise (Hiederer & Durrant 2010), a decision was taken to transfer 1/3 of the 'forest' points to arable land and grassland areas. In addition to the CLC2000, 90 m elevation data from the Shuttle Radar Topography Mission (SRTM) were included in the spatial stratification to derive altitude, slope, curvature and aspect data. Since the minimum distance between the points of the general LUCAS survey is 2 km, the covariates which were initially resampled at 1 km resolution, have been transformed into 12 km resolution. A maximum of 36 LUCAS samples can occur in a 12 km by 12km grid cell.

For the stratification, each landform attribute was divided into 8 quantiles (classes), meaning that in every quantile the number of pixels is the same. The quantiles of each landform attribute and the land use classes were combined leading to a number of approximately 20,000 strata (landscape elements with internally consistent characteristics) which were mapped (the quantile combination lead to different number of pixels per stratum). The strata which were in a raster form have been transformed into vector to obtain a unique value of the strata in each location. By this method, 30,795 unique strata (polygons) are assigned for the EU. The polygon number was attached to each LUCAS point. Within each polygon, the number of points per land use was calculated. If for each land use, the number was higher than three, the points were selected. Within the selected point subset, a random number between 1 and n (where n represents the total number of points per polygon and per land use, being higher than 3) was allocated for defining the triplet order (choice 1, choice 2 and choice 3 – see the next section for an explanation of the triplet concept). For each country, if the number of triplets per land use was insufficient, the polygons having more than 6 points (for the specific land use) allowed the selection of other triplets. This process continued until the maximum possible number or the expected number of points per land use was achieved. If the number of triplets per land use was higher than what was expected, the triplets with the highest number of pixels (the most representative) were ranked and selected. In any case, when one land use was underestimated another land use (if possible arable land, grassland and permanent crops since they are the most difficult to sample) was overestimated.

This approach allowed the selection of sampling locations proportional to the surface areas of each country and the main land use types within each country.

Due to lower spatial accuracy of the CORINE land cover compared to the actual LUCAS point data, there can be some difference in the planned vs. surveyed land covers/ land uses at the individual survey points.

Distribution of the sampled sites across major land use classes by countries are given in Table 2.1.

389285Table 2.1 LUCAS 2009 Topsoil samples by countries and main land uses*

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

**The numbers given in this table correspond to samples which can be uniquely associated to a geographical reference.*

2.2 The triplet concept in survey design

The surveyors received a list of triplets of points belonging to the same land cover class within the surveyed area. A triplet is a group of three LUCAS ID points that have common properties, such as slope, aspect and land cover. Triplets were established to hold alternative locations for the surveyor to collect a soil sample should the initial LUCAS ID point designated for the collection of a soil sample not be physically accessible. The surveyor collected a sample form only one point of each triplet. There is no priority among the points of each triplet. The surveyor had the freedom to choose the point form where the soil sample was collected according to his daily route. As a general rule, the surveyor had to collect the soil sample on the first point they choose to sample in a triplet. If the sample could not be collected at the first point chosen, there was still the possibility to visit the second and the third point and collect the soil sample in one of them. When a sample is taken in any one point in the triplet, further sampling from the same triplet was unneeded.

2.3 Soil sampling

Samples were collected from the designated locations by a process of composite sampling. Five soil sub-samples were taken at each sampling site and a mixture of these soil samples were taken to the laboratory. The following principles were applied at the sampling location:

- The soil sample must represent the area characterised by the LUCAS point.
- The central sub-sampling location coincides with the LUCAS point.
- The other four sub-samples are collected at a distance of two meters from the central sub-sampling location in the shape of a cross.

The sampling methodology is illustrated by figure 2.1.

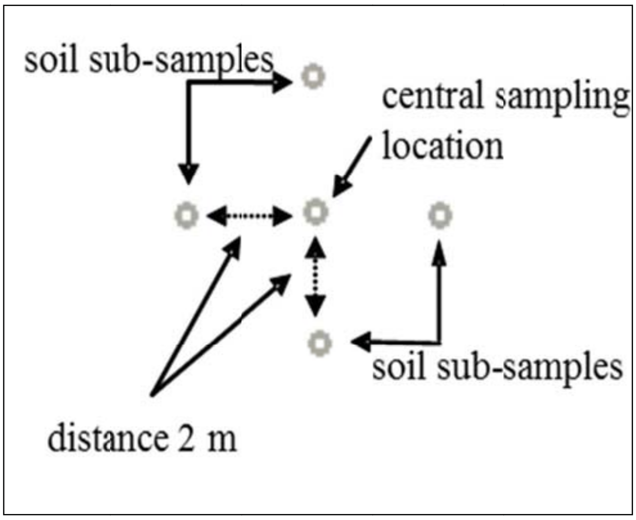

Figure 2.1 Sub-sampling methodology for a composite sample.

In mineral soils, vegetation residues and litter were removed from the surface and the topsoil was sampled to an approximate depth of 20 cm. In case of peat, organic material was sampled. A "mineral" topsoil may still contain fine roots, their parts and brownish homogeneous organic materials, , which would have been removed by the central soil sampling laboratory through sieving in accordance with established procedures. The five soil samples were placed together in a plastic container. By mixing these sub-samples together, the required composite samples were prepared. At each location about 500 grams of the composite sample were taken and placed into labelled plastic bags.

Samples were collected in proportion to the area and in the participating countries (Table 2.1). From the total of 19,967 samples, more than 96% of the samples originated from the five main land cover types (Table 2.1). Remaining soil samples are from other land uses.

In addition to the 2009 survey, the same methodology was extended in 2012 to Bulgaria and Romania, where 664 and 1427 topsoil samples, respectively, were collected. This report does not contain the results of the analyses on these soil samples, which are still to be completed.

2.4 Spatial representativity of the data

The purpose of the LUCAS soil survey was to establish baseline values of topsoil properties on the selected sampling points as a reference to enable future comparisons. LUCAS soil points are representative for the land use and topography within each country, to different degree, depending on the heterogeneity of land use and topography of the country. LUCAS survey does not cover areas above 1,000 m in elevation.

The selection of the soil sampling sites has an inherent bias towards agricultural land (predominantly under arable cultivation), followed by grasslands and woodlands. This means that results based exclusively on LUCAS soil samples may over represent properties from the more heavily sampled conditions whiles under-representing others (Fig. 2..2). Specific examples include rough grazing and wetlands. This bias may limit the spatial extrapolation of the data to heavily sampled land cover classes. More research is needed in this area, especially in relation to the production of more detailed maps (e.g. 1 km cells or finer).

The survey was designed to allocate sampling points with similar densities in each country, rather than to allocate sampling points according to soil heterogeneity in different regions in the EU. The first approach is often used for monitoring schemes, while the second approach is the basis of systematic soil survey for mapping purposes. As one country might have very different soil heterogeneity from another (for details see Ibáñez et al., 2013), soil samples of the LUCAS survey differ to a great extent, regarding the area representation is concerned.

The applicability of the LUCAS soil survey for soil mapping – as it was not designed for this purpose - is therefore possibly problematic. Another limitation of the LUCAS soil data for soil mapping arise from the fact that it only includes information on the topsoil. Soil maps are based on surveys that sample full soil profiles and make spatial relationships between soil properties in a three dimensional space, usually represented on two dimensional map sheets.

Spatial representativity of soil samples of full profiles in a survey designed for soil mapping depends on the pedological heterogeneity of the area. Table 2.2 provides an overview in this respect. When assessing LUCAS soil data against the criteria of international soil survey guidelines, we can assume that it might be regarded as an exploratory survey. As information on subsoil properties are not available, this hypothesis needs to be carefully taken, since soil survey needs to take subsoil information into account as well.

On the other hand, digital soil mapping techniques which include auxiliary variables (land cover, climate etc.) might improve spatial accuracy of soil mapping, compared to traditional methods. However, there needs to be further research into the strength of the relationships between soil characteristics and common covariates such as land cover and elevation (i.e. a similar land cover types may occur on different soil types while conversely, different land cover units may occur on a single soil type, especially if one involves farming practices). Assessing the representativity of the LUCAS soil sampling sites against pan-European soil variability has yet to be carried out and may require significant effort.

It is worth reflecting that the full LUCAS land use/land cover survey utilises 250,000 samples to validate changes in the vegetative properties of the European land surface – a characteristic that can easily be visualised by satellite or airborne sensors. One could argue that the 10% sample used in the topsoil survey are nowhere near sufficient in number to spatially categorise in detail the complexity of soil patterns across the EU. An interesting analogy can be drawn from the current exercise to complete the soil mapping of ‘terra incognita’ in the Republic of Ireland where a comparable number of samples have been collected to categorise the soils of around 50% of the country (approximately 2% of the EU).

Table 2.2 Relationships between the goal of the soil survey, sampling density and scale of derived soil maps*
(The table is indicative to soil surveys designed for soil mapping)

Kind of survey or map and level of intensity	Purpose and use of the of the survey results	Area represented by one sample (ha)	Indicative scale of published maps
precision farming (intensive, level1)	special; executive purpose – within parcel	< 1	> 1:1000
detailed (field scale, level 2)	special; executive purpose – for parcel	1-50	1:1000 – 1:10.000
semi-detailed (farm to regional scale, level 3)	general and special; planning puropse	50-1000	1:10.000 – 1:100.000
reconessaince (regional scale, level 4)	general; planning purpose	1000 – 5000	1:100.000 – 1:250.000
reconessaince (regional to national scale, level 5)	general; orientation purpose on national scale	5000 – 20000	1:250.000 – 1:500.000
exploratory surveys and compilations (national to continental scales, level 5)	general; orientation purpose on continental and global scale	> 20000	< 1:500.000

- Based on the works of: Baranyai et al. (1989), Dent & Young (1981) Legros (1996), Curlik & Surina (1998), Garkusa (1958), Hengl & Husnjak (2006), Rasio & Vianello (1995) Szabolcs (1966) and Western (1978).

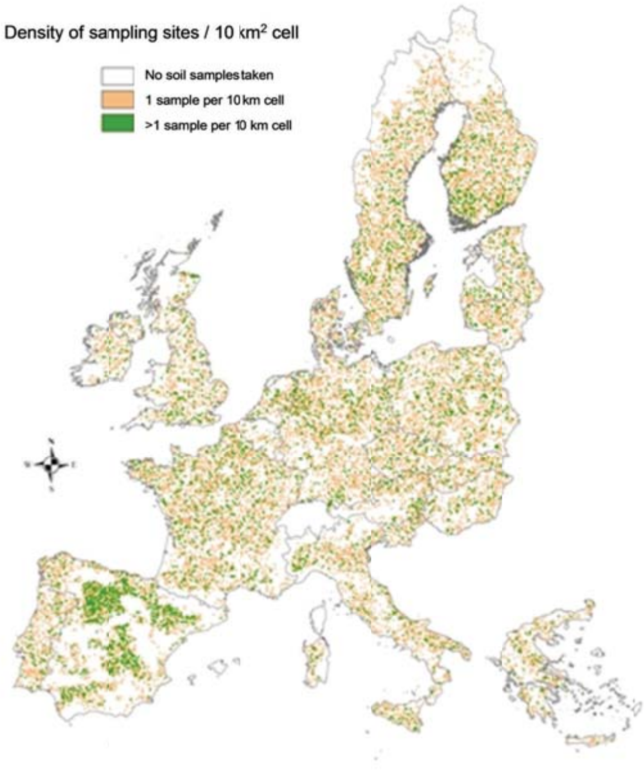

Figure 2.2 Density of LUCAS topsoil sampling as measured by the number of sites in a grid of 10 km. x 10 km. Areas with no or low numbers of sampling sites may lead to certain soil types being under represented or missing in the database. Also these areas may give rise to uncertainties in modelling exercises (see chapter 7).[2]

[2] http://eusoils.jrc.ec.europa.eu/library/themes/erosion/Erodibility/

In summary – LUCAS data are representative on regional (NUTS 2) to country level for areas below 1,000 m elevation across the EU. They are, however, not representative of local conditions and certainly not of specific field conditions.

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3. The LUCAS Topsoil Database version 1.0

Gergely Tóth

3.1 Database properties

Version 1.0 of the LUCAS Topsoil database includes analytical data from topsoil samples with unique geo-reference for each sample taken during the 2009 LUCAS exercise, covering 23 EU Member States (Eurostat 2013) and the complementing surveys in Cyprus and Malta.

The complete dataset includes data from 19,969 samples from 25 Member States (see table 2.1 in chapter 2). The LUCAS Topsoil data are stored in three formats: (1) MS Excel worksheet (2) Text file and (3) MS Access relational database.

The Excel worksheet is configured as 17 fields (columns): 4 fields with identifiers and 13 fields with soil attribute information (Table 3.1).

The text file stores the results of the measurement of the multispectral reflectance of soil samples (Table 3.2).

The Excel worksheet and the text file are distributed to the general public through the European Soil Data Centre. Access is provided through the URL:

http://eusoils.jrc.ec.europa.eu/projects/lucas/data.html

Data from the LUCAS Topsoil Survey can also be viewed using the ESDAC Web-Tool, accessible from the above site. For details of the ESDAC Web-Tool see chapter 10 of this report.

Soil attribute data of individual LUCAS Topsoil samples can be linked to databases of the general LUCAS land use and land cover survey through POINT_ID.

Please note that in some cases the predefined LUCAS point location could not be physically accessed. In these cases the land use / land cover assessment was performed from a point in its vicinity, but pertaining to the planned LUCAS location. The soil sampling was done at that point.

The location of soil sampling is registered by Global Positioning system (GPS) coordinates. (GPS_LAT and GPS_LONG). There may be an imprecision in the GPS coordinates, therefore GPS_LAT and GPS_LONG are given for orientation purposes only.

For Cyprus and Malta, there are no ‘official’ LUCAS points but only points were soil sampling was performed.

For some soil sampling locations (ca. 70), the GPS coordinates are not available. In these cases, the coordinates of the general LUCAS survey points can be used to orientate about the soil sampling location.

Table 3.1 Fields in the LUCAS Topsoil v1.0 database

Field			Units/Values
Code	Relevance	Description[3]	
POINT_ID	LUCAS point	Unique identifier of the LUCAS survey point	8 digit number
coarse	soil sample	coarse fragments	in %
clay	soil sample	clay content	in %
silt	soil sample	silt content	in %
sand	soil sample	sand content	in %
pH_in_H_2O	soil sample	pH measured from water solution	-
pH_in_CaCl	soil sample	pH measured from CaCl solution	-
OC	soil sample	organic carbon content	g/kg
$CaCO_3$	soil sample	$CaCO_3$ content	g/kg
N	soil sample	Nitrogen content	g/kg
P	soil sample	Phosphorus content	mg/kg
K	soil sample	Potassium content	mg/kg
CEC	soil sample	Cation Exchange Capacity	cmol(+)/kg
Notes	soil sample	additional observations	free text
sample_ID	soil sample	Unique identifier of the soil sample	3 to 7 digit number
GPS_LAT	soil sampling location	Latitudinal GPS coordinate of the soil sampling location (WGS84)	decimal degrees NA = No signal / No GPS information available
GPS_LONG	soil sampling location	Longitudinal GPS coordinate of the soil sampling location (WGS84)	decimal degrees NA = No signal / No GPS information available

Table 3.2 Information stored in textile (multispectral properties) of the LUCAS Topsoil data v1.0

Code	Description
##SAMPLE NAME	Sample ID (duplicates)
##SPECTRUM	Wavelengths of the measurement (400-2499.5 nm) and measured reflectance (nnn,nn; n,nnnnnn)

Data on land cover/ land use at the LUCAS points can be accessed from the website of Eurostat:

http://epp.eurostat.ec.europa.eu/portal/page/portal/lucas/data

This website provides detailed information on the methodologies and classifications of the LUCAS 2009 survey.

A relational database structure was also developed to store data to facilitate data management including a possible future update, and maintain information on data quality and extension with new attribute information (Figure 4.1).

[3] For reference methods see chapter 3.2

The database includes four tables:

1. LULCdata table stores information on land use/cover from each LUCAS point;

2. PosCoord table stores information on the geographic position of the LUCAS points including country, climatic region and geographic coordinates;

3. SoilData table stores results of laboratory measurements of key soil attributes. On completion, data from the analysis of heavy metals levels will be included in this table;

4. QAinfo table stores information on the results of consistency/quality assessment of the data.

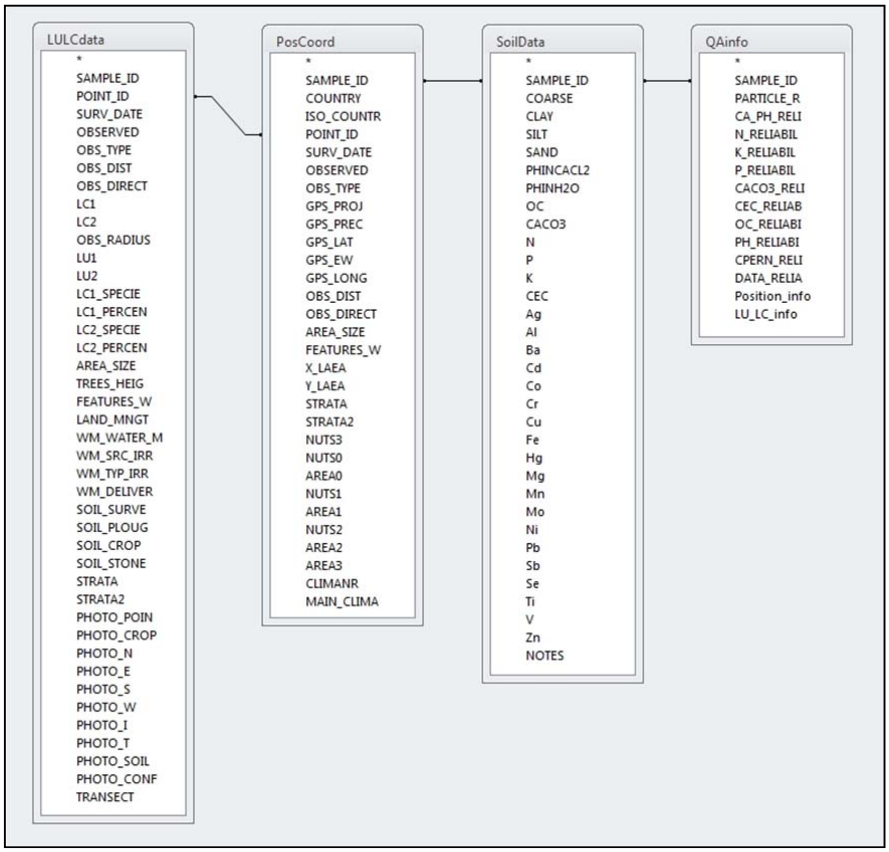

Figure 3.1 Structure and content of the LUCAS Topsoil Database V1.0

The Access database is stored in the European Soil data Centre (ESDAC) at the Joint Research Centre and used for database management purposes.

3.2 Methods of laboratory analysis of samples

Table 3.2 shows the list of measured parameters, together with the methodologies used and precision of measurement records.

Analysis of the soil parameters followed standard procedures (see literature for the applied ISO methods). The same methods were used in the Biosoil Survey[4]. Coarse fragments were measured in the first phase of the analysis. Diffuse high resolution reflectance spectra were collected for all samples using a spectroscope measuring a continuous reflectance spectrum from 400 to 2500 nm with 0.5 nm spectral resolution. These measurements followed the protocol of the Soil Spectroscopy Group (SPS 2011) and the procedures prescribed by the FOSS spectroscope (FOSS 2009).

Laboratory analysis of the samples was performed between December 2009 and June 2011.

Analysis of soil samples are currently extended to measure additional elements, including Ag, Al, As, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Sb, Se, Ti, V and Zn.

Results are foreseen for 2014.

Table 3.2. Soil parameters of LUCAS-soil samples analysed in 2009-2011

Parameter	**Unit**	**Decimals**	**Method/ Standard**
Coarse fragments	%	0	ISO 11464. 2006
Particle size distribution	-	-	ISO 11277. 1998
Clay content	%	0	
Silt Content	%	0	
Sand Content	%	0	
pH($CaCl_2$)	-	2	ISO 10390. 1994
pH(H_2O)	-	2	ISO 10390. 1994
Organic carbon	g/kg	1	ISO 10694. 1995
Carbonate content	g/kg	0	ISO 10693. 1994
Phosphorus content	mg/kg	1	ISO 11263. 1994
Total nitrogen content	g/kg	0	ISO 11261. 1995
Extractable potassium content	mg/kg	1	USDA, 2004
MULTISPECTRAL Properties (With diffuse reflectance measurements saturation)			FOSS Manual 2009
Cation exchange capacity	cmol(+)/kg	1	ISO 11260. 1994

[4] http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/EUR24729.pdf

3.3 Quality assurance in data preparation

A series of quality control procedure were applied throughout the survey, laboratory analysis and database development. A uniform sampling design, standardised methodology and nomenclature have been applied to secure the internal coherence of the data (Eurostat 2009). Surveyors were requested to follow precisely described quality assurance procedures during field activities and sampling (Eurostat 2009). An internal supervisor performed a second quality check, backed by internal quality control (QC) modules of the Data Management Tool (Eurostat 2009). In the framework of Eurostat Quality Assurance Framework, the LUCAS survey also underwent an external peer review process.

The quality control of the soil analysis was secured by the quality assurance (QA) accredited central laboratory in several steps, including control of registration of samples, application of local reference material, repeated analyses of randomly selected samples and a participation in the International Soil-Analytical Exchange Program (Szováti et al. 2011).

Raw soil data stored in the database (Figure 3.1) was assessed against pedological criteria set by soil experts of the Joint Research Centre (see chapter 4). These included simple coherence measures (e.g. the sum of sand+silt+clay fractions should equal 100%), flagging data with extreme values (e.g. pH) and with controversial characteristics (e.g. extreme low pH and high $CaCO_3$). An unreliability signal is associated to each outlying sample in the QAinfo table of the relational database.

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4. Quality control of data against pedological criteria

Rannveig Guicharnaud

4.1 Pedological hypothesis tested

A pedological data quality control was conducted on the LUCAS soil dataset as to assess expected trends in soils systems in terms of the soils pedology. These included;

(1) Correlations between soil organic carbon (OC) and nitrogen (N) as soil organic matter is composed of both, carbon (C) and N in a relatively fixed ratio of 12:1 in mineral soils to around 30:1 in organic soils. Soil samples exhibiting ratio in excess of 40:1 need further consideration.

(2) Correlation between the soil cation exchange capacity (CEC) and clay with soil OC, as both are important players in the soil CEC. The soil organic fraction is believed to account for 50-90 % for the soil CEC due to the large amount of negatively charged surface sites available to bind cations. Furthermore, clays are also an important contributor for cation exchange capacity due to isomorphic substitution where Si^{+4} and Al^{+3} in clay crystal lattices are replaced with cations of lower positive charge or by deprotonation of hydroxyl groups on clay surfaces leading to excess negative charge available to bind cations from soil solution.

Additionally assumptions where made towards the fact that;

(1) Greater OC concentrations should be expected in forest/grassland soils compared to cropped soils, as ploughing, which often is associated with cropped systems, increases soil organic matter decomposition;

(2) Greater phosphorous (P) and potassium (K) where present in cropped soils compared to other forest soils due to fertilizer application of cultivated soils;

(3) Higher pH was expected in cropped soils compared to organic soils (such as forest soils, wetland soils, ≥20% OC), due to liming which is often associated with cultivation increasing the soil pH. Moreover cultivated soils often have higher pH due to lower soil OC content and therefore lower supply of organic acids;

(4) Calcium carbonate ($CaCO_3$) was not expected at sites with low pH as its solubility is pH dependent and it does not form under acidic conditions;

(5) Principal component analyses (PCA) was conducted on the LUCAS topsoil dataset to assess which measured soil parameters (pH, $CaCO_3$, CEC, clay, C%, N%, K, P, sand, silt, coarse) differentiated soils from different land cover groups.

4.2 Results

Figure 4.1 gives an overview of selected relationships of soil properties in all samples collected in the LUCAS-Topsoil Survey. In addition to displaying the range of soil parameters in the survey, the most obvious outliers may easily be detected from this figure. Due to the large number of data points the dataset is more conveniently sorted according to land use classification and/or countries of origin and a more detailed study may be conducted to identify outliers and samples not displaying logical pedologic relationships.

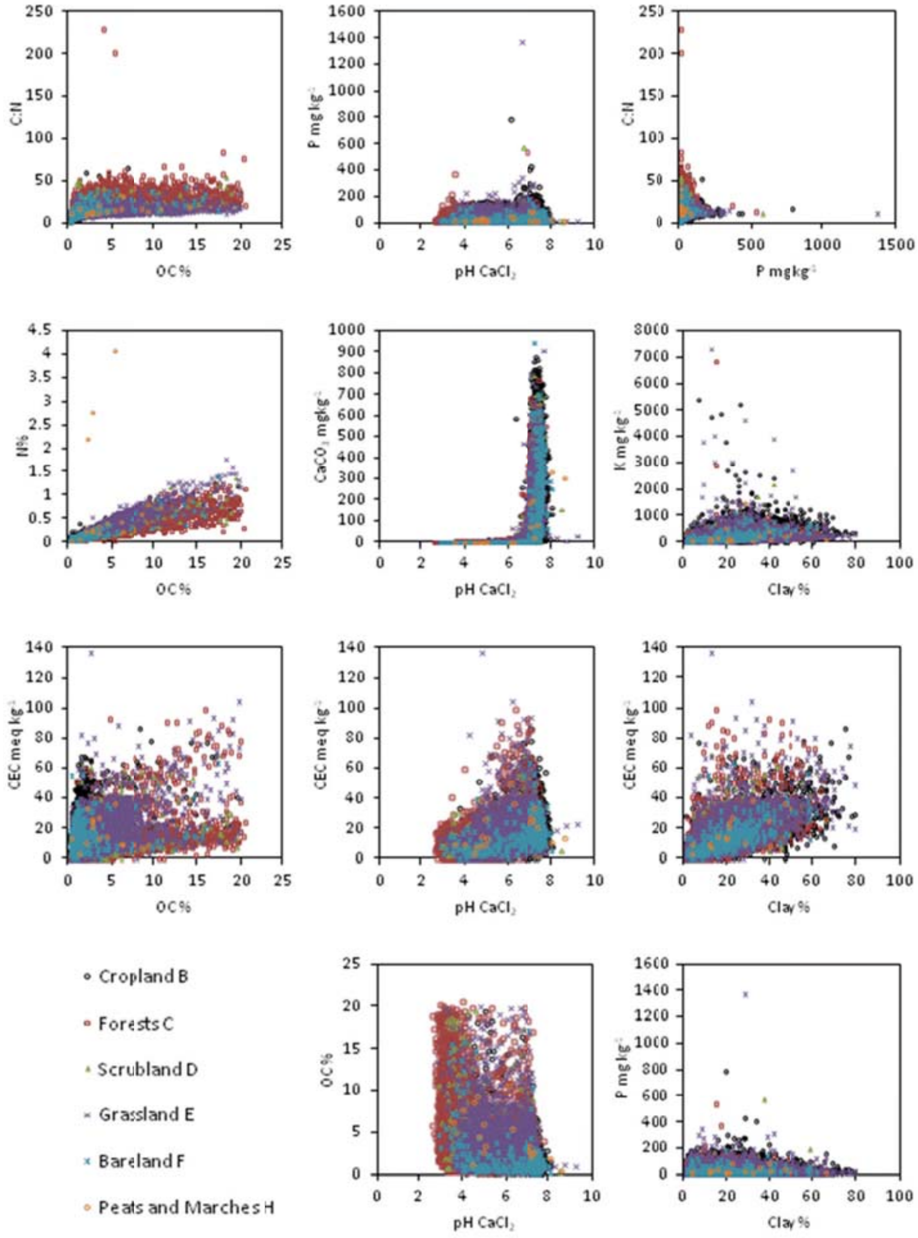


Figure 4.1 Overview of selected relationships of soil properties (C:N vs OC%, P mg kg^{-1} vs pH $CaCl_2$, C:N vs P mg kg^{-1}, N% vs OC%, $CaCO_3$ vs pH $CaCl_2$, K mg kg^{-1} vs clay % , CEC meq kg^{-1} vs OC%, CEC meq kg^{-1} vs clay %, OC % vs pH $CaCl_2$, P mg kg^{-1} vs clay %) in all samples collected in the LUCAS project in all land cover groups (cropland, forest, scrubland, grassland, bare land, peat and marsh).

As expected, strong positive correlations where found between N % and OC % in all soils and land cover groups (crop, forest, grassland).

Figure 4.2 displays correlations between C % and N % in different land cover systems (Fig. 4.2). This was in agreement with the assumptions made, that soil organic matter is composed of both C and N and is present in a relatively fixed ratio of around 12:1 and above.

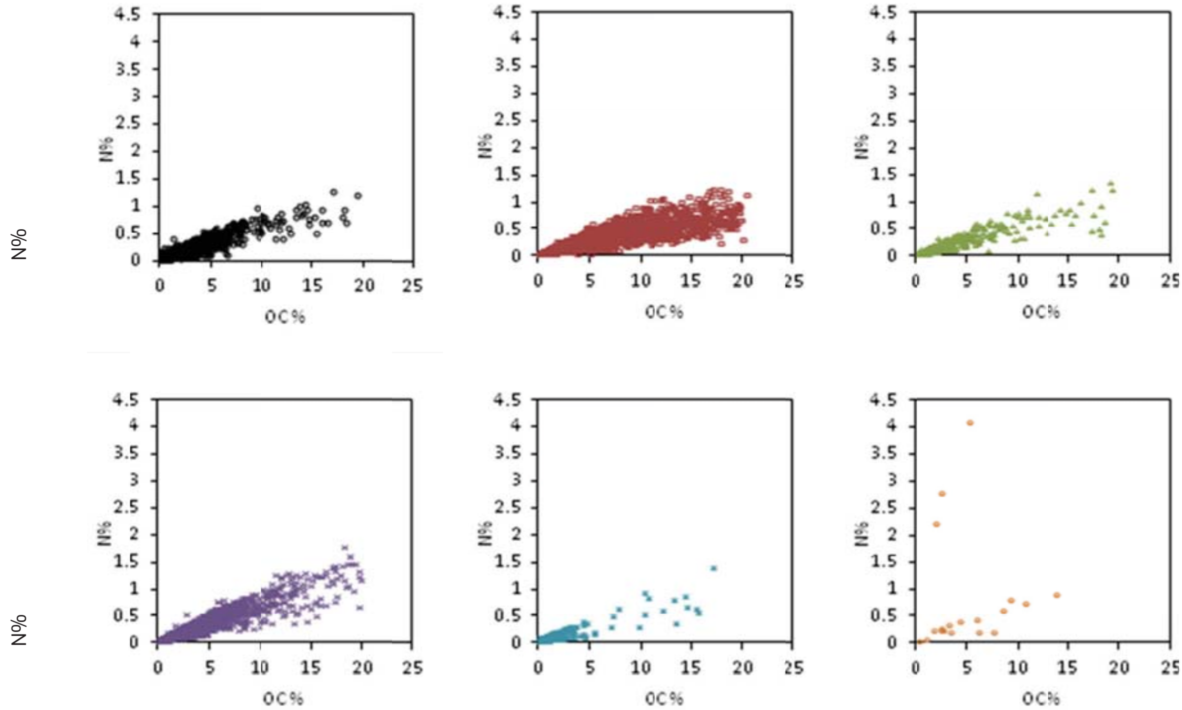


Figure 4.2 Relationship between N% and C% in different land cover systems.

Black = Cropland, Red = Forest, Green = Scrubland, Purple = Grassland, Blue= Bare land, Orange = Wetlands.

The C:N ratios of soils were generally between 10:1 and 20:1 and were increased with elevated C%, in other words the soils became increasingly N depleted (Fig. 4.3).

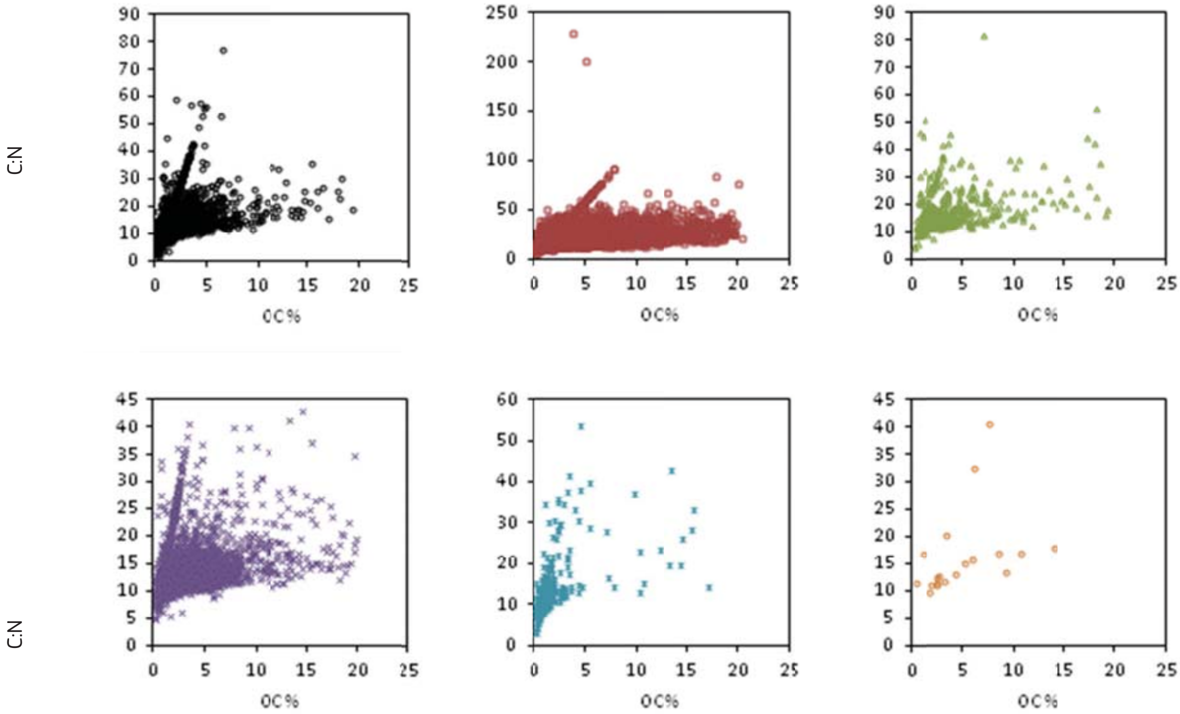
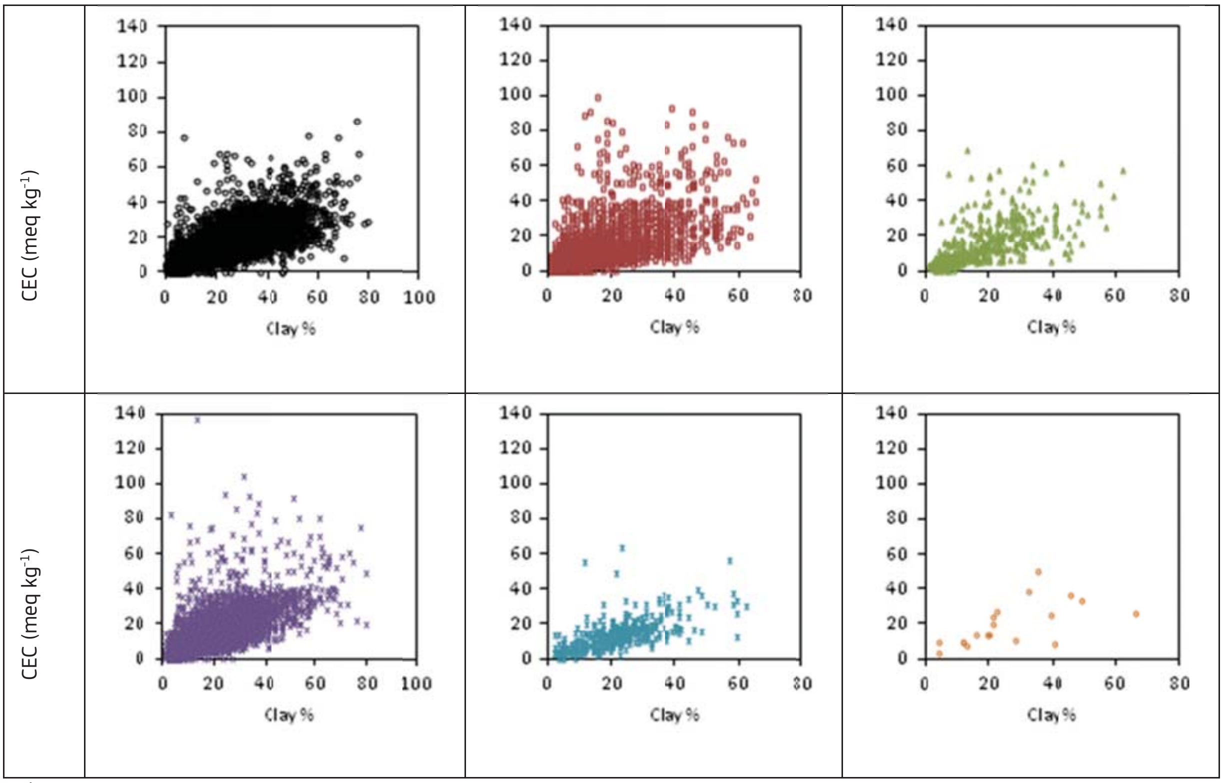


Figure 4.3 Relationship between C:N ratio and C% in different land cover classes.

Black = Cropland, Red = Forest, Green = Scrubland, Purple = Grassland, Blue = Bare land, Orange = Wetlands

Generally, there was a strong positive relationship between the soil CEC and the soil clay content in cropland, forest and grassland systems (Fig. 4.4), supporting the theory that clays are an important contributor for soil CEC due to their reactive surfaces.



Clay vs CEC

Figure 4.4 Relationships between soil cation exchange capacity CEC and soil clay content in different land cover systems.

Black = Cropland, Red = Forest, Green = Scrubland, Purple = Grassland, Blue = Bare land, Orange = Wetlands

There was likewise generally a positive correlation between the soil CEC and the soil OC (Fig. 4.5). This is in agreement with OC organic matter being negatively charged increasing the soil CEC.

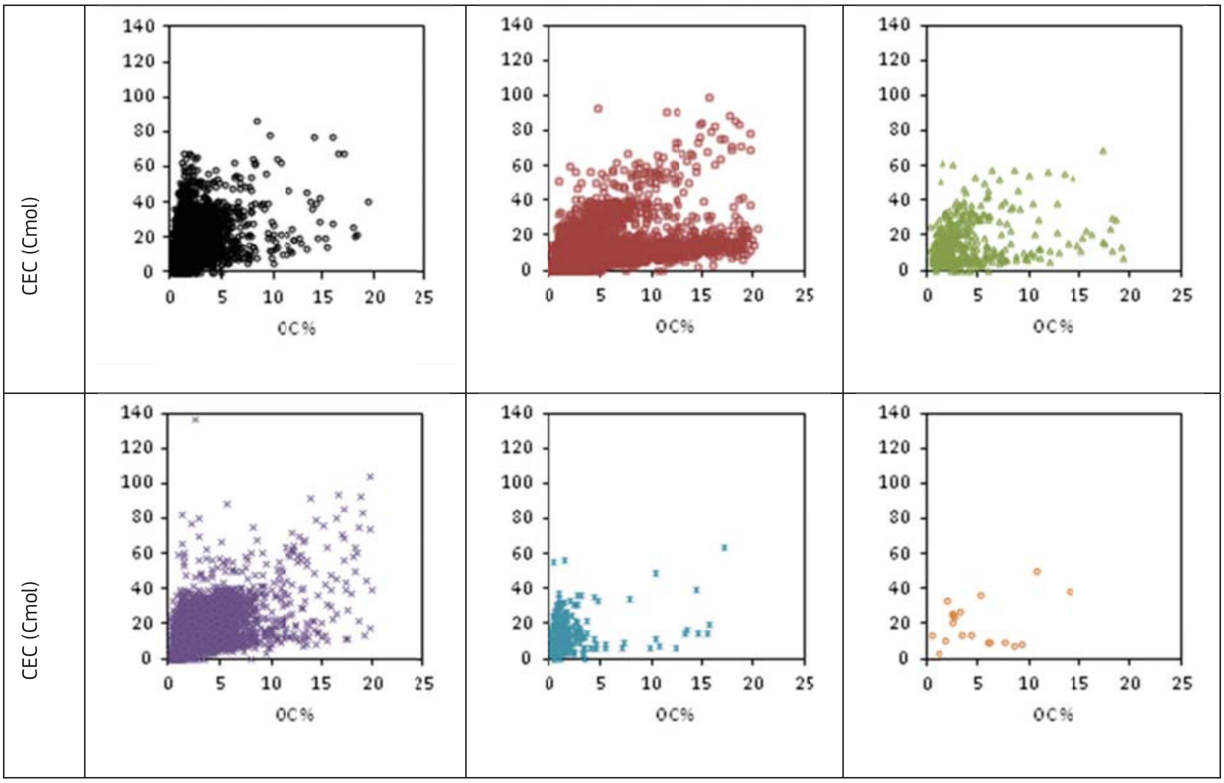


Figure 4.5 Relationships between soil cation exchange capacity CEC and soil OC content in different land cover systems.

Black = Cropland, Red = Forest, Green = Scrubland, Purple = Grassland, Blue = Bareland, Orange = Wetlands.

Moreover, the soil CEC was the greatest when both high clay concentration and C % where measured in soils (Figure 4.6).

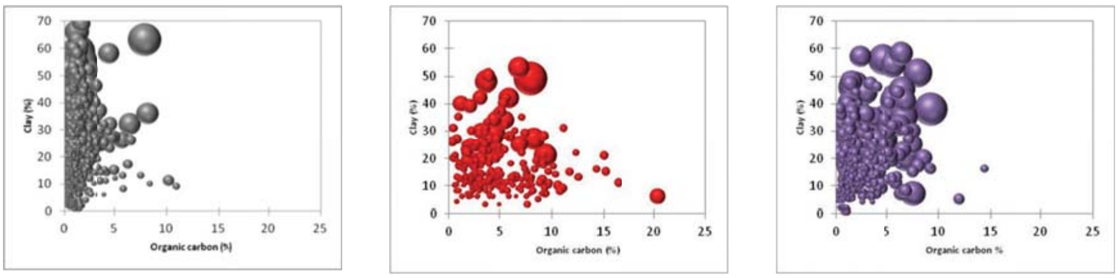


Figure 4.6 Soil CEC dependence on organic C % and clay % in a selected member state country (Spain).

Grey dots represent cropland, red dots represent forests and purple dots represent grasslands. The size of the dots is proportional to CEC.

Although variability was high in all land use classes, grassland and forest soils, demonstrated greater C % levels than cropped soils (Figure 4.7). High OC levels are a characteristic of grasslands mainly due to their dense root system. In forest soils, high OC are related to humus rich topsoil layers.

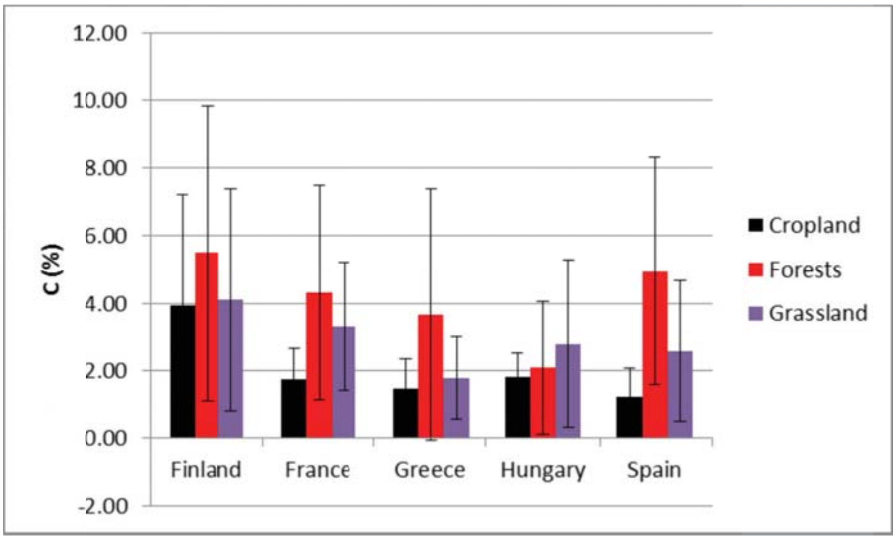


Figure 4.7 Soil OC %. Black columns represent cropland, red columns represent forests and purple columns represent grassland. Error bars represent one standard deviation of means.

Cropland soils displayed the highest pH values of all land cover groups (Figure 4.8). Forest soils, likewise exhibited lower P levels (Figure 4.9). This is commonly observed in forest soils due to P retained in mineral-organic complexes. It was assumed that lower K concentrations in forest soils where attributed to lack of fertilization and cation leaching which is prominent at the low pH (Fig. 4.10). High standard deviations of means for P and K in grassland soils are due to outliers in the dataset that have not been removed yet (Figures 4.9 and 4.10).

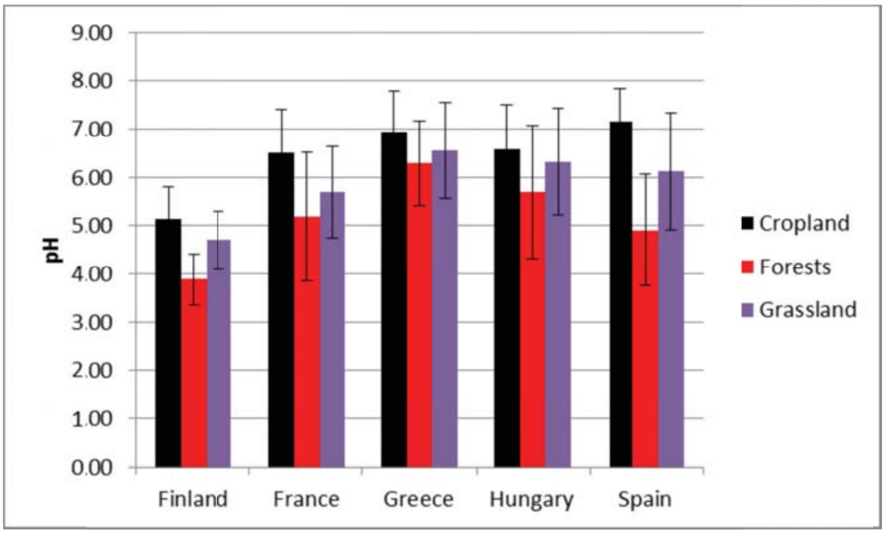


Figure 4.8 Soil pH. Black columns represent cropland, red columns represent forests and purple columns represent grassland. Error bars represent one standard deviation of means.

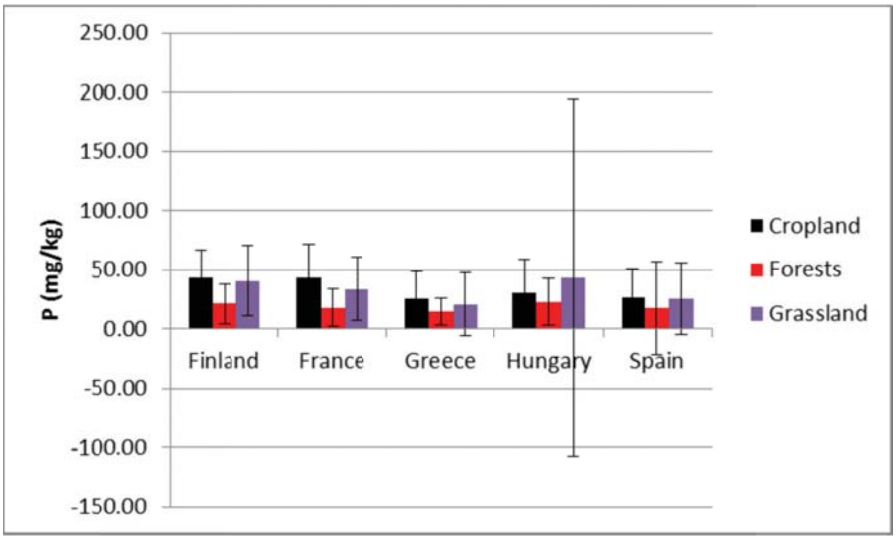


Figure 4.9 Soil P mg kg^{-1}.Black columns represent cropland, red columns represent forests and purple columns represent grassland.

Error bars represent one standard deviation of means.

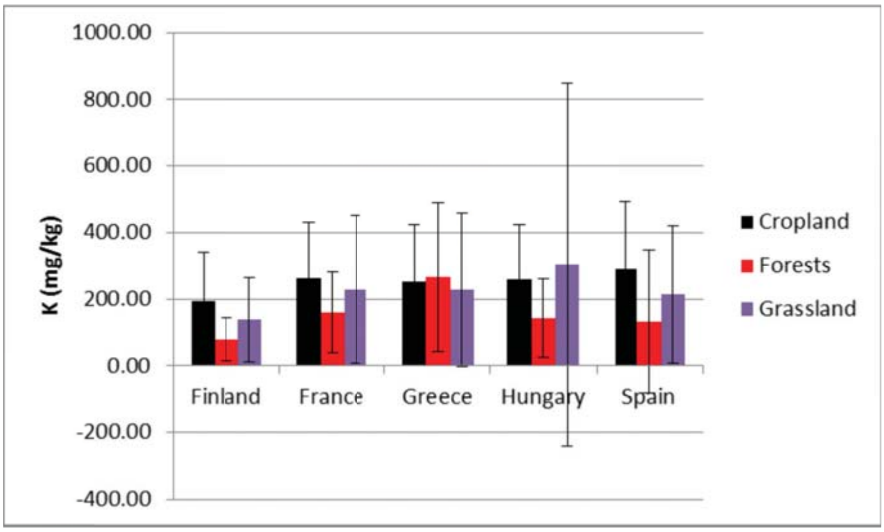


Figure 4.10 Soil K mg kg^{-1}. Black columns represent cropland, red columns represent forests and purple columns represent grassland.

Error bars represent one standard deviation of means.

In the LUCAS dataset, calcium carbonate ($CaCO_3$) notable concentrations were only observed at pH 6.5 and above (Figure 5.11) which was expected as $CaCO_3$ is highly soluble under acidic conditions.

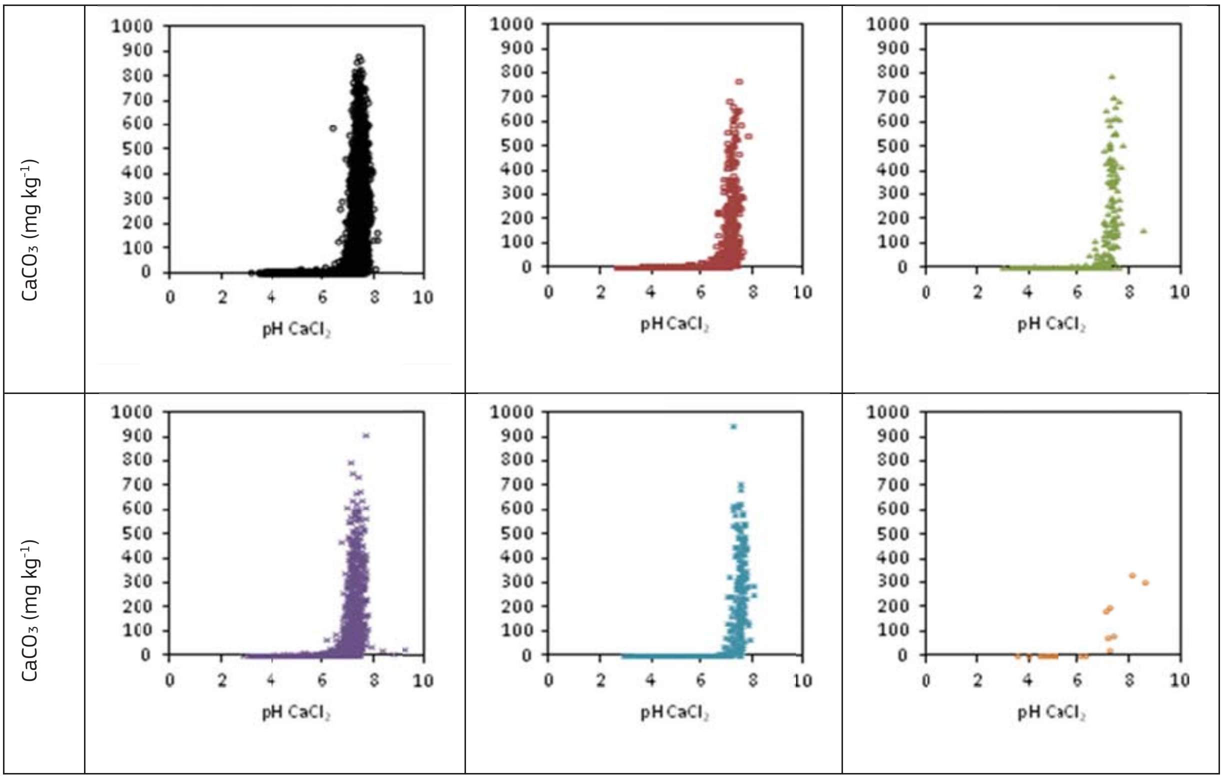


Figure 4.11 Relationships between soil $CaCO_3$ and soil pH ($CaCl_2$) in different land cover classes.

Black = Cropland, Red = Forest, Green = Scrubland, Purple = Grassland, Blue = Bare land, Orange = Wetlands

Principal component analyses revealed that the soil texture was a strong factor differentiating forest soils from other soils within the LUCAS soil dataset (Figure 4.12).

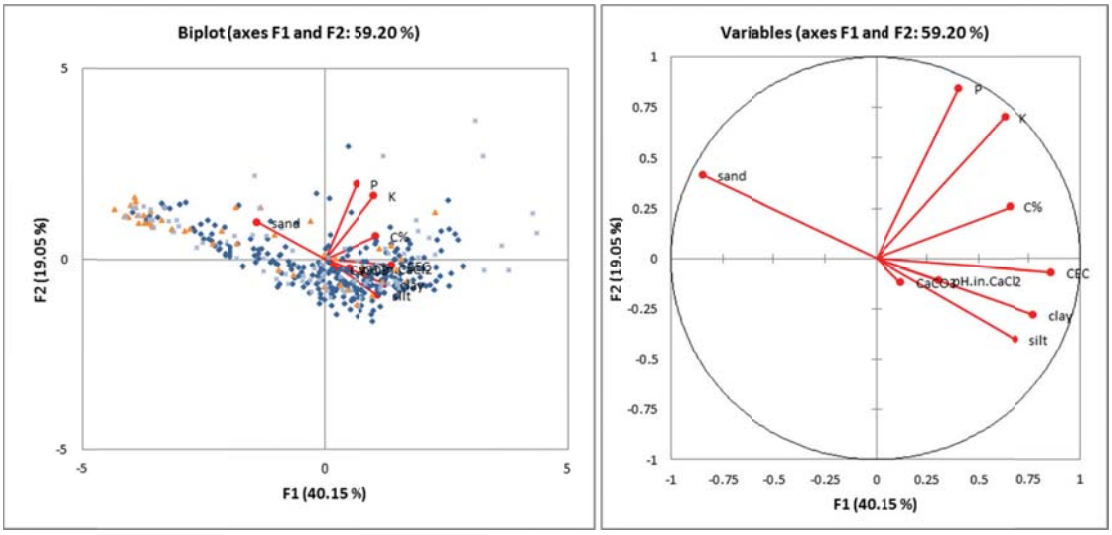


Figure 4.12 Principal component analyses plot showing grouping of soil from different land cover groups in a selected member state country (Hungary). The vectors included are all measured soil parameters within the LUCAS soil dataset (sand, silt, clay %, OC%, P mg kg^{-1}, K mg kg^{-1}, pH $CaCl_2$).

Conclusions

From a pedological point of view, the LUCAS topsoil data displayed expected behaviour. Differences between the land cover groups were observed as contrasting abundance of the measured variables than different geochemical relationships.

5. Spatial representation of soil properties of LUCAS soil samples

Tamás Hermann

LUCAS soil samples were classified using common pedological/agrochemical classes. Class values for each sampling location are displayed to visualise results of the survey. Overview maps are presented below. Please note that points on the maps appear to cover, or be representative for, larger areas than they cover in reality. This is due to the large differences in the map scale and the spatial visualization of the point values.

Another issue worth keeping in mind is the bias in the selection of the soil sampling sites towards agricultural land (predominantly annual cropland), followed by grasslands and woodlands. This means that representation of LUCAS soil property classes may over represent properties from the more heavily sampled conditions whiles under-representing others.

Figures 5.1-5.9 display soil property classes of the LUCAS soil sampling locations.

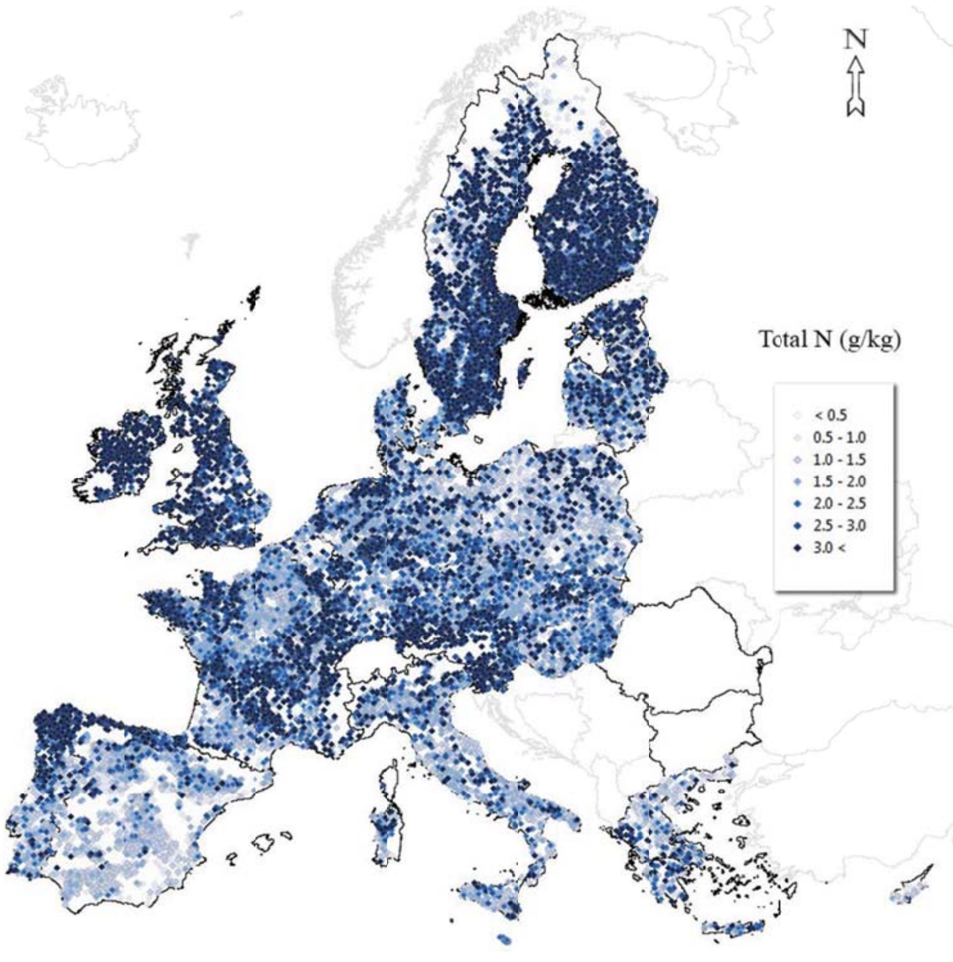


Figure 5.1 Spatial representation of topsoil total nitrogen content class of LUCAS samples.

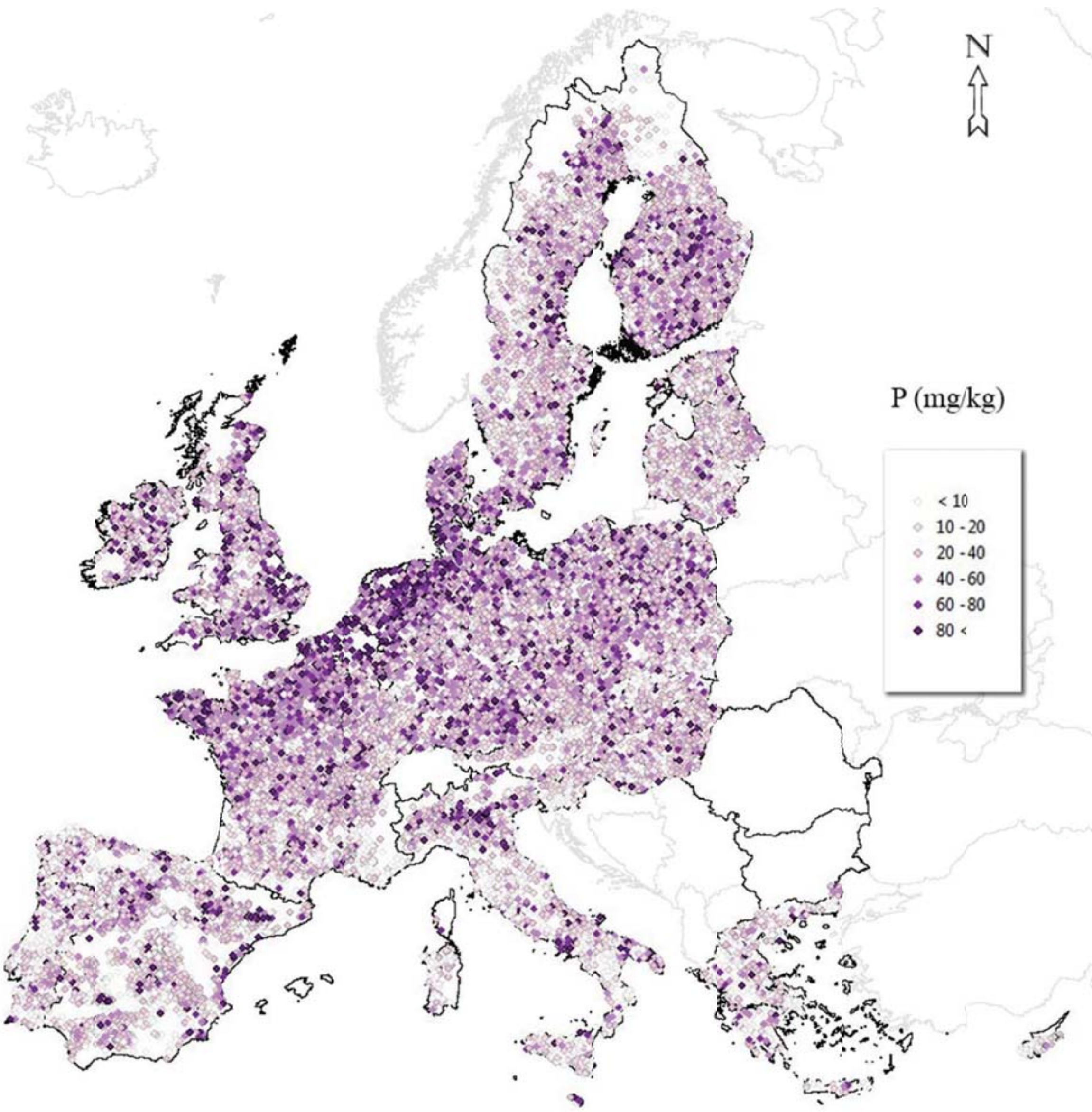


Figure 5.2 Spatial representation of topsoil phosphorus content class of LUCAS samples.

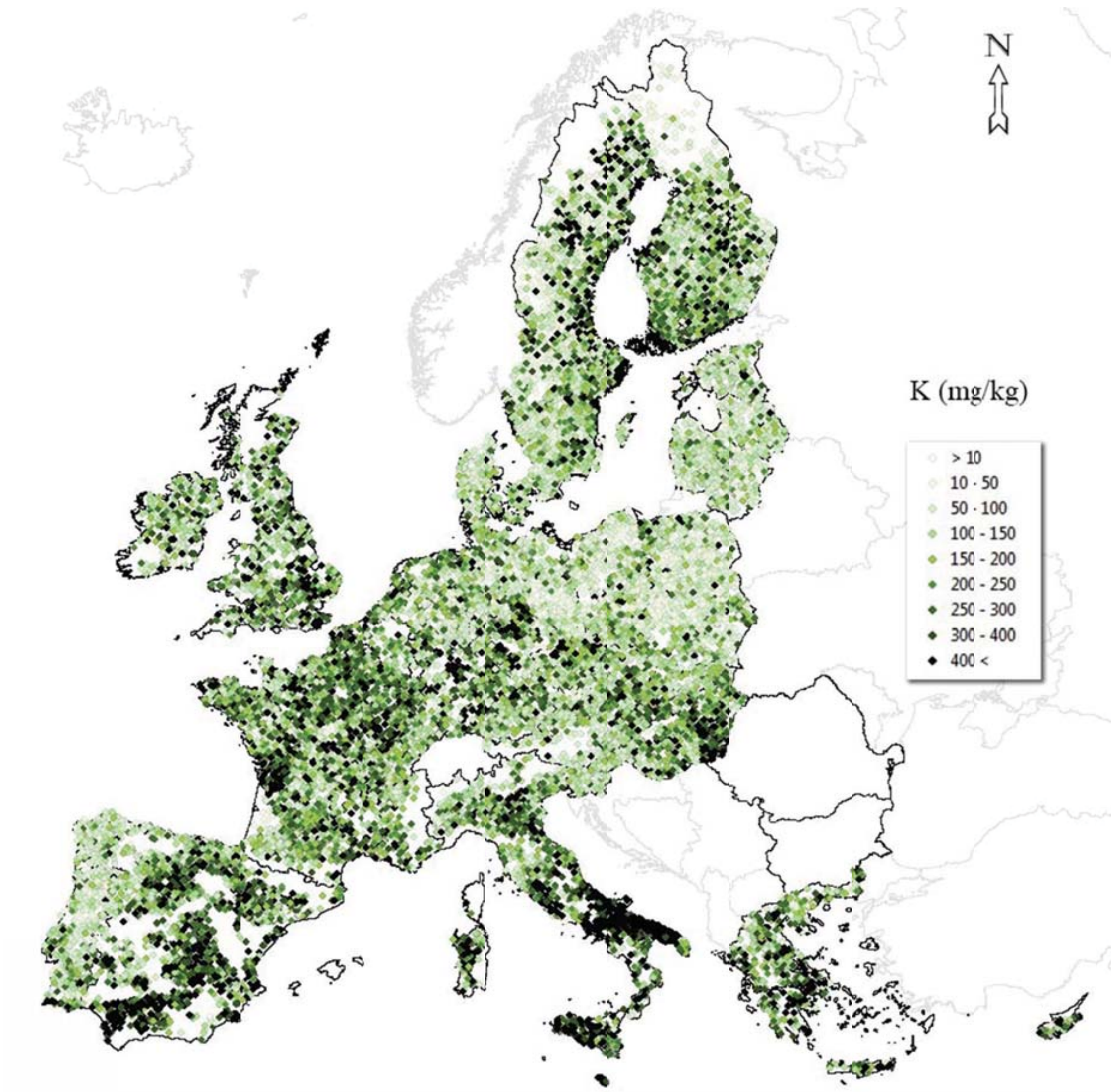


Figure 5.3 Spatial representation of topsoil potassium content class of LUCAS samples.

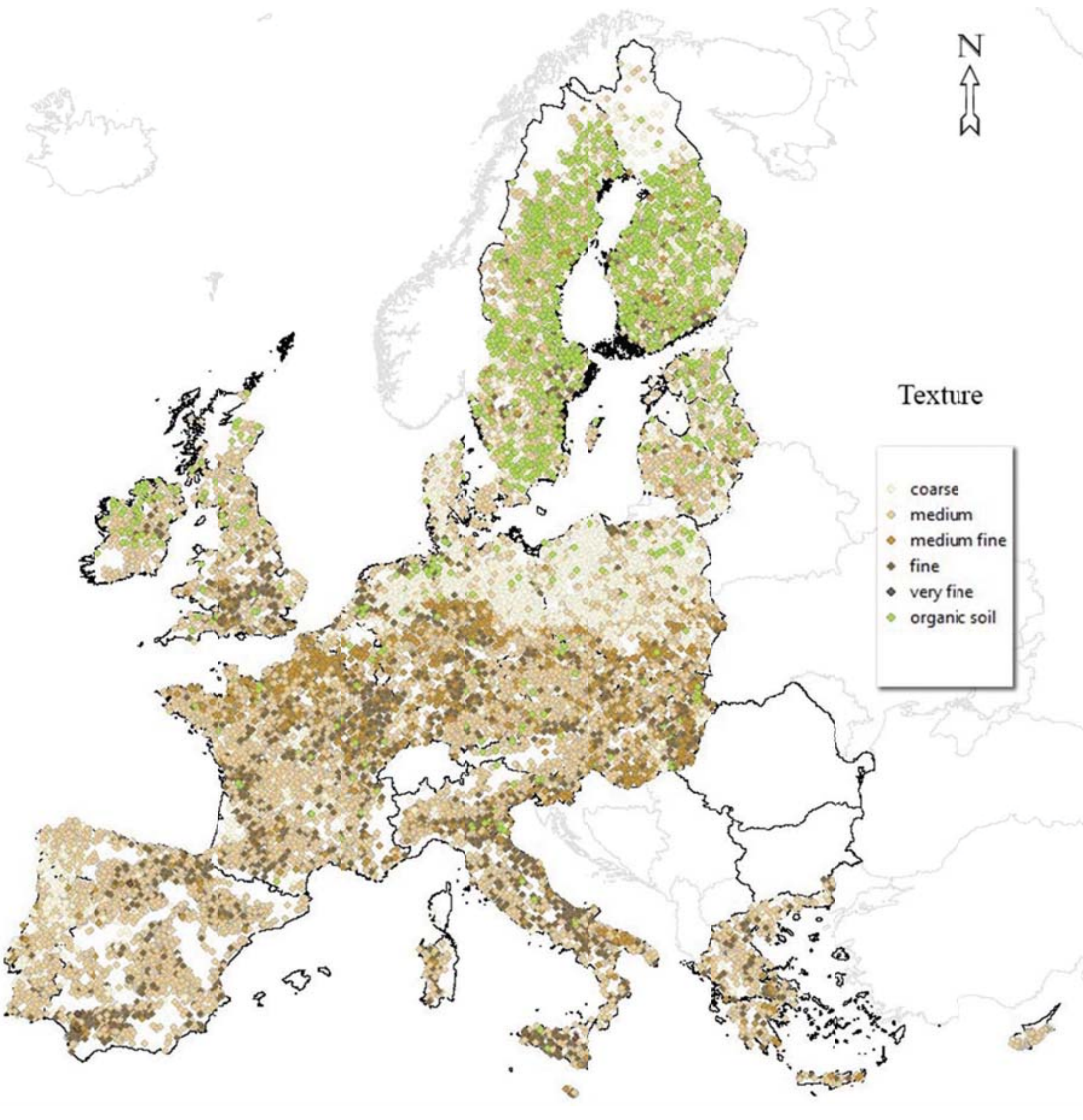


Figure 5.4 Spatial representation of topsoil texture class of LUCAS samples
Texture classification is based on the FAO (1995) scheme.

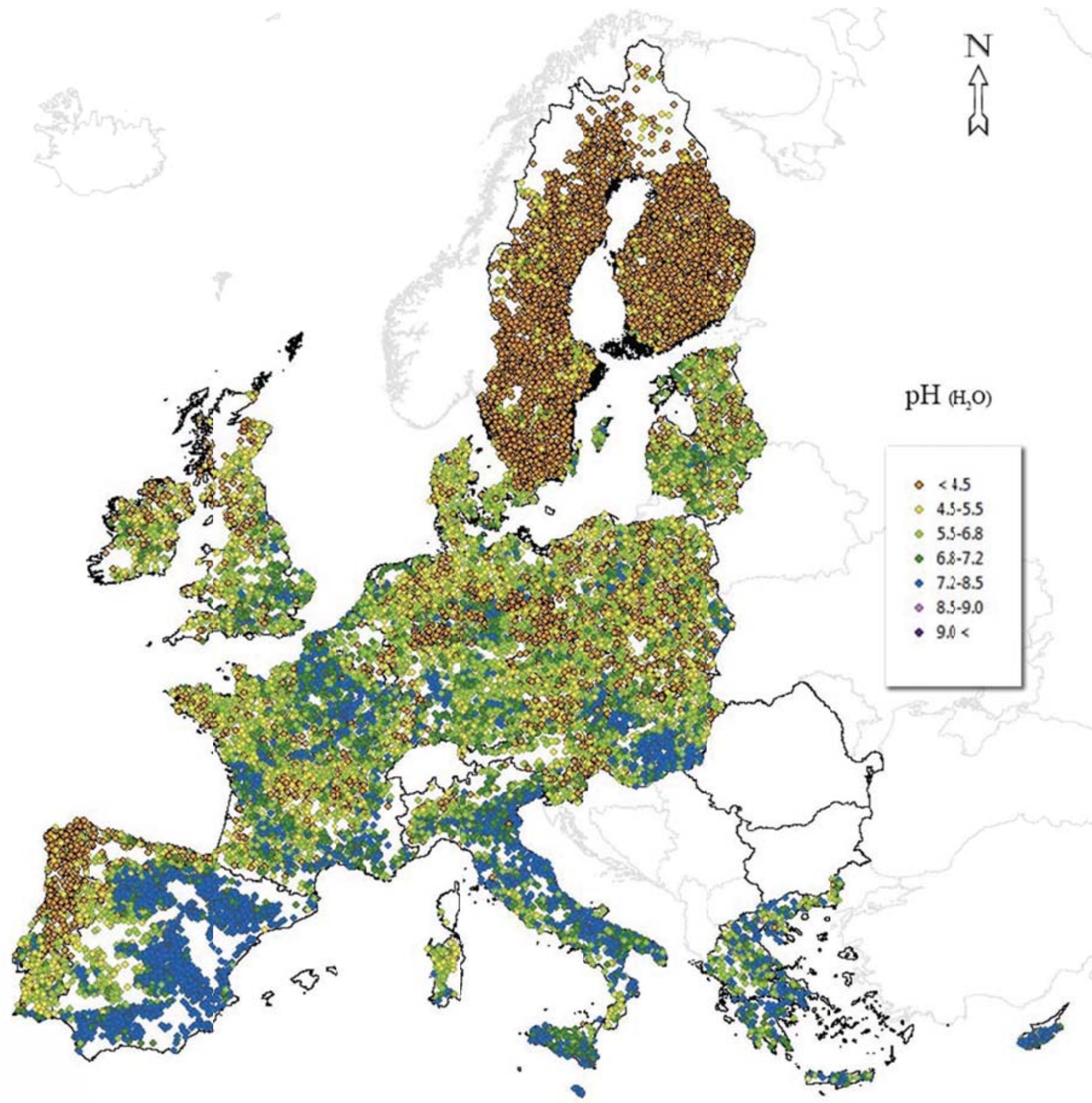


Figure 5.5 Spatial representations of topsoil $pH_{(H2O)}$ class of LUCAS samples.

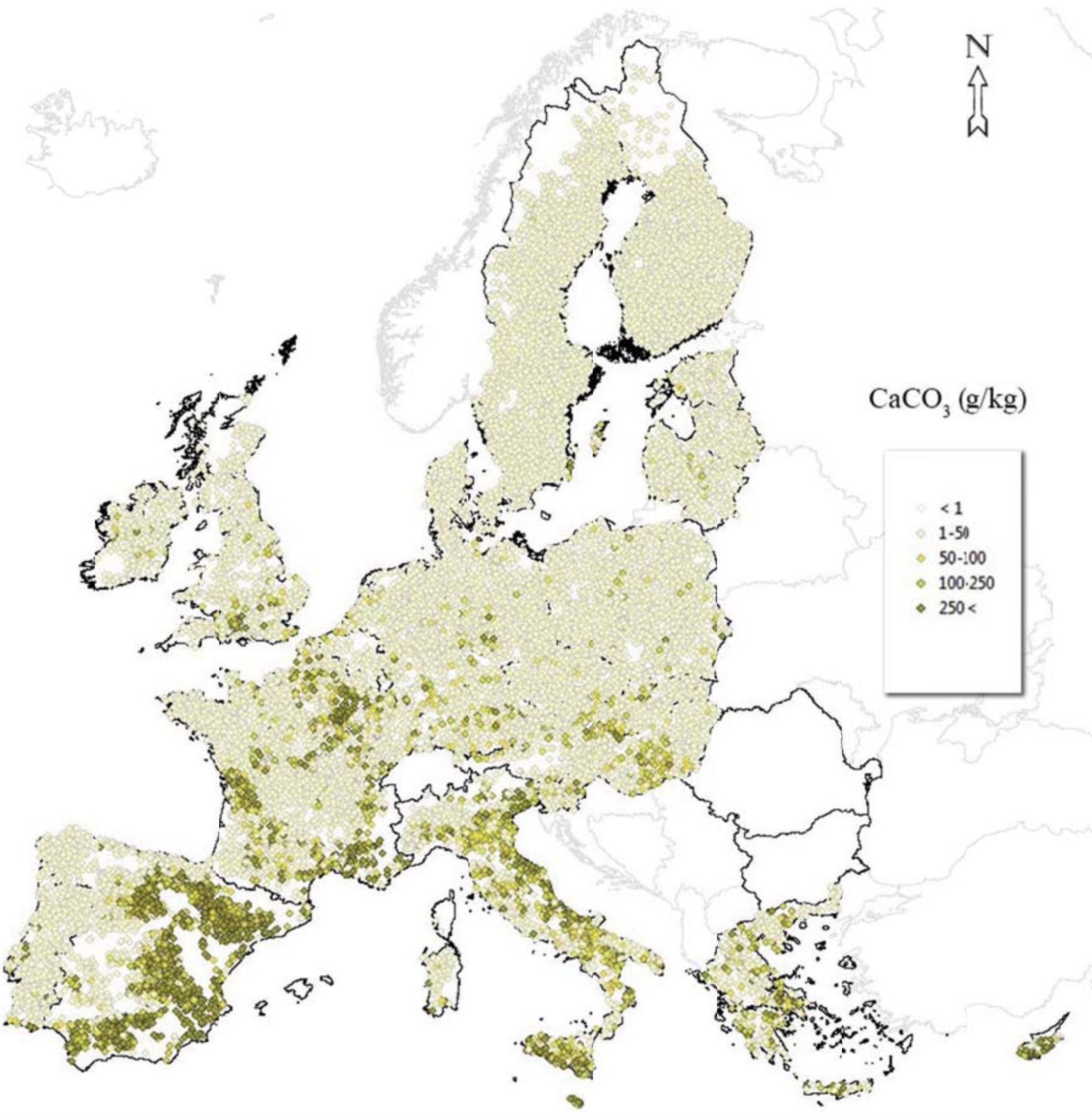


Figure 5.6 Spatial representations of topsoil $CaCO_3$ content class of LUCAS samples.

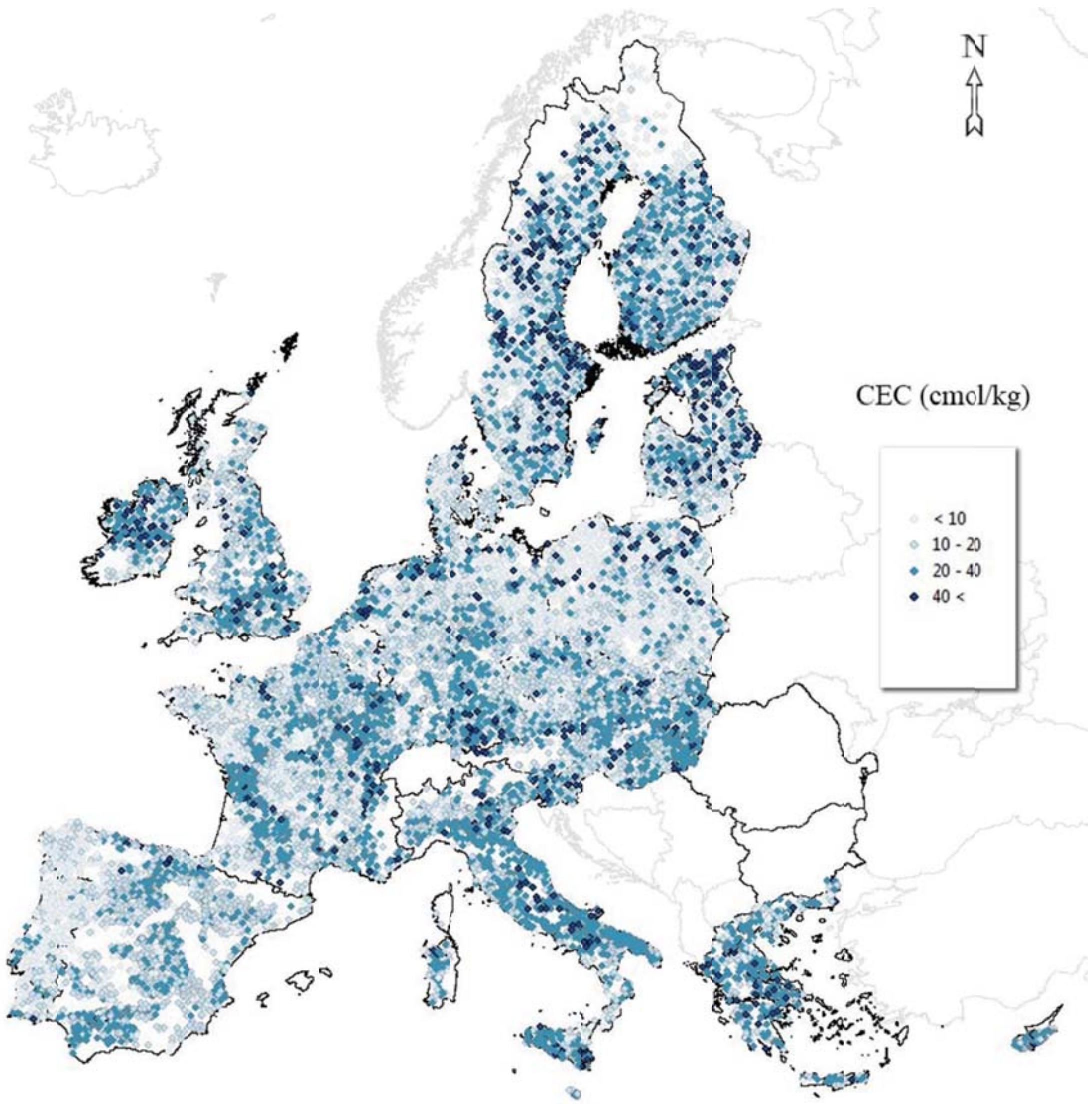


Figure 5.7 Spatial representations of topsoil cation exchange capacity class of LUCAS samples.

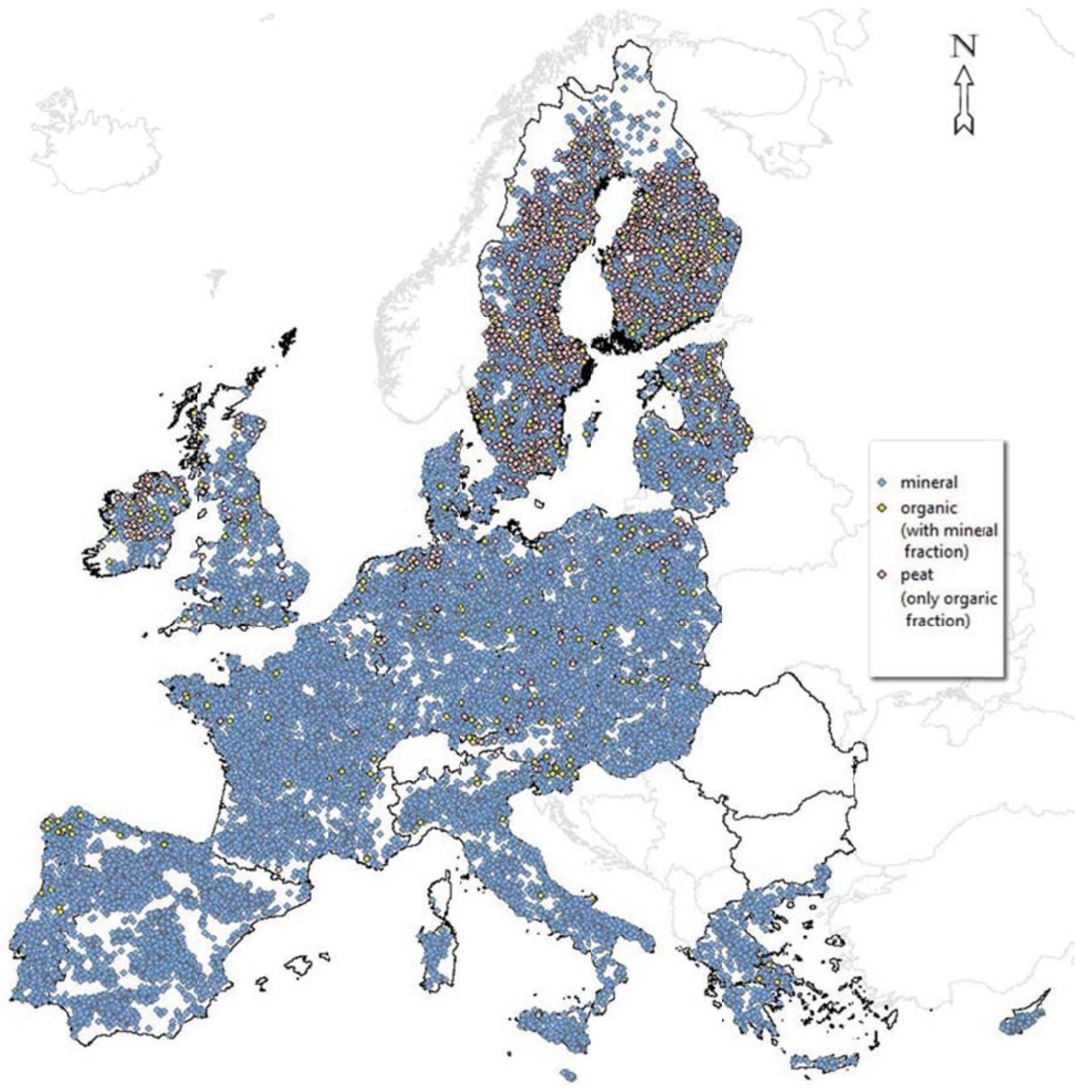


Figure 5.8 Spatial representations of topsoil category of LUCAS samples.

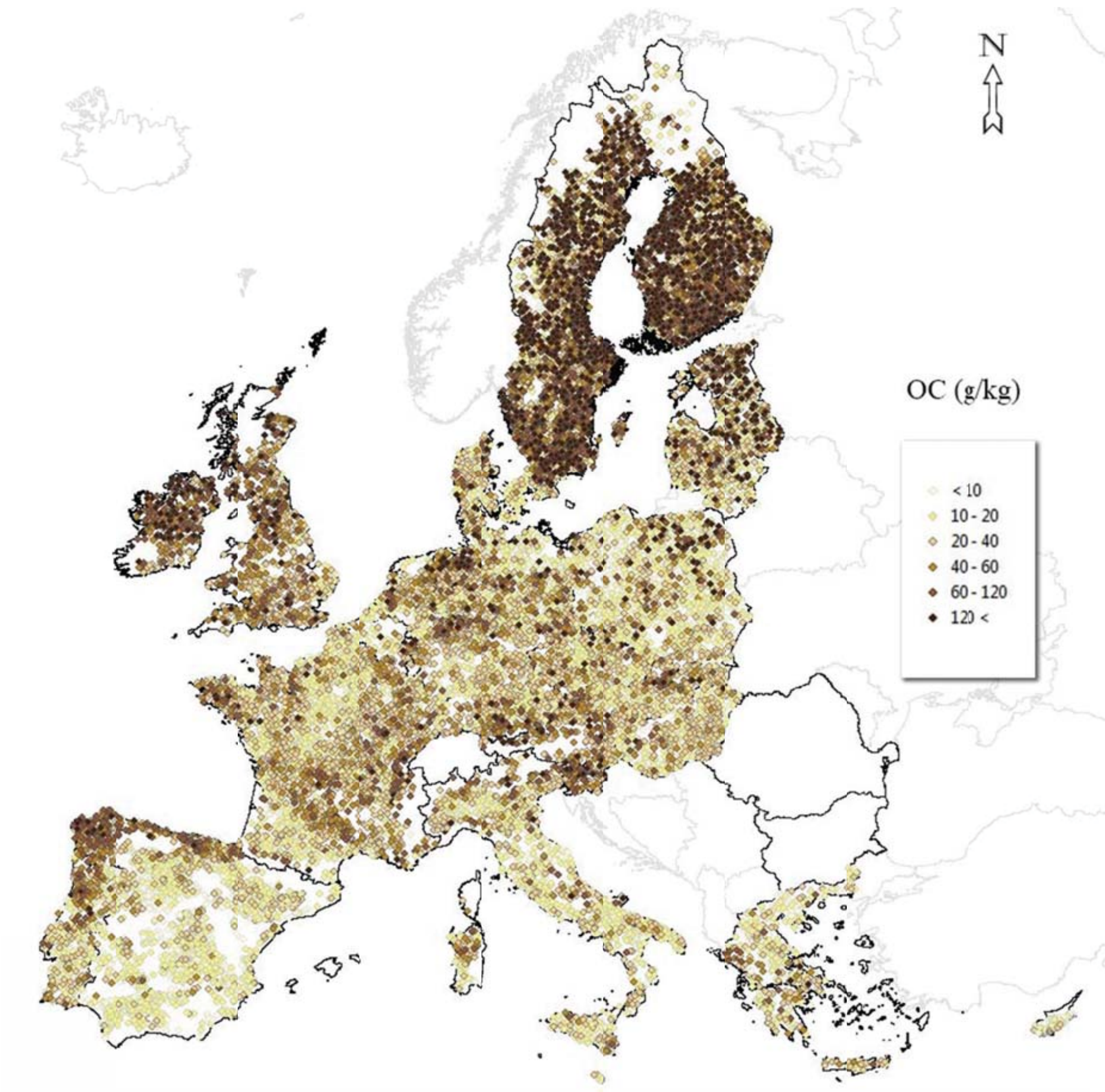


Figure 5.9 Spatial representations of topsoil organic carbon content of LUCAS samples.

6. Land-use specific comparative analysis of soil characteristics in the EU

Gergely Tóth, Arwyn Jones and Luca Montanarella

The LUCAS topsoil database provides a range of opportunities to compare soil characteristics across land use types and management practices, countries and climatic factors. However, a comprehensive assessment of all factors and their interactions is beyond the capacity of this introduction.

In the first step of the evaluation process, nine characteristic European climate systems were identified where the complex effects of water availability and thermal regime are distinct for soil. Thirty-five climatic areas (Hartwich et al., 2005) were arranged into nine climatic groups. The climatic groups embody regions where the concepts of Boreal and Boreal to Temperate (CZ1), Atlantic (CZ2), Sub-oceanic (CZ3), Sub-oceanic to Sub-continental (CZ4), Subcontinental, partly arid (CZ5), Temperate Mountainous (CZ6), Mediterranean semi-arid (CZ7), Mediterranean Temperate and Sub-oceanic (CZ8) and Mediterranean Mountainous (CZ9) climatic characteristics prevail. Climate zones are shown in figure 6.1.

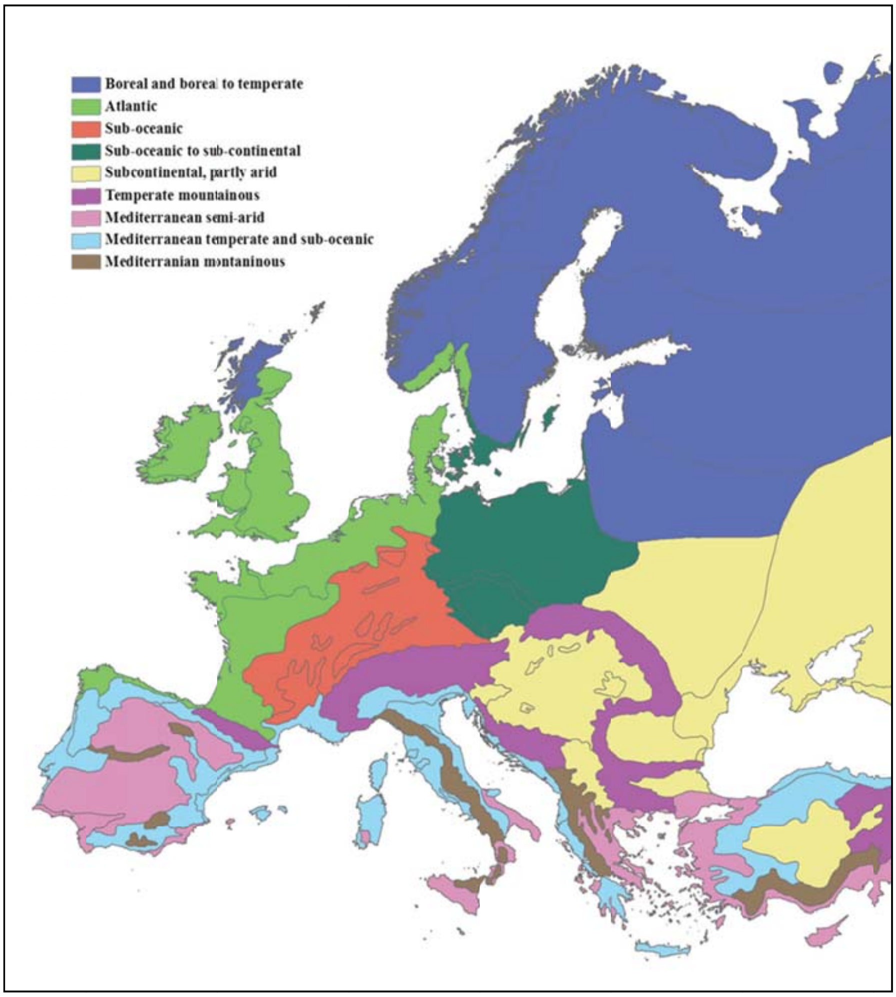


Figure 6.1 Climate zones of Europe.

Sub regions indicated denote slight variations within the main climate zone (e.g. elevation).

6.1 Croplands

The LUCAS dataset was sub-sampled to extract only the mineral soils of croplands. In the context of the LUCAS programme, croplands are defined as:

- land where crops are planted and cultivated.

Sub-categories of croplands in the LUCAS survey include:

a. **Cereals** (B11 Common wheat, B12 Durum wheat, B13 Barley, B14 Rye, B15 Oats, B16 Maize, B17 Rice, B18 Triticale, B19 Other cereals)

b. **Root crops** (B21 Potatoes, B22 Sugar beet, B23 Other root crops)

c. **Non-permanent industrial crops** (B31 Sunflower, B32 Rape and turnip rape, B33 Soya, B34 Cotton, B35 Other fibre and oleaginous crops, B36 Tobacco)

d. **Dry pulses, vegetables and flowers** (B41 Dry pulses, B42 Tomatoes, B43 Other fresh vegetables, B45 Strawberries)

e. **Fodder crops** (B51 Clovers, B52 Lucerne, B53 Other Leguminous and mixtures for fodder, B54 Mix of cereals, B55 Temporary grassland)

f. **Permanent crops** (B71 Apple fruit, B72 Pear fruit, B73 Cherry fruit, B74 Nuts trees, B75 Other fruit trees and berries, B76 Oranges, B77 Other citrus fruit) **and other permanent crops** (B81 Olive groves, B82 Vineyards, B83 Nurseries, B84 Permanent industrial crops)

As the population from permanent croplands was not sufficient to draw adequate assumptions in all cases, analysis presented in this section has focused only on soil properties under annual crops (bullet points a-e in the above list).

A series of descriptive statistics and multiple comparison tests were performed to assess the topsoil data from croplands in different climatic regions of the EU. One-way ANOVAs tests were performed to assess if there were significant differences between climate zones concerning their soil characteristics (on a 0.05 level).

6.1.1 Regional variability of topsoil texture of croplands

Particle size distribution data measured for the soil samples were classified into five texture categories according to the FAO scheme (1990). In order to be compliant with the requirements of the texture classification, particle size data measured using the ISO 11277 method (ISO 1998) were transformed to uniform texture classes according to Hollis et al. (2006). The particle size distributions of all mineral soil samples in the LUCAS database according to the different climatic zones are shown in figure 6.2, while those collected from soils under annual crops are shown in figure 6.3. Distribution of soils in different texture classes are indicated using the same texture triangles that display particle size distribution of the samples (Figures 6.2 and 6.3). These figures show that there are considerable differences in topsoil textures between the climate zones. Coarse and medium textured soils dominate Boreal and Boreal to Temperate (CZ1) and Sub oceanic to Sub-continental (CZ4) areas, course texture having the largest share among all climate zones in the latter. The dominance of medium textured soils is characteristic for all other climatic zones, but this domination is most pronounced in the Temperate Mountainous (CZ6) and Mediterranean Semi-Arid (CZ7) climate zones. Fine texture soils have the highest share in the Mediterranean Mountainous region (CZ9) with 30% of all samples from this region, and the lowest share in the Boreal and boreal to temperate zone (CZ1) with 6.1%. Less than 1% of the soils in this region have very fine texture. The very fine textured soils are also relatively rare in other European regions, exceeding 1% of all samples only in the Sub-continental, Partly Arid (CZ5) and in the Mediterranean Mountainous (CZ9) regions. Interestingly, annual crops are cultivated on very fine textured soils to a higher proportion than the share of these soils in all land use classes in six climatic zones (CZ1, 4, 5, 6, 8 and 9).

Their share is less only on areas with abundant water (CZ2 and 3) and areas with aridity (CZ7) where heavy texture might be disadvantage. Croplands, on the other hand are always more abundant on fine texture soil in all regions except one (Temperate Mountainous CZ6), while medium fine texture can be found in higher fraction under croplands than in other uses in all regions without exception. Coarse textured soils in all climate zones have a lower proportion in annual croplands than in all land uses and the proportion of medium textured soils in this regard is only higher in the Boreal and Boreal to Temperate (CZ1) and the Sub-oceanic to Sub-continental (CZ4) climatic zones.

The above finding illustrate both the climatic dependency of texture formation in the European Union and highlight the soil texture aspect in land use optimisation strategies applied by the farmers under different climates.

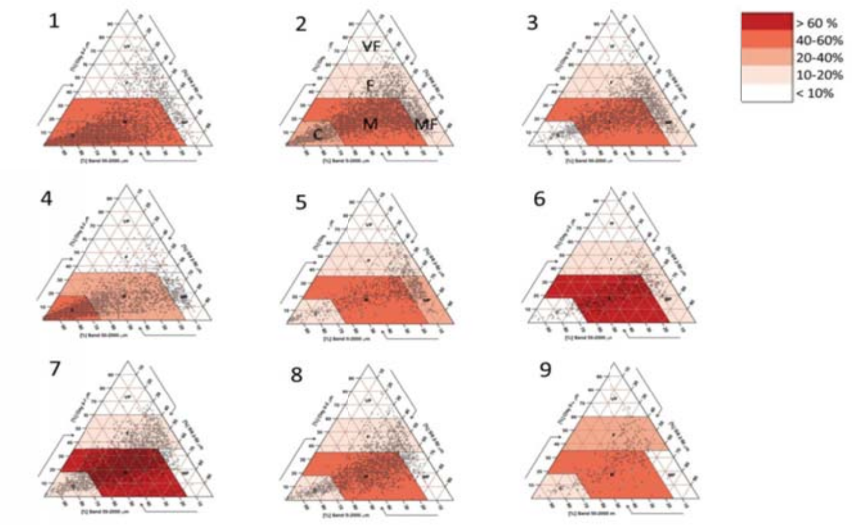


Figure 6.2 Particle size distribution and texture classes of mineral topsoil of croplands in the EU for different climatic zones for all land use types.

for climate categories 1-9 see Table 6.1.
texture classes: VF- very fine, F –fine, MF – medium fine, M – medium, C –coarse
colour legend indicates % of the samples in the corresponding texture category

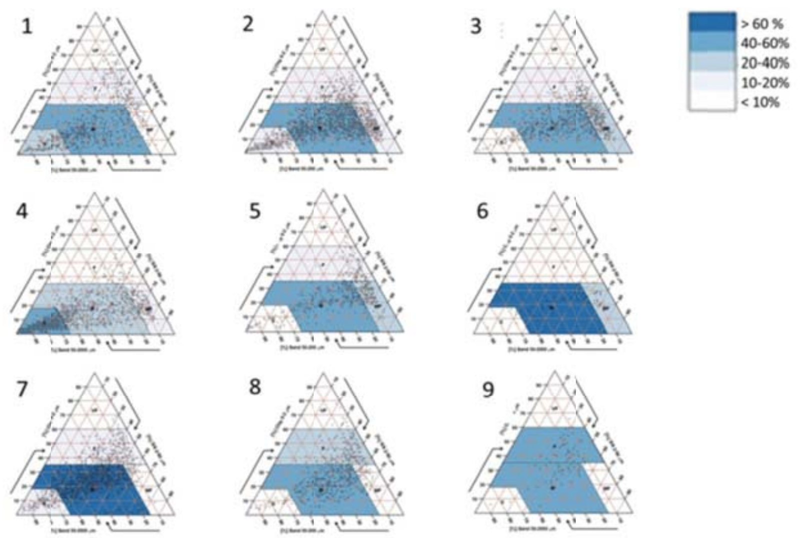


Figure 6.3 Particle size distribution and texture class of mineral topsoil of croplands of the EU for different climatic zones.

for climate categories 1-9 see Table 6.1.
texture classes: VF- very fine, F –fine, MF – medium fine, M – medium, C –coarse
colour legend indicates % of the samples in the corresponding texture category

6.1.2 Regional variability of topsoil organic carbon of croplands

Data from the LUCAS soil survey confirms the common perception (Jones et al., 2005) that soil organic carbon (SOC) levels increase following a south-east to north-west trend in the EU. Differences in SOC concentrations attributed to climatic factors can exceed 200% between mineral soils under croplands in the boreal/boreal-to-temperate region and those in the Mediterranean semi-arid climate, (Table 6.1). However, standard deviation values highlight the high variability of SOC concentrations within climatic zones. In every zone SOC levels reach, or even exceed, the magnitude that was measured between mean levels of the different climatic zones. This phenomenon shows that the combined effect of other soil forming factors and soil properties is on the same order of magnitude with the effect of climate when studying SOC on a continental scale.

Table 6.1. Soil organic carbon concentration (g/kg) in topsoils of annual croplands (AC) and permanent croplands (PC) in different climatic regions of Europe

Climate zone		Land use type	Mineral soils		
No.	Name		mean	std	n
1	Boreal and boreal to temperate	AC	27	18	703
		PC	16	5	3
2	Atlantic	AC	20	12	1993
		PC	22	14	36
3	Sub-oceanic	AC	19	10	784
		PC	25	13	32
4	Sub-oceanic to sub-continental	AC	15	9	1392
		PC	16	10	25
5	Subcontinental, partly arid	AC	18	7	506
		PC	17	7	13
6	Temperate mountainous	AC	17	8	89
		PC	26	13	22
7	Mediterranean semi-arid	AC	12	7	1433
		PC	13	8	463
8	Mediterranean temperate and sub-oceanic	AC	16	11	559
		PC	17	12	380
9	Mediterranean mountainous	AC	15	6	77
		PC	18	10	49

Multiple comparison tests showed that SOC levels in annual croplands of the boreal and boreal to temperate zone (CZ1) are significantly higher than SOC levels in annual croplands of any other climatic zones. Mean SOC level in the Atlantic zone (CZ2) is significantly higher than in zones to its east and south, except for the Sub-oceanic zone (CZ3) with which the observed difference was not significant. Mean SOC content in croplands with annual crops in the Sub-oceanic to sub-continental zone (CZ5) significantly differs from those in all zones, except in Temperate mountainous (CZ6), Mediterranean temperate and sub-oceanic (CZ8) and Mediterranean mountainous (CZ9). SOC content in the Mediterranean semi-arid zone (CZ7) is significantly lower than SOC in any other regions, except for the mountainous regions in the Mediterranean (CZ9), where LUCAS has quite low number of samples from.

According to the data from the LUCAS Topsoil Survey, differences between SOC concentration in annual and permanent croplands is statistically significant (on a 0.05 level) only in the Sub-oceanic (CZ3), Temperate mountainous (CZ6), Mediterranean semi-arid (CZ7) and in the Mediterranean mountainous regions (CZ9). In other regions, the difference in SOC content cannot be statistically proven by the LUCAS topsoil data. Nevertheless, these figures highlight the potential of the dataset to perform analysis on the effect of land use on SOC levels in different European regions.

6.1.3 Regional variability of topsoil pH of croplands

Soil pH is a consequence of several soil forming factors and parallel soil processes (Boruvka et al., 2007). Analysis based on the LUCAS topsoil database shows that climate has a substantial role in this control mechanism (Figure 6.4.). While the majority of north-western cropland soil in the EU (CZ1-4) has an acidic reaction, soil in the Mediterranean (CZ7-9) is generally alkaline. In the partly arid Sub-continental zone (CZ5) and Temperate mountainous regions (CZ6), neutral to alkaline soils dominate croplands, and these types of soils are already present in considerable areas of the Sub-oceanic regions as well. Parent material and other local conditions might overwrite the general trends and can dominate over climate in the determination of soil pH.

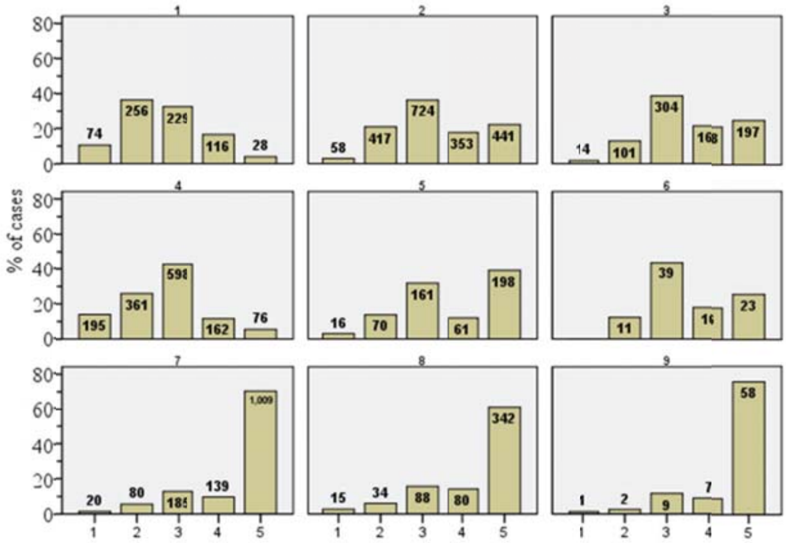


Figure 6.4 Percentage distribution of pH categories (1-5) in mineral soil samples from annual croplands in the EU for different climatic zones (CZ1-9).

(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 - 7.2; 5: >= 7.2
numbers at the bars show sample size; (for climate zone names see Table 6.1)

Very acidic (pH<4.5) soils are present in the Mediterranean area while soils with high pH (>7.2) can be found under predominantly leaching conditions of the Atlantic and Sub-oceanic zones. Although the topsoil pH of croplands, especially in the neutral and acidic range, is subject to change as a result of liming, figures based on the LUCAS topsoil data suggest that soil reaction component of cropping conditions are closely determined by natural conditions.

6.1.4 Regional variability of topsoil cation exchange capacity of croplands

Cation exchange capacity (CEC) is the sum of exchangeable bases plus total soil acidity at a specific pH and is an indication of the ability of a soil to hold plant nutrients. CEC data (Figure 6.5) from the LUCAS topsoil database show natural correlation to those of pH (Figure 6.4.) in samples from the north-western climatic zones. Domination of cropland soils with low to medium CEC in these regions (CZ1-4) can be attributed to textural characteristics and clay mineralogy. The negative effect of these characteristics on CEC in these regions, in most cases, cannot be compensated by the high CEC of organic matter. If the applied laboratory method shows potential rather than actual CEC of acid soils, it is possible to assume that unfavorable natural soil conditions exist as far as soil fertility or filtering and buffering capacity are concerned for much of the cropland areas in these regions. However, it should be noted that with regards to fertility, climate and crop management can compensate the negative soil characteristics. In the Mediterranean mountainous (CZ9), Sub-continental and, to a lesser extent, the arid zones (CZ5), croplands have soils with higher CEC occur in a larger proportion than in other regions.

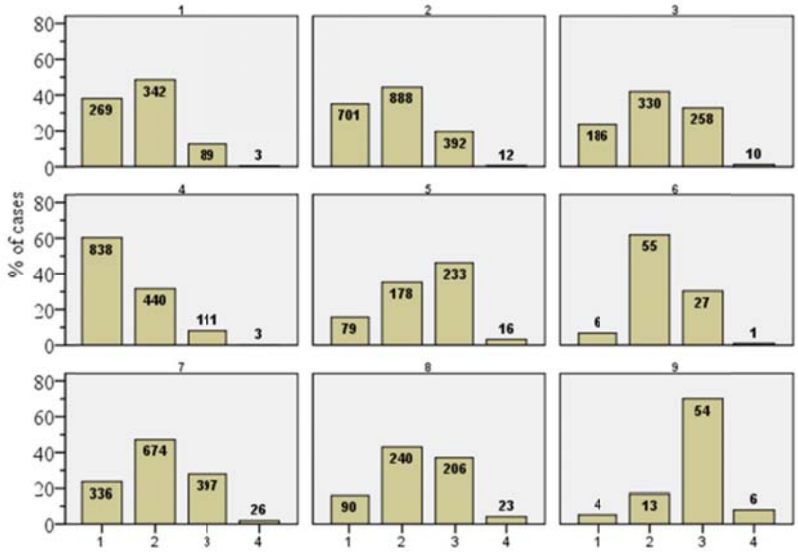


Figure 6.5 Distribution of cation exchange capacity categories (1-4) in mineral soil samples from annual croplands in the EU for different climatic zones (1-9).

(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see Table 6.1)

6.1.5 Regional variability of topsoil calcium carbonate content of croplands

The calcium carbonate ($CaCO_3$) content of cropland soils in European regions display strong climate dependence. Cropland soils in the Mediterranean contain systematically higher amount of $CaCO_3$ than in the north-western regions of the continent (Figure 6.6.). For many crops, 0.1-5% $CaCO_3$ is optimal and we can see that croplands soils with these values have the highest areal share in all regions, except the Mediterranean semi-arid. This phenomenon indicates a conscious adaptation of the land use for the best fitting conditions where possible and/or amelioration of acidic land to support plant growth (Figure 6.6.)

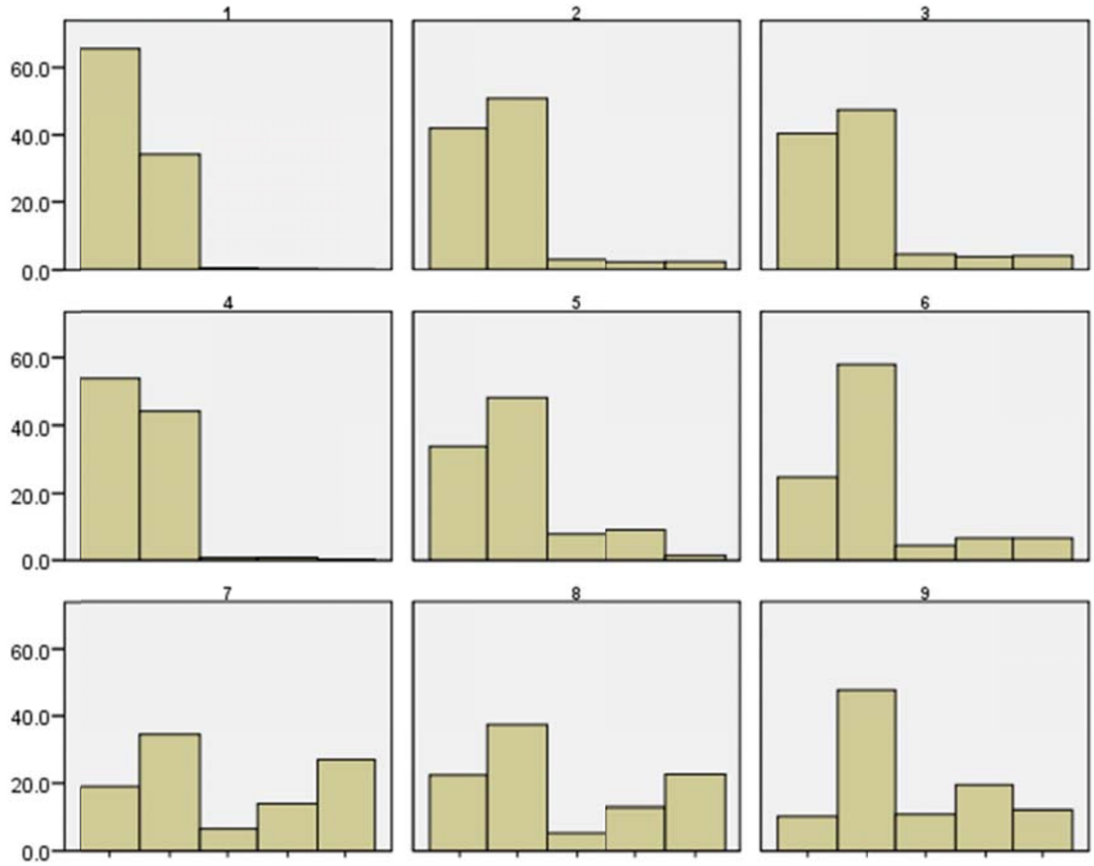


Figure 6.6 $CaCO_3$ content in mineral soils in land uses other than annual cropland in the EU for different climatic zones.

1: $CaCO_3$ <= 0.1 (g/kg); 2: >=0.1 and < 50; 3: >=50 and <100; 4: >=100 and <250; 5: >=250

(for climate zone names see Table 6.1)

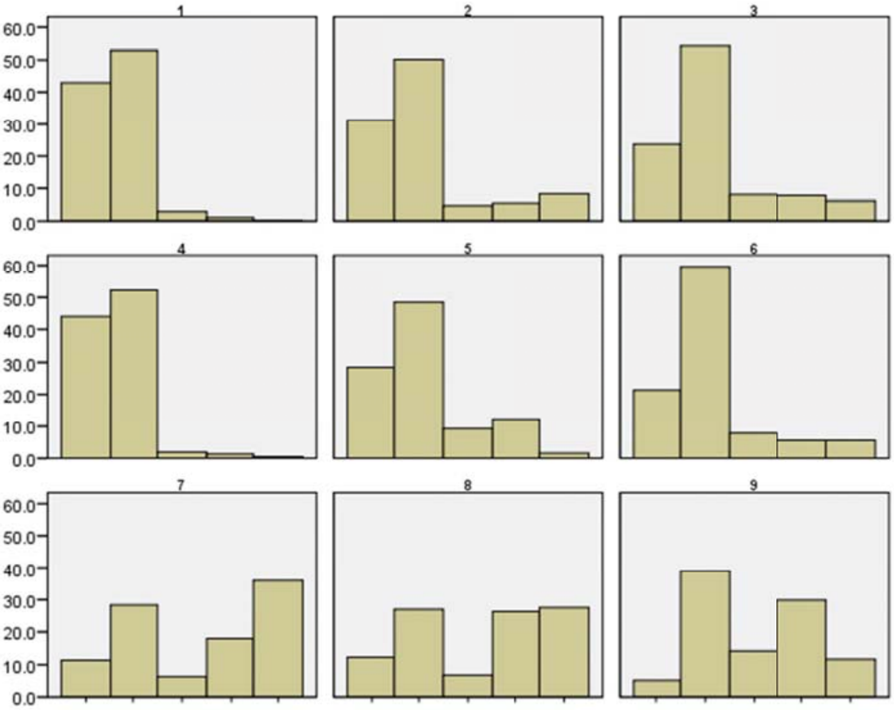


Figure 6.7 $CaCO_3$ content of croplands in the EU (annual crops, mineral soils) for different climatic zones.

1: $CaCO_3$ <= 0.1 (g/kg); 2: >=0.1 and < 50; 3: >=50 and <100; 4: >=100 and <250; 5: >=250
(for climate zone names see Table 6.1)

6.1.6 Regional variability of topsoil total nitrogen content of croplands

Total nitrogen (N) content of soils is an important measure for agricultural and environmental applications. The variability of N in mineral cropland soils shows large diversity among the climatic regions of the EU, as shown in figure 6.8. More than half of the cropland samples from the sub-oceanic and Mediterranean (semi-arid) regions fall into one category (0.5-1 g/kg). Cropland soils temperate and mountainous influence in the Mediterranean also show certain degree of skewedness with regards to the distribution of N categories in the samples, while in the Mediterranean countries this is towards the lower N content categories, in the other regions is towards the medium ranges, with presenting an approximately normal distribution of N categories of the samples. Data presented in figure 6.8 illustrate the variability of situation in the climatic zones of the EU, thus demonstrating the complexity of scientific studies that need to be undertaken to arrive to a coherent evaluation of soil ecosystem services where nitrogen is accounted.

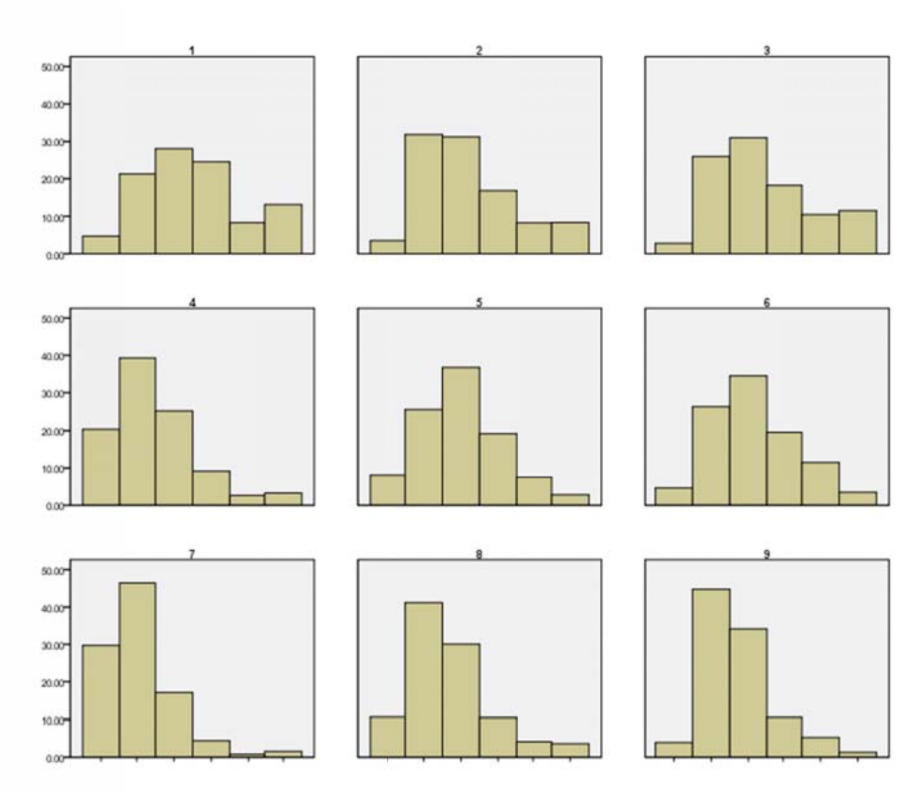


Figure 6.8 Nitrogen content of topsoil in croplands in the EU (annual crops, mineral soils) for different climatic zones.

in % of samples in classes; classes - 1: <1; 2: >=1 and <1.5; 3: >=1.5 and <2; 4: >=2 and <2.5;
5: >=2.5 and <3; 6: >=3
(for climate zone names see Table 6.1)

The establishment of numerical relationships between the total nitrogen content and other parameters (e.g. plant available mineral forms of nitrogen) in a harmonised manner for applications on regional to continental scale remains a task for future research.

6.1.7 Regional variability of topsoil phosphorus content of croplands

Phosphorus (P) in cropland topsoils is one of the most relevant indicators of the intensity of fertiliser application. According to the LUCAS topsoil database, two groups of climatic zones can be distinguished in the EU based on the P levels of their cropland soils. The first group includes those zones where lower P levels dominate in cropland (CZ1, CZ5, CZ6, CZ7, CZ8, CZ9); while in the second group (CZ2, CZ3, CZ4) all categories have significant share in croplands. This result suggests higher phosphorus input on agricultural land where water is not a limiting factor of crop production.

Phosphorus content is predominantly management driven soil property, therefore a regional analysis of the LUCAS phosphorus data is suggested.

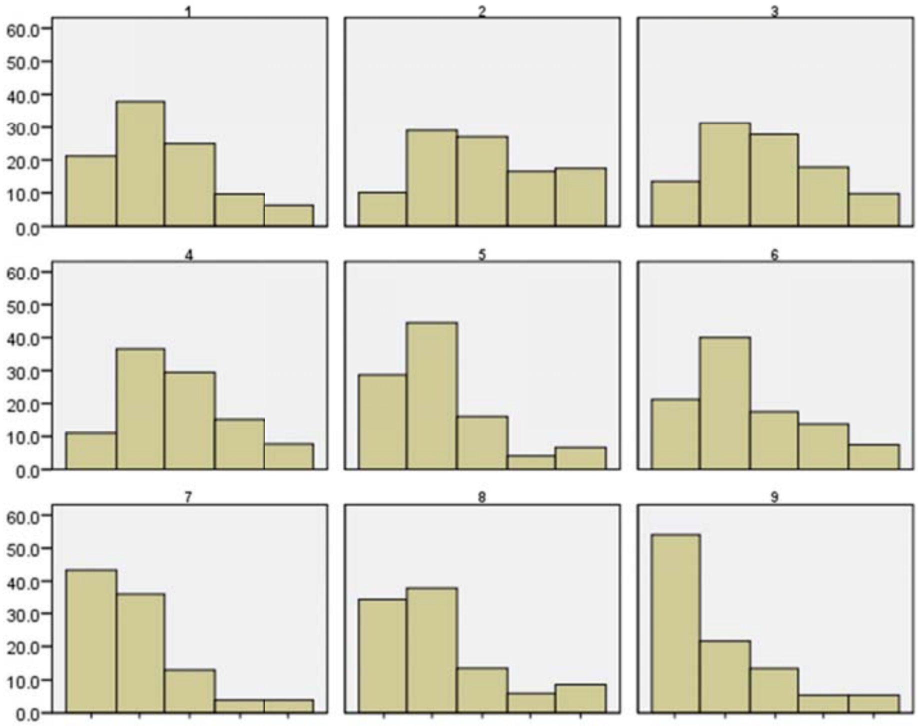


Figure 6.9 Phosphorus content of croplands in the EU (annual crops, mineral soils) for different climatic zones.

in % of samples in classes; Classes - 1: <20 (mg/kg); 2: >=20 and <40; 3: >=40 and <60; 4: >=60 and <80; 5: >=80
(for climate zone names see Table 6.1)

6.1.8 Regional variability of topsoil potassium content of croplands

Among the three macronutrients investigated, potassium (K) has the most even distribution across the EU (Figure 6.10.). As available K, to a degree, is determined by clay content and mineralogy, the distributions on figure 6.10. provide a good indication of potential K turnover of soils in European countries. On the other hand, fertiliser inputs modify K levels. Therefore, to obtain a clear picture on management driven K dynamics of soils, further studies will be needed with consideration of (soil specific) fertiliser inputs. While these kinds of studies are beyond the scope of this report, there is a need for complex evaluation of soil characteristics which interact and determine the quality of soil.

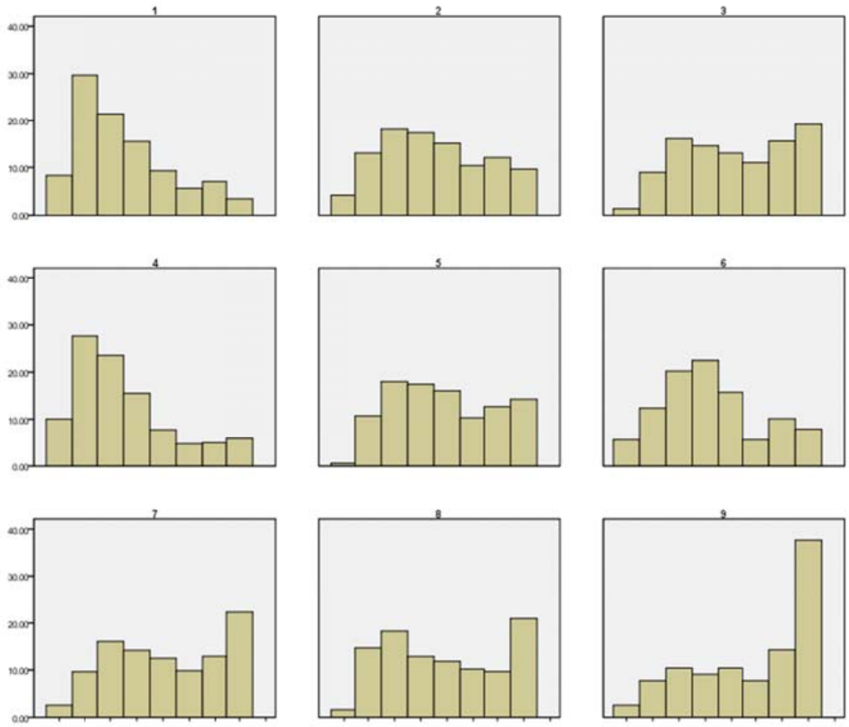


Figure 6.10 Potassium content of croplands in the EU (annual crops, mineral soils) for different climatic zones.

% of samples in classes; Classes – 1: <50 (mg/kg); 2: >=50 and <100; 3: >=100 and <150; 4: >=150 and <200; 5: >=200 and <250; 6: >=250 and <300; 7: >=300 and <400; 8: >=400
(for climate zone names see Table 6.1)

6.2 Grasslands

The dataset was sub-sampled to extract only the mineral soils of grasslands. In the context of the LUCAS programme, grasslands are defined as:

- land predominantly covered by communities of grassland, grass like plants and shrubs (the LUCAS code is E00). The density of tree-crown is less than 10% and the density of tree+shrub-crown is less than 20%.

Sub-categories of grasslands in the LUCAS survey include:

- **pastures under sparse tree or shrub cover**, coded as E10. This includes dry grasslands, dry edaphic meadows, steppes with gramineae and Artemisia, plain and mountainous grassland, wet grasslands, alpine and subalpine grasslands, saline grasslands, arctic meadows and temporarily unstocked areas within forests.

- **grassland without tree/shrub cover,** coded as E20. Land is predominantly covered by communities of grassland, grass like plants and forbs without trees and shrubland. Temporary (and artificial) grassland is also included in this category.

- **spontaneously re-vegetated surfaces,** coded as E30. This includes mostly agricultural land which has not been cultivated this year or the years before. It has not been prepared for sowing. This class can also be found on unused land, storage land, etc.

In total, 4866 samples were categorised as representing grasslands (just over 24% of the final database). In this exercise, no division of sub-classes is made.

No grassland samples were reported for Malta.

6.2.1 Regional variability of topsoil texture of grasslands

Particle size distribution data measured for the soil samples were classified into texture categories according to FAO schema (1990). In order to be compliant with the requirements of the texture classification, particle size data measured using the ISO 11277 method (ISO 1998) were transformed to uniform texture classes according to Hollis et al. (2006). The particle size distributions of all mineral soil samples in the LUCAS database according to the different climatic zones are shown in figure 6.2, while those collected from mineral soils under grasslands are shown in figure 6.11.

These figures show that there are considerable differences in topsoil textures of grasslands between the climate zones although the predominant classes are medium texture. Coarse and medium textured soils dominate Boreal and Boreal to Temperate (CZ1) and Sub oceanic to Sub-continental (CZ4). The dominance of medium textured soils is characteristic for all other climatic zones, although slightly less pronounced for the Sub-continental zone (CZ5). Only in the Mediterranean Mountainous region (CZ9) do soils with finer textures become significantly evident.

The data seem to suggest that grasslands are predominantly found on free draining, coarse to loamy soils which are relatively nutrient rich and less susceptible to waterlogging conditions.

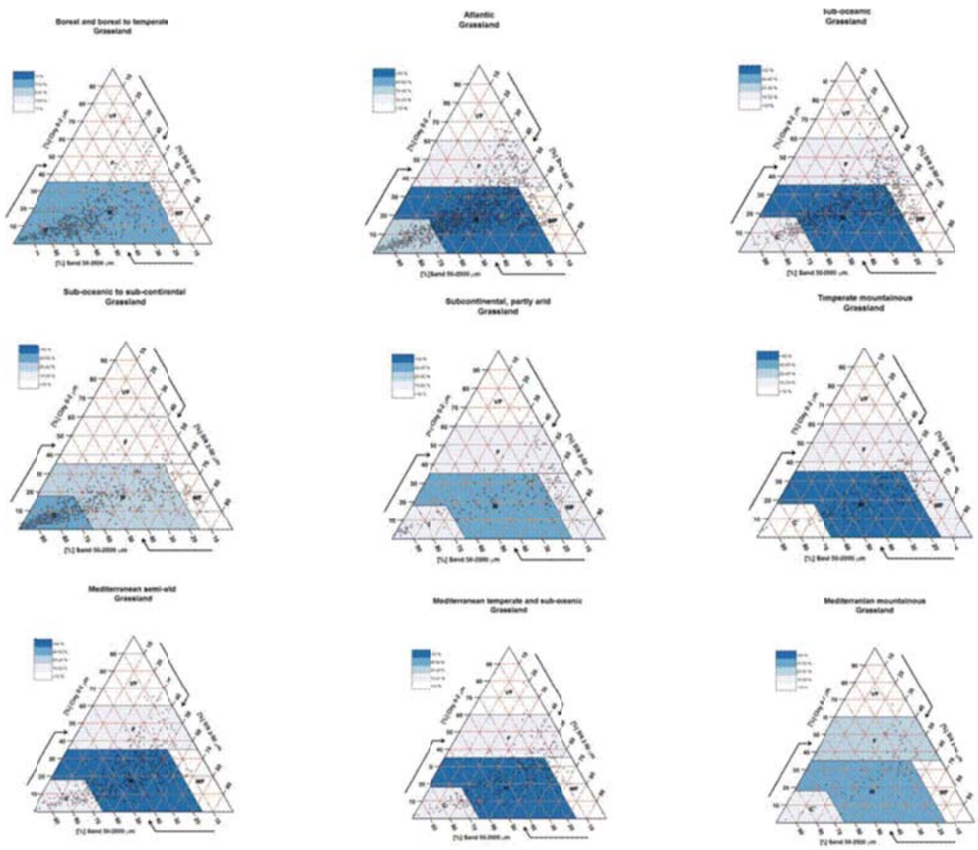


Figure 6.11 Particle size distribution and texture class in mineral topsoils of grasslands in the EU for different climatic zones.

for climate categories 1-9 see Table 6.2.
texture classes: VF- very fine, F –fine, MF – medium fine, M – medium, C –coarse
colour legend indicates % of the samples in the corresponding texture category

6.2.2 Regional variability of topsoil organic carbon of grasslands

Data from the LUCAS soil survey confirms the common perception (Jones et al., 2005) that soil organic carbon (SOC) levels increase following a south-east to north-west trend in the EU. Higher organic carbon levels are found in Boreal and boreal to temperate, Atlantic, Sub-oceanic and the Temperate mountainous zones with highest mean values being found in the Atlantic Zone (CZ2) – reflecting the cool, humid conditions that encourage the growth of grasses and the accumulation of soil organic matter. Lowest values are found in the Mediterranean semi-arid zone (CZ8). Differences in SOC concentrations attributed to climatic factors can exceed 200% between mineral soils under grasslands in the Atlantic region and those in the Mediterranean semi-arid climate (Table 6.2).

However, standard deviation values highlight the high variability of SOC concentrations within climatic zones. In every zone, SOC levels reach, or even exceed, the magnitude that was measured between mean levels of the different climatic zones.

Table 6.2. Soil organic carbon concentration (g/kg) in the mineral topsoils of grasslands in different climatic regions of Europe

Climate zone		Mineral soils		
No.	Name	mean	std	n
1	Boreal and boreal to temperate	28	19	529
2	Atlantic	40	22	1178
3	Sub-oceanic	34	16	748
4	Sub-oceanic to sub-continental	24	20	600
5	Subcontinental, partly arid	26	19	166
6	Temperate mountainous	34	18	208
7	Mediterranean semi-arid	17	12	423
8	Mediterranean temperate and sub-oceanic	25	18	304
9	Mediterranean mountainous	22	12	60

6.2.3 Regional variability of topsoil pH of grasslands

Soil pH is a consequence of several soil forming factors and parallel soil processes (Boruvka et al., 2007).

Analysis based on the LUCAS topsoil database shows that grasslands reflect this control mechanism (Figure 6.12.). While the majority of north-western grasslands soil in the EU (CZ1-4) and Temperate mountainous regions (CZ6) have an acidic reaction, soils in the Mediterranean (CZ7-9) are generally alkaline. In the partly arid Sub-continental zone (CZ5) grasslands soils show a range of conditions from acid, neutral to alkaline soils, probably reflecting variations in the chemistry of parent material.

It is interesting to note that some very acidic (pH<4.5) soils are present in the Mediterranean area while soils with high pH (>7.2) can also be found under predominantly leaching conditions of the Boreal and boreal to temperate, Atlantic, Sub-oceanic and Sub-oceanic to sub-continental zones. Conversely, the most acidic class is absent in the Mediterranean mountainous zone (CZ1).

It is clear that the data reflect soil conditions associated with acid grasslands, neutral grassland (comprising species with wide tolerances, those that prefer neither strongly acid nor calcareous conditions) and calcareous grasslands.

At a field scale, variations in soil pH may occur within relatively small areas such as where limestone outcrops emerge amongst neutral glacial drift or due to the effects of flushing from base-rich springs. In many parts of the EU, grasslands under more acidic conditions are limed to raise the soil pH and thus ensure higher productivity.

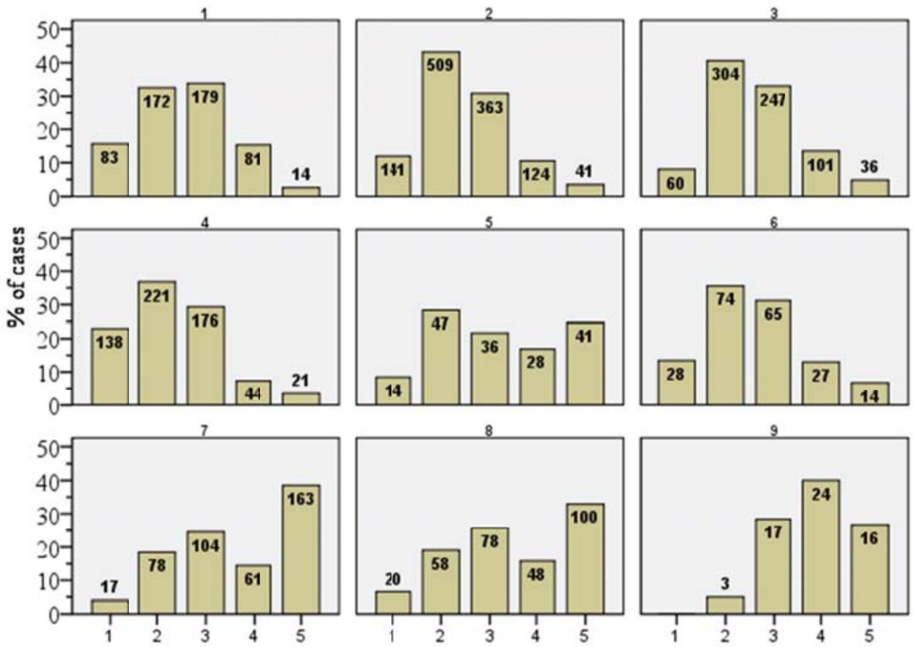


Figure 6.12 Percentage distribution of pH categories (1-5) in mineral soil samples from grasslands in the EU for different climatic zones (CZ1-9).

(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 - 7.2; 5: >= 7.2
numbers at the bars show sample size; (for climate zone names see Table 6.2)

6.2.4 Regional variability of topsoil cation exchange capacity of grasslands

Cation exchange capacity (CEC) is the sum of exchangeable bases plus total soil acidity at a specific pH and is an indication of the ability of a soil to hold plant nutrients. CEC data (Figure 6.13) from the LUCAS topsoil database show a degree of natural correlation to those of pH (Figure 6.12.).

Grassland soils of the northern and western regions (CZ1 and CZ4) are generally characterized by low to medium CEC. In CZ1 and CZ4, more than 50% of the samples have CEC values of < 10 in cmol(+)/kg while a further 30% fall between 10-20 cmol(+)/kg. These conditions can be attributed to coarse textural characteristics and lack of clay mineralogy. While the overall number of samples is low, the grassland soils of the Mediterranean mountainous zone (CZ9) show the highest overall CEC values. In the more continental and Mediterranean zones (CZ2-3 and CZ5 – CZ8) significant proportions of grassland samples have generally low CEC levels but at the same time their grasslands have higher CEC levels occurring in larger proportions than in other regions.

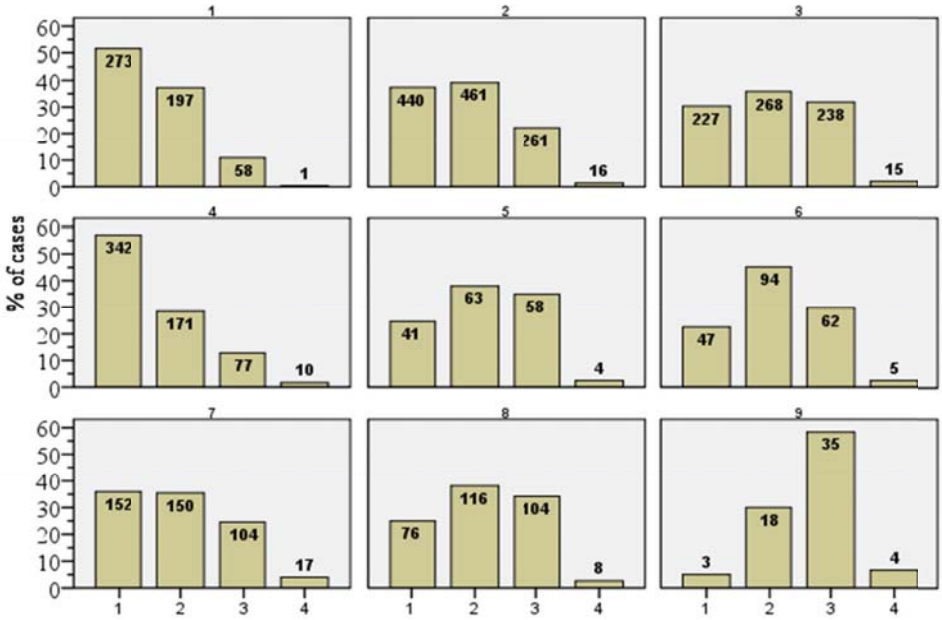


Figure 6.13 Distribution of cation exchange capacity categories (1-4) in mineral soil samples from grasslands in the EU for different climatic zones (1-9).

(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see Table 6.2)

6.2.5 Regional variability of topsoil calcium carbonate content of grasslands

The calcium carbonate ($CaCO_3$) content of grassland soils in the EU shows strong climate dependence.

Grassland soils in the Mediterranean contain systematically higher amount of $CaCO_3$ than in the north-western regions of the continent (Figure 6.14). For CZ1-4 and CZ6, around 90% of the samples show $CaCO_3$ content of less than 50 g/kg. These data reflect the predominantly leached soils of these regions. In the Subcontinental, partly arid zone (CZ5), the situation is similar but showing some soils with higher concentrations.

As expected, calcium carbonate levels are more balanced and even higher in the Mediterranean regions (CZ7-9), reflecting the generally lime-rich parent materials, lower rainfall and higher temperatures that favour the retention of carbonates in the soil.

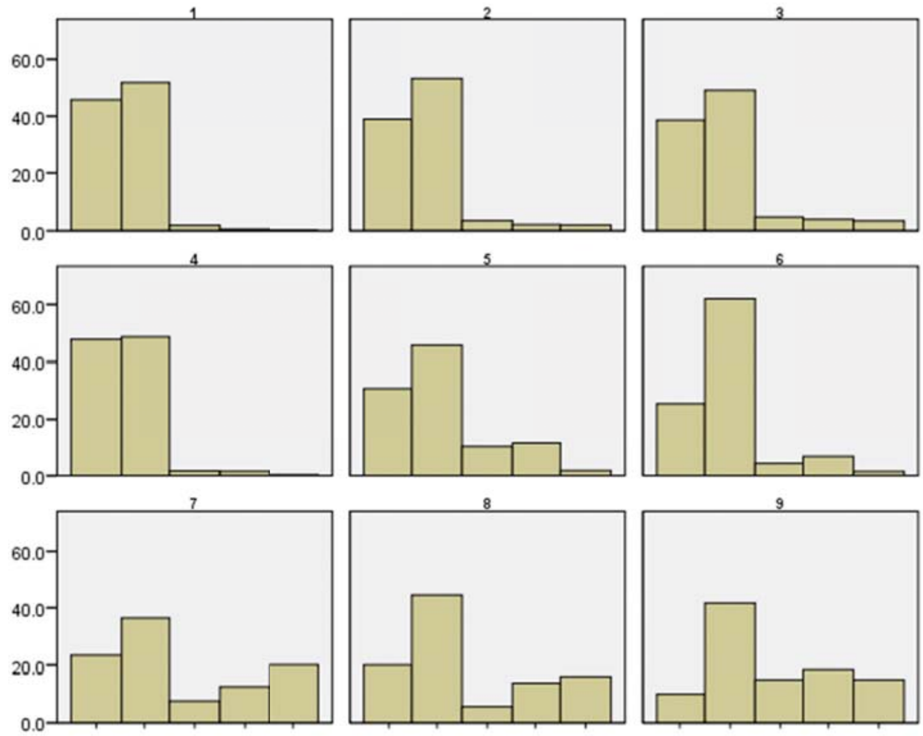


Figure 6.14 $CaCO_3$ content of mineral topsoils of grasslands in the EU for different climatic zones.

1: $CaCO_3$ <= 0.1 (g/kg); 2: >=0.1 and < 50; 3: >=50 and <100; 4: >=100 and <250; 5: >=250
(for climate zone names see Table 6.2)

6.2.6 Regional variability of topsoil total nitrogen content of grasslands

Total nitrogen (N) content of soils is an important measure for agricultural and environmental applications.

The variability of N in mineral grasslands soils shows large diversity among the climatic regions of the EU, as shown in figure 6.15. More than half of the samples from the Atlantic, sub-oceanic and Temperate mountainous zones (CZ2, 3 and 6) fall into the 3 g/kg category. These very high values may signify the application of mineral fertilizers to boost grassland productivity.

Grassland soils in the other regions show a general even distribution of N levels, with a slight degree of skewedness towards the lower N content categories (CZ5 shows similar distribution but with an opposite trend towards higher N content categories), in the other regions is towards the medium ranges, with presenting an approximately normal distribution of N categories of the samples.

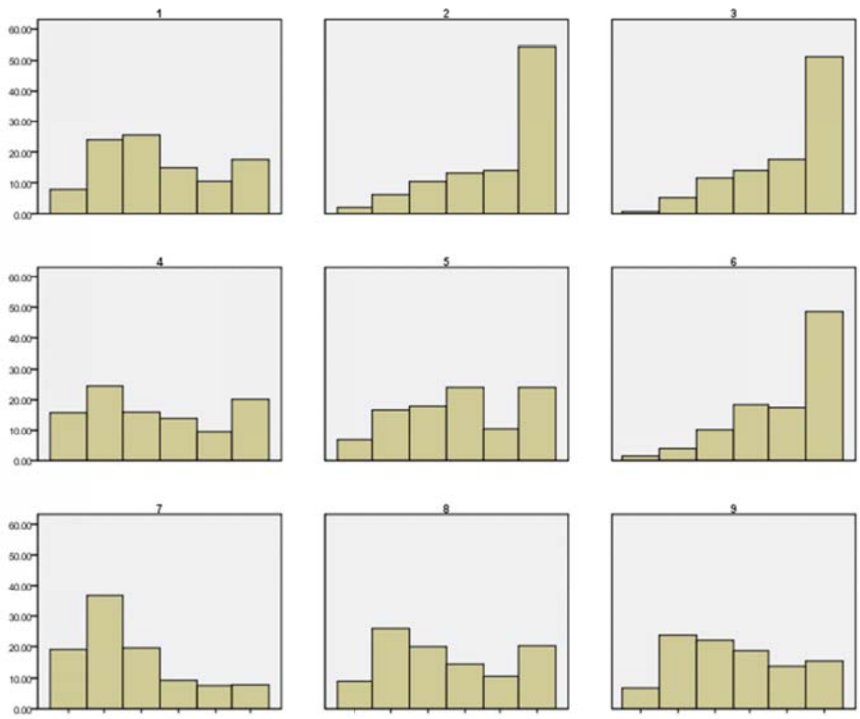


Figure 6.15 Nitrogen content of mineral topsoils of grasslands in the EU for different climatic zones.

in % of samples in classes; classes - 1: <1; 2: >=1 and <1.5; 3: >=1.5 and <2; 4: >=2 and <2.5; 5: >=2.5 and <3; 6: >=3

(for climate zone names see Table 6.2)

6.2.7 Regional variability of topsoil phosphorus content of grasslands

Phosphorus (P) in grassland topsoils can be an indication of fertiliser application or, as in the case of naturally acid grasslands, an indicator of organic matter levels.

According to the LUCAS topsoil database, the climatic zones display two groups of P distribution. The first group includes those zones characterized by middle to low levels of P (CZ1-4) while in the second group (CZ5-9), the degree of skewness towards the lower levels is even stronger (the proportion of samples with P levels > 60 mg/kg is significantly reduced – generally below 20%).

These data imply that the majority of grassland soils are either not subject to P applications or that the humid climate leaches the P from the topsoil.

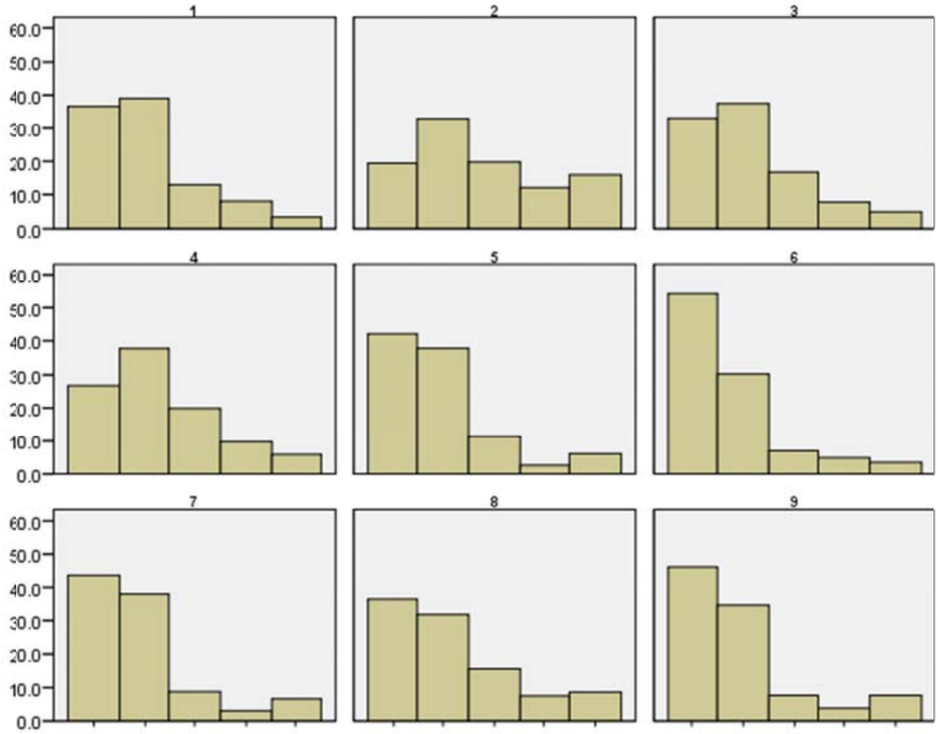


Figure 6.16 Phosphorus content of mineral topsoils of grasslands in the EU for different climatic zones.

(in % of samples in classes; Classes - 1: <20 (mg/kg); 2: >=20 and <40; 3: >=40 and <60; 4: >=60 and <80; 5: >=80
(for climate zone names see Table 6.2)

6.2.8 Regional variability of topsoil potassium content of grasslands

Available K is determined either by clay content and mineralogy or by fertiliser inputs. Figure 6.17 shows that potassium (K) has two broad distribution patterns across the EU.

The first group, predominantly the Mediterranean regions (CZ7-9), is characterised by a generally even but low distribution of samples across the K levels (no category possesses more than 20% of the total sample) and a pronounced number falling in to the highest K category (> 400 mg/kg). The second group contains all the other regions (CZ1-6) where around 50% of the samples contain low – middle levels of potassium (<150 mg/kg).

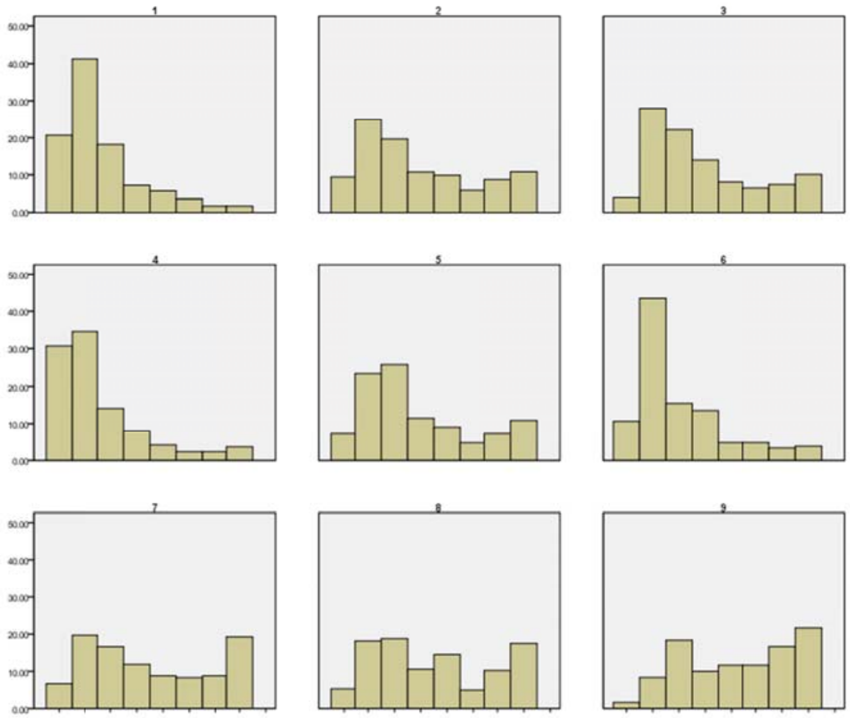


Figure 6.17 Potassium content of mineral topsoils of grasslands in the EU for different climatic zones.

% of samples in classes; Classes – 1: <50 (mg/kg); 2: >=50 and <100; 3: >=100 and <150; 4: >=150 and <200; 5: >=200 and <250; 6: >=250 and <300; 7: >=300 and <400; 8: >=400

(for climate zone names see Table 6.2)

6.3 Shrublands

The dataset was sub-sampled to extract only the mineral soils of shrublands. In the context of the LUCAS programme, shrublands are defined as:

- land dominated (i.e. more than 20% of the surface) by shrubs and low woody plants. It may include sparsely occurring trees within a limit of a tree-crown area density of 10%. In central part of the EU, only heath lands and some ruderal communities fall into this category.

Sub-categories of shrublands within the LUCAS survey include:

- **Shrubland with sparse tree cover** (coded as D10). These are areas dominated (more than 20% of the surface) by shrubs and low woody plants, including sparsely occurring trees with a tree-crown area density between 5 and 10 %. This class includes scrub land (pines, rhododendrons, maquis, matorral and deciduous thickets) and heathland with gorse, heather or broom.

- **Shrubland without tree cover** (coded as D20). These are areas dominated (more than 20% of the surface) by shrubs and low woody plants. Sparsely occurring trees should not cover more than 5% of the area. This class includes scrub land (pines, rhododendrons, maquis, matorral and deciduous thickets), dwarf shrub tundra with dwarf birches and willows, heather and dwarf juniper vegetation, garrigues with strawberry trees, thyme, white rock rose, lavender and rosemary, heathland with gorse, heather or broom, spiny Mediterranean heaths (phrygana) and xerophytic areas with succulents.

In total, only 425 samples were categorised as representing shrublands (just over 2% of the final database).

No shrublands were reported for Belgium, Luxembourg, Malta or the Netherlands.

6.3.1 Regional variability of topsoil texture of shrublands

Particle size distribution data measured for the shrubland soil samples were classified into texture categories according to the FAO (1990) scheme. In order to be compliant with the requirements of the texture classification, particle size data measured using the ISO 11277 method (ISO 1998) were transformed to uniform texture classes according to Hollis et al. (2006).

The particle size distributions of all mineral soil samples in the LUCAS database according to the different climatic zones are shown in figure 6.2, while those collected from soils under shrublands are shown in figure 6.18.

These figures show that the topsoil textures of shrublands throughout the EU fall into three broad groups between the climate zones. Coarse and medium textured soils dominate Boreal and Boreal to Temperate (CZ1) and Sub oceanic to Sub-continental (CZ4). The Atlantic (CZ2), Mediterranean temperate and sub-oceanic (CZ8) and Mediterranean Mountainous regions (CZ9) show higher proportions of soils with medium (i.e. loamy) textures although there are still a significant number of shrubland areas on coarse textured soils. In the Sub-oceanic (CZ3), Sub-continental (CZ5), Temperate mountainous (CZ6) and the Mediterranean semi-arid (CZ7) regions, soils with coarse textures are largely absent.

The data seem to suggest that shrublands are predominantly found on either free draining, coarse or loamy soils.

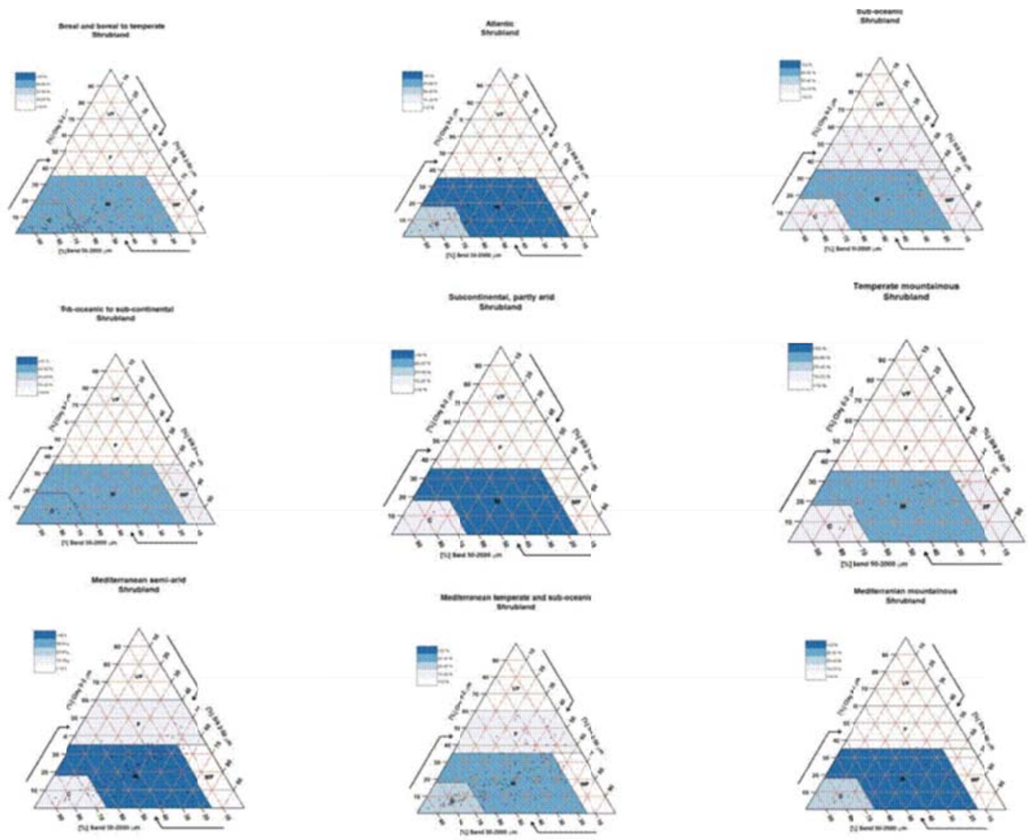


Figure 6.18 Particle size distribution and texture class of mineral topsoil in shrublands in the EU for different climatic zones.

for climate categories 1-9 see Table 6.3.
texture classes: VF- very fine, F –fine, MF – medium fine, M – medium, C –coarse
colour legend indicates % of the samples in the corresponding texture category

6.3.2 Regional variability of topsoil organic carbon of shrublands

Data from the LUCAS soil survey confirms the common perception (Jones et al., 2005) that soil organic carbon (SOC) levels increase following a south-east to north-west trend in the EU (Table 6.3). For shrublands, higher organic carbon levels are found in Boreal and boreal to temperate, Atlantic, Sub-oceanic and the Temperate mountainous zones with highest mean values being found in the Atlantic Zone (CZ2) – reflecting the cool, humid conditions that encourage the growth of understory grasses and the accumulation of soil organic matter. Lowest values are found in the Mediterranean semi-arid zone (CZ8). SOC concentrations in mineral soils under shrublands in the Atlantic region are around 100% higher than those in the Mediterranean semi-arid climate, reflecting the very different climatic and vegetative factors. It is worth reflecting that mean topsoil organic carbon levels in shrublands are higher than those of grassland in all climatic zones.

However, standard deviation values highlight the high variability of SOC concentrations within climatic zones. In every zone, SOC levels reach, or even exceed, the magnitude that was measured between mean levels of each individual climatic zone.

Table 6.3. Soil organic carbon concentration (g/kg) in the mineral topsoil of shrublands in different climatic regions of Europe

Climate zone		Mineral soils		
No.	Name	mean	std	n
1	Boreal and boreal to temperate	39	29	62
2	Atlantic	41	26	38
3	Sub-oceanic	36	21	16
4	Sub-oceanic to sub-continental	39	17	16
5	Subcontinental, partly arid	28	16	11
6	Temperate mountainous	34	19	20
7	Mediterranean semi-arid	23	16	108
8	Mediterranean temperate and sub-oceanic	36	25	136
9	Mediterranean mountainous	25	24	18

6.3.3 Regional variability of topsoil pH of shrublands

Soil pH is a consequence of several soil forming factors and parallel soil processes (Boruvka et al., 2007).

Analysis of the LUCAS topsoil database shows that shrublands reflect this control mechanism (Figure 6.19.). Around 75% of samples from shrublands in the Boreal and boreal to temperate zone (CZ1) show very acidic conditions (pH <4.5) and a total absence of any alkaline samples. This situation is also reflected in the Atlantic zone (CZ2) but with a broader spread of measurements. These patterns reflect the high leaching conditions of soils in these humid climates. In the Sub-oceanic (CZ3), Sub-oceanic to sub-continental (CZ4), Sub-continental zone (CZ5) and Mediterranean temperate and sub-oceanic (CZ8) zones, pH values have a relatively broad distribution showing a range of conditions from acid, neutral to alkaline soils, probably reflecting variations in the chemistry of the underlying parent material. Contrastingly, shrubland soils in Temperate mountainous (CZ6), Mediterranean semi-arid (CZ7) and Mediterranian mountainous (CZ9) generally tend to be more alkaline, while the most acidic classes are virtually absent from the Mediterranean mountainous region.

It is clear that the data show that the broad shrubland category reflects a wide range of soil pH conditions.

At a field scale, variations in soil pH may occur within relatively small areas such as where limestone outcrops emerge amongst neutral glacial drift or due to the effects of base-rich groundwater.

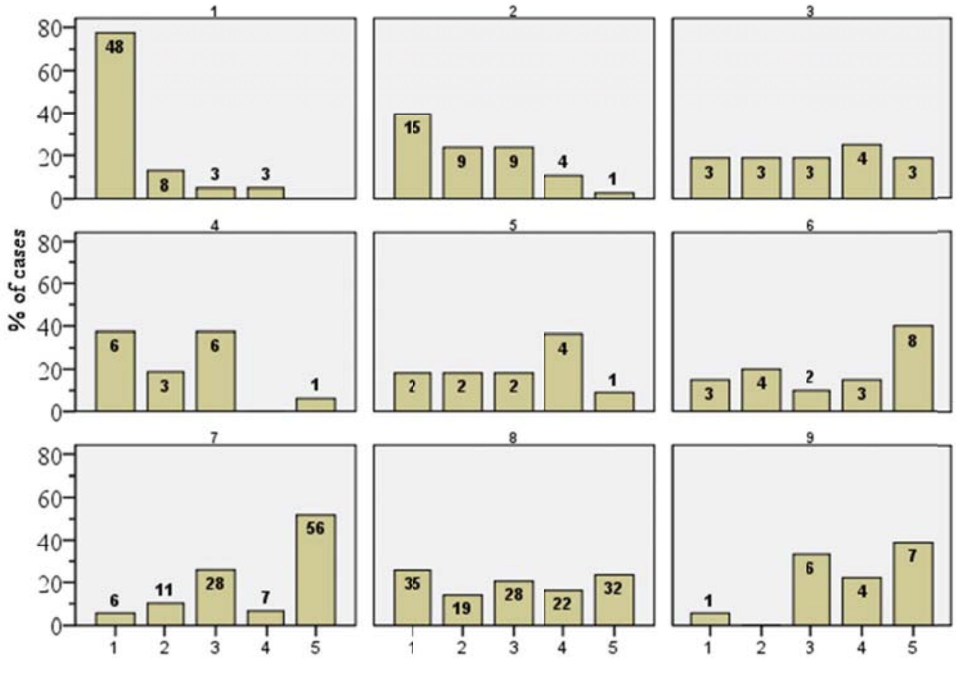


Figure 6.19 Percentage distribution of pH categories (1-5) in mineral soil samples from annual shrublands in the EU for different climatic zones (CZ1-9).

(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 - 7.2; 5: >= 7.2 numbers at the bars show sample size; (for climate zone names see Table 6.3)

6.3.4 Regional variability of topsoil cation exchange capacity of shrublands

Cation exchange capacity (CEC) is the sum of exchangeable bases plus total soil acidity at a specific pH and is an indication of the ability of a soil to hold plant nutrients. CEC data (Figure 6.20) from the LUCAS topsoil database show a degree of natural correlation to those of pH (Figure 6.19.).

Shrubland soils of the northern and western regions (CZ1, CZ2 and CZ4) are generally characterized by low to medium CEC. In CZ1 and CZ4, around than 60% of the samples have CEC values of < 10 in cmol(+)/kg while soils with the highest CEC values are absent (> 40 cmol(+)/kg). These conditions can be attributed to coarse textural characteristics and a general lack of clay mineralogy. In all the other climatic zones, CEC levels are more evenly distributed although the proportion with the highest CEC values are low throughout (it should be stressed that the overall number of samples is very low for shrublands is low and may give a bias to the evaluation).

This pattern suggests that shrublands are generally characterized by nutritionally poor, possibly marginal, soils that support a very adapted plant community.

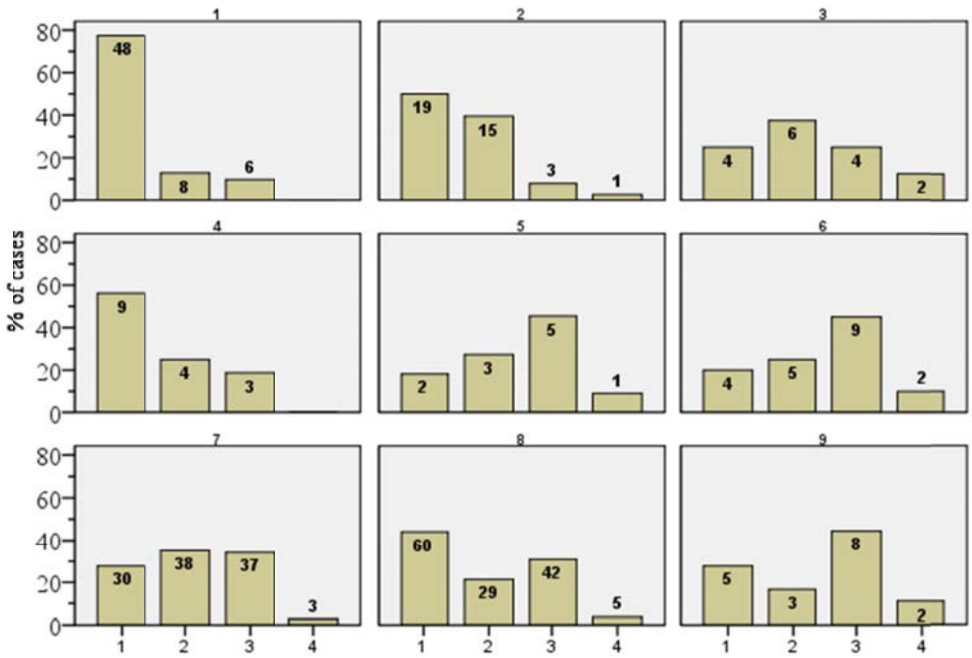


Figure 6.20 Distribution of cation exchange capacity categories (1-4) in mineral soil samples from shrublands in the EU for different climatic zones (1-9).

(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see Table 6.3)

6.3.5 Regional variability of topsoil calcium carbonate content of shrublands

The calcium carbonate ($CaCO_3$) content of shrublands soils in the EU shows strong climate dependence (Figure 6.21).

As a general comment, the soils of shrublands generally show low levels of calcium carbonate. The soils of shrublands in the Mediterranean area contain systematically higher amounts than in the north-western regions of the continent. For CZ1-5 and CZ8, around 75% of the samples show $CaCO_3$ content of less than 50 g/kg. These data reflect the predominantly acidic nature of shrubland soils. In the Temperate mountainous (CZ6) and Mediterranean temperate and sub-oceanic zone (CZ8), the situation is strongly bimodal with a strong grouping of samples showing lower values with another group showing higher levels.

As expected, calcium carbonate levels are more balanced in the Mediterranean regions (CZ7-9), reflecting the generally lime-rich parent materials, lower rainfall and higher temperatures that favour the retention of carbonates in the soil.

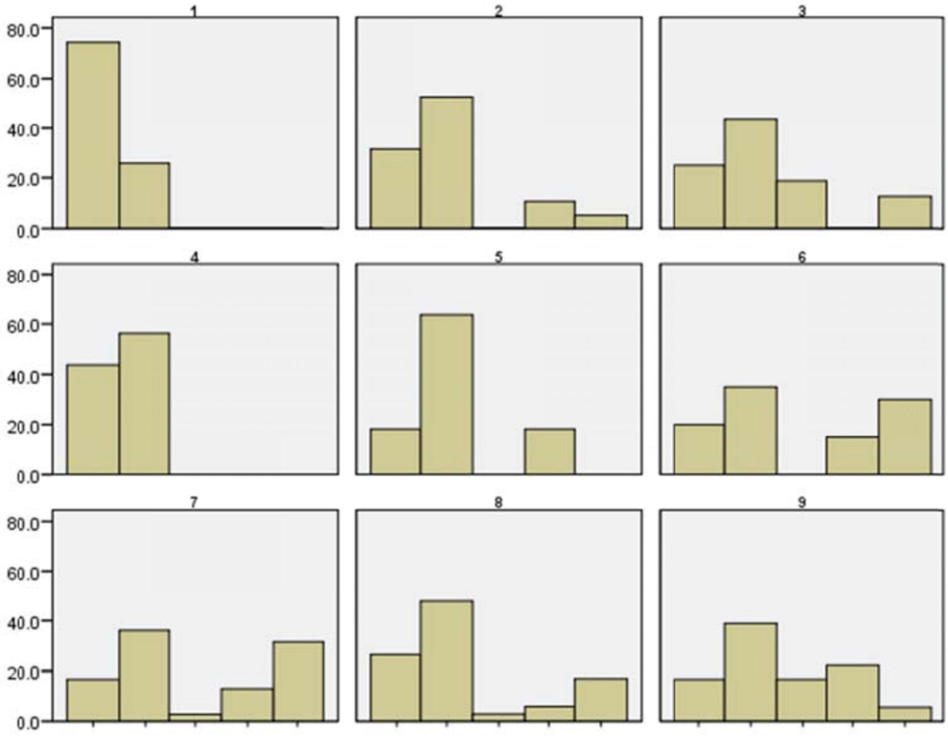


Figure 6.21 $CaCO_3$ content of mineral topsoils of shrublands in the EU for different climatic zones.

1: $CaCO_3$ <= 0.1 (g/kg); 2: >=0.1 and < 50; 3: >=50 and <100; 4: >=100 and <250; 5: >=250
(for climate zone names see Table 6.3)

6.3.6 Regional variability of topsoil total nitrogen content of shrublands

Total nitrogen (N) content of shrubland soils is an important measure of environmental conditions as they are generally not subject to mineral fertilizer applications.

The variability of N in mineral shrublands soils shows large diversity among the climatic regions of the EU, as shown in figure 6.22. While most samples in the Boreal and Boreal to Temperate Zone (CZ1) show generally low N levels, most climatic zones are characterized by shrubland soils with medium to high levels of N.

Climate zones 2-6 and 8 show a pronounced skewness towards higher N classes with more than 40% of the samples from the Atlantic, sub-oceanic, Temperate mountainous zones and Mediterranean temperate and sub-oceanic zones (CZ2, 3, 6 and 8) falling into the >3 g/kg category. Only the Mediterranean semi-arid (CZ7) and Mediterranean mountainous (CZ9) zones show a relatively even distribution of N levels.

The relatively large proportion of samples in the highest N category may signify the consequences of atmospheric N deposition on shrublands.

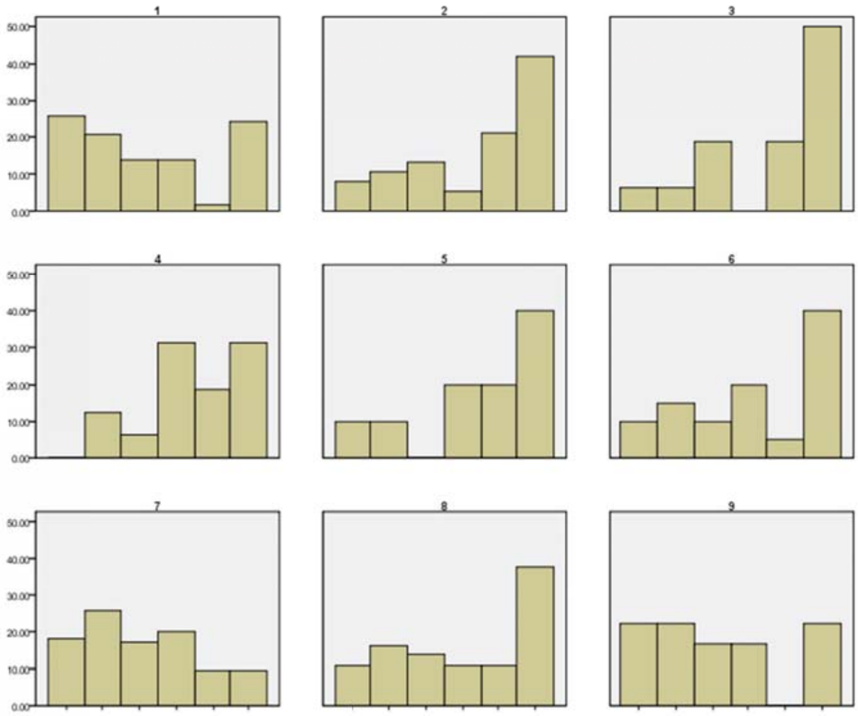


Figure 6.22 Nitrogen content of mineral topsoils of shrublands in the EU for different climatic zones.

in % of samples in classes; classes - 1: <1; 2: >=1 and <1.5; 3: >=1.5 and <2; 4: >=2 and <2.5;
5: >=2.5 and <3; 6: >=3
(for climate zone names see Table 6.3)

The establishment of numerical relationships between the total nitrogen content and other parameters (e.g. plant available mineral forms of nitrogen) in a harmonised manner for applications on regional to continental scale remains a task for future research.

6.3.7 Regional variability of topsoil phosphorus content of shrublands

By common consensus, phosphorus (P) levels in shrublands should be low and they are normally not subjected to management by fertilizer applications.

Analysis of the LUCAS topsoil database for P levels gives rise to two groups with broadly similar characteristics. The first group consists of seven zones (CZ1-3, 6-9) that are characterized by generally low levels of P (<40 mg/kg) with generally more than half the samples falling in the lowest category.

The second group (CZ4 & 5) is also broadly characterized by lower P levels but, in comparison to the first group, the proportion of samples in higher categories is greater.

Overall, P levels in shrublands are lower than those of grasslands in all climate zones.

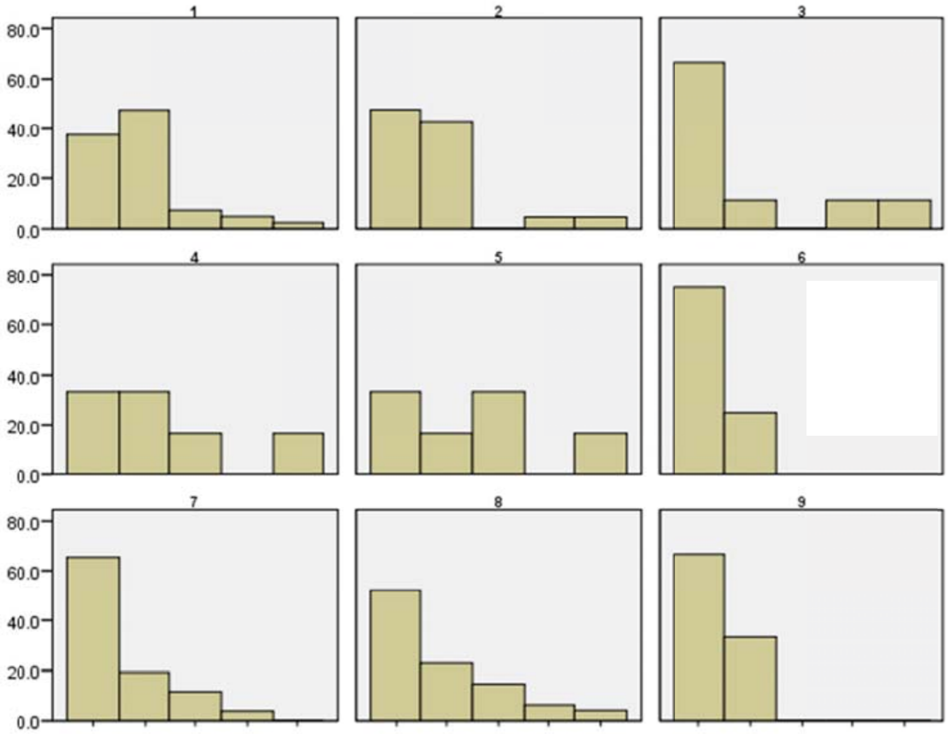


Figure 6.23 Phosphorus content of mineral topsoils of shrublands in the EU for different climatic zones.

in % of samples in classes; Classes - 1: <20 (mg/kg); 2: >=20 and <40; 3: >=40 and <60;   4: >=60 and <80; 5: >=80
(for climate zone names see Table 6.3)

6.3.8 Regional variability of topsoil potassium content of shrublands

Available K is determined either by clay content and mineralogy or by fertiliser inputs. Figure 6.24 shows that potassium (K) has two broad distribution patterns across the EU.

The first group (CZ1-5, and to a lesser extent 7 & 8) display a skewness towards the lower categories of K content, with around 50% of the samples of CZ1, CZ2, CZ4 contain very low levels (<100 mg/kg).

The second group, predominantly the Mediterranean (CZ7-9) and Temperate mountainous (CZ6) regions, is also characterised by a generally low levels even but with a slightly higher proportion more evenly distribution among the higher levels.

Interestingly, CZ2, 3, 7 and 8 all show a peak of samples falling into the highest K category (> 400 mg/kg).

The LUCAS data reflect the general soil texture for shrublands and the overall lack of intensive management practices in these areas.

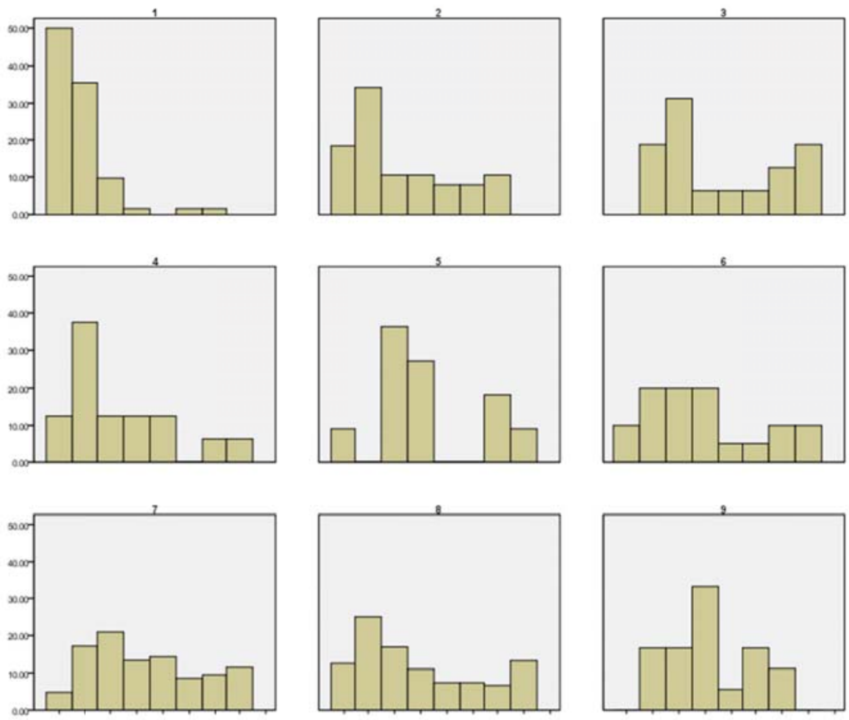


Figure 6.24 Potassium content of mineral topsoils in shrublands in the EU for different climatic zones.

% of samples in classes; Classes – 1: <50 (mg/kg); 2: >=50 and <100; 3: >=100 and <150; 4: >=150 and <200; 5: >=200 and <250; 6: >=250 and <300; 7: >=300 and <400; 8: >=400
(for climate zone names see Table 6.3)

6.4 Woodlands

The dataset was sub-sampled to extract only the mineral soils of woodlands. In the context of the LUCAS programme, woodlands are defined as:

- areas covered by trees with a tree crown area of at least 10%. Woody hedges also belong to this class.

Sub-categories of woodlands within the LUCAS survey include:

- **Broadleaved and evergreen woodland** (coded as C10). These are areas with a tree-crown area density of more than 10% and composed of more than 75% of broadleaved/evergreen species such as acacia (*Acacia ssp*.), alder (*Alnus ssp*), ash (*Fraxinus excelsior*), aspens (*Populus tremula*), beech (*Fagus sylvatica*), birch (*Betula sp*.), carob (*Ceratonia siliqua*), elm (*Ulmus sp*.), eucalyptus (*Eucalyptus globulus*), hedge (*Acer campestre*), hornbeam (*Carpinus betulus*), linden (*Tilia ssp*.), maple (*Acer sp*.), palm trees of the Mediterranean and Macaronesian zones (*Phoenix theophrasti, Ph. canariensis*), poplars (Populus nigra), oaks (Quercus sp), rowan (*Sorbus aucuparia*), wild olive (*Olea europaea ssp. sylvestris*) and willows (*Salix sp*.).

- **Coniferous woodland** (coded as C20). These are areas with a tree-crown area density of more than 10% and composed of more than 75% of coniferous species such as cedars (*Cedrus sp*.), cypresses (*Cupressus sempervirens*), firs (*Abies sp*.), Douglas firs (*Pseudotsuga menziesii*), larches (*Larix ssp*), pines (*Pinus sp*.: Scots pines, Black pines, Siberian pines, Weymouth pines, Maritime pine, Mediterranean stone pine etc), spruce (*Picea sp*), xerophyte conifers: (Brutia pine, Umbrella pine, Aleppo pine, Corsican pine) and Christmas trees.

- **Mixed woodland** (coded as C30). These are areas with a tree-crown area density of more than 10% and composed of broadleaved/evergreen and coniferous comprising both >25% of the tree canopy.

For larger plots, woodlands in the LUCAS database are also given a secondary forest cover code according to the forest type classification of the European Environment Agency (e.g. boreal, mesophytic deciduous forest, mire and swamp forests, plantations).

In total, 4441 samples were categorised as representing woodlands (just over 22% of the final database).

No woodlands were reported for Malta.

Given the wide range of tree spices, this analysis is only intended as a broad overview of the data collected from woodland environments. The reader is also directed to documentation on the corresponding Biosoils data collection programme.

http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/EUR24729.pdf

6.4.1 Regional variability of topsoil texture of woodlands

Particle size distribution data measured for the woodland soil samples were classified into texture categories according to the FAO (1990) scheme. In order to be compliant with the requirements of the texture classification, particle size data measured using the ISO 11277 method (ISO 1998) were transformed to uniform texture classes according to Hollis et al. (2006).

The particle size distributions of all mineral soil samples in the LUCAS database according to the different climatic zones are shown in figure 6.2, while those collected from soils under woodlands are shown in figure 6.25.

These figures show that the topsoil textures of woodlands throughout the EU are highly diverse between the climate zones. Coarse textured soils dominate the Sub oceanic to Sub-continental (CZ4) zone while the Boreal and Boreal to Temperate (CZ1), Atlantic (CZ2) and, to a slightly lesser extent, the Mediterranean temperate and sub-oceanic (CZ8) have a balance of coarse to medium textures. The Sub-oceanic (CZ3), Sub-continental (CZ5), Temperate mountainous (CZ6) and Mediterranean Mountainous (CZ9) regions all show a spread of textures, including finer clay and silt fractions. However, most samples fall into the middle, loamy categories.

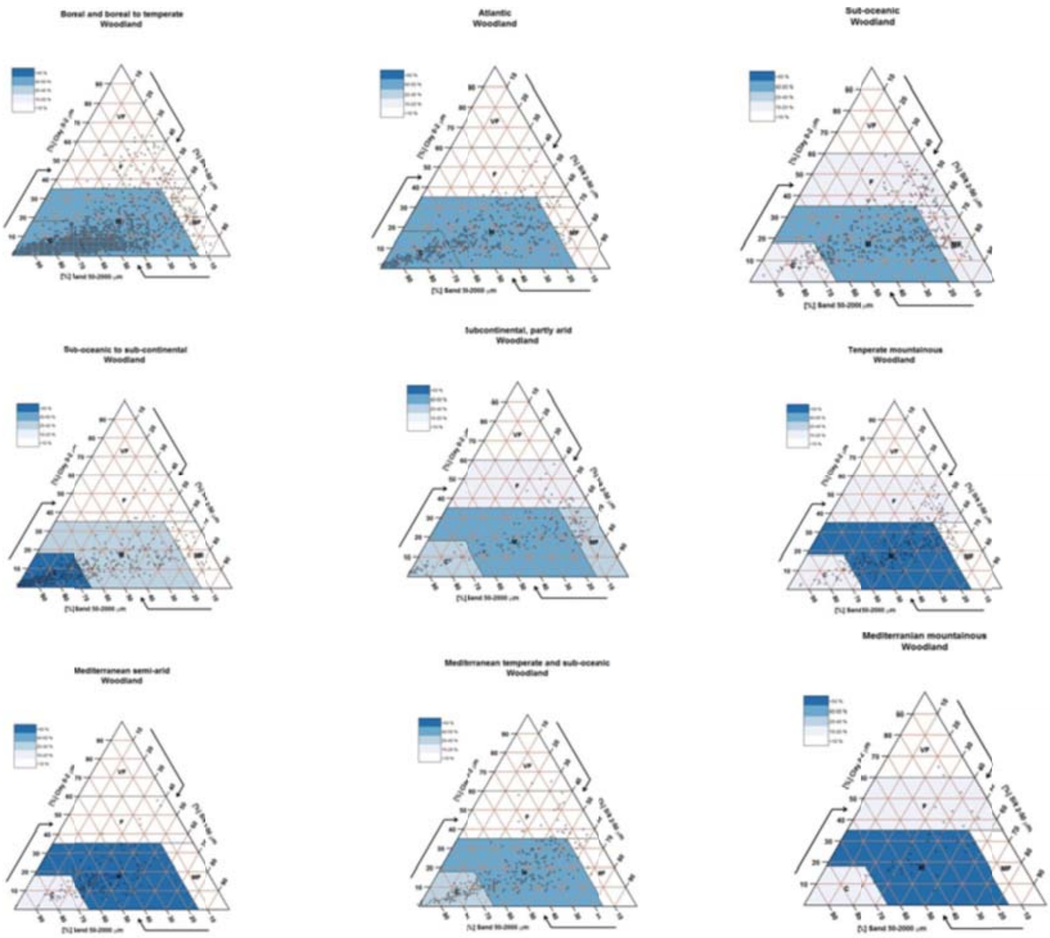


Figure 6.25 Particle size distribution and texture class of mineral topsoils in woodlands in the EU for different climatic zones.

for climate categories 1-9 see Table 6.4.
texture classes: VF- very fine, F –fine, MF – medium fine, M – medium, C –coarse
colour legend indicates % of the samples in the corresponding texture category

6.4.2 Regional variability of topsoil organic carbon of woodlands

Data from the LUCAS soil survey confirms the common perception (Jones et al., 2005) that soil organic carbon (SOC) levels increase following a south-east to north-west trend in the EU (Table 6.4). However, samples from the Mediterranean mountainous have a mean level that is comparable to more northern and westerly parts of the EU.

For woodlands, higher organic carbon levels are found in Boreal and boreal to temperate, Atlantic, Sub-oceanic, Temperate mountainous and Mediterranean mountainous zones with highest mean values being found in the Atlantic (CZ2) and Sub-oceanic zones – reflecting the cooler and humid conditions that encourage the accumulation of soil organic matter. Lowest values are found in the Mediterranean semi-arid zone (CZ8). SOC concentrations in mineral soils under woodlands in the Atlantic region are over 200% higher than those in the Mediterranean semi-arid climate, reflecting the very different climatic and vegetative factors. It is worth reflecting that mean topsoil organic carbon levels in woodlands are higher than those of both shrublands and grassland in all climatic zones apart from the Sub-oceanic to sub-continental and Mediterranean semi-arid zones.

However, standard deviation values highlight the high variability of SOC concentrations within climatic zones. In every zone, SOC levels reach, or even exceed, the magnitude that was measured between mean levels of each individual climatic zone.

Table 6.4. Soil organic carbon concentration (g/kg) in the mineral topsoil of woodlands in different climatic regions of Europe

Climate zone		Mineral soils		
No.	Name	mean	std	n
1	Boreal and boreal to temperate	42	27	2238
2	Atlantic	44	27	396
3	Sub-oceanic	44	25	358
4	Sub-oceanic to sub-continental	31	23	614
5	Subcontinental, partly arid	29	22	144
6	Temperate mountainous	43	26	208
7	Mediterranean semi-arid	19	12	165
8	Mediterranean temperate and sub-oceanic	36	24	279
9	Mediterranean mountainous	40	29	39

6.4.3 Regional variability of topsoil pH of woodlands

Soil pH is a consequence of several soil forming factors and parallel soil processes (Boruvka et al., 2007). Analysis of the LUCAS topsoil database shows that woodlands reflect this control mechanism (Figure 6.26.).

Around 80% of samples from woodlands in the Boreal and boreal to temperate (CZ1) and Sub-oceanic to sub-continental (CZ4) zones show very acidic conditions (pH <4.5) for woodlands and an almost total absence of alkaline samples. This reflects the predominant podzolic conditions of the former and the coarse textured, highly leached soils of the latter.

Although slightly less pronounced, this situation is also reflected in the Atlantic (CZ2), Sub-oceanic (CZ3), Sub-continental zone (CZ5), Temperate mountainous (CZ6) and Mediterranean temperate and sub-oceanic (CZ8) zones but with a broader spread of measurements.

In the Mediterranean semi-arid (CZ7) and Mediterranean mountainous (CZ9) the distribution is less acidic and tending to neutral, with highest proportions of alkaline samples. This probably reflects the chemistry of the parent material.

It is clear that the data show that the broad woodlands category reflects a wide range of soil pH conditions, with a predominance towards more acidic conditions when outside of the Mediterranean region.

At a field scale, variations in soil pH may occur within relatively small areas such as where specific conditions may not reflect more regional trends (e.g. limestone outcrops amongst neutral glacial drift).

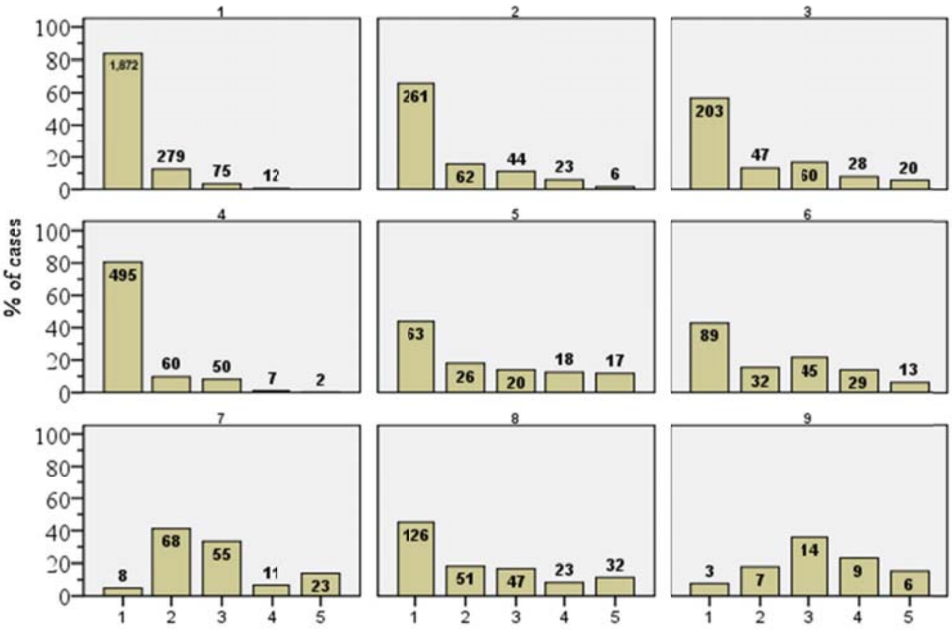


Figure 6.26 Percentage distribution of pH categories (1-5) of mineral topsoils in woodlands in the EU for different climatic zones.

(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 - 7.2; 5: >= 7.2
numbers at the bars show sample size; (for climate zone names see Table 6.4)

6.4.4 Regional variability of topsoil cation exchange capacity of woodlands

Cation exchange capacity (CEC) is the sum of exchangeable bases plus total soil acidity at a specific pH and is an indication of the ability of a soil to hold plant nutrients. CEC data (Figure 6.27) from the LUCAS topsoil database show a degree of natural correlation to those of pH (Figure 6.26.).

Woodland soils of the northern, western, central (CZ1, CZ2, C3 and CZ4), Mediterranean semi-arid (CZ7) and Mediterranean temperate and sub-oceanic zone (CZ8) are generally characterized by low to medium CEC while the proportion of soils with the highest CEC values (> 40 cmol(+)/kg) are quite low. In CZ1, 2 and 4, around 70% of the samples have CEC values of <10 in cmol(+)/kg.

In the remaining climatic zones (CZ5, 6 & 9), CEC levels show a more normal distributed with greater proportions in the higher CEC categories. Only the Mediterranean mountainous (CZ9) displays a notable proportion of soils with higher CEC levels.

This pattern suggests that woodlands outside of the temperate and Mediterranean mountains are generally characterized by soils that lacking in nutrients. In many cases, these conditions can be attributed to coarse textural characteristics and a general lack of clay mineralogy.

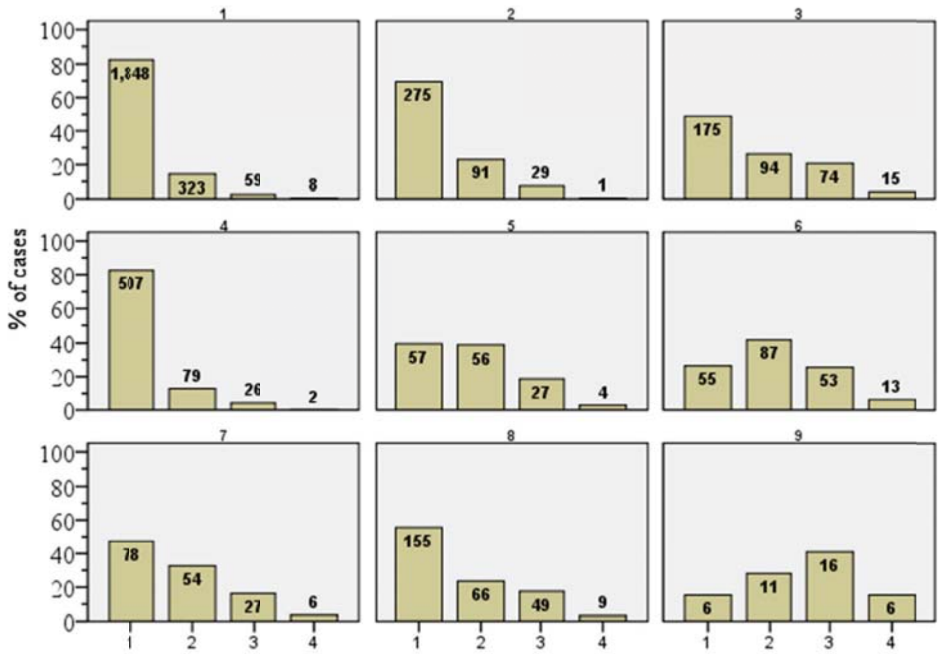


Figure 6.27 Cation exchange capacity categories of mineral topsoils in woodlands in the EU for different climatic zones.

(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see Table 6.4)

6.4.5 Regional variability of topsoil calcium carbonate content of woodlands

The calcium carbonate ($CaCO_3$) content of woodland soils in the EU shows strong climate dependence (Figure 6.28).

The soils of woodlands in the Mediterranean area contain systematically higher amounts than in the north-western regions of the continent. Climate zones 7-9, plus to a lesser extent CZ5-6, all show greater proportions of samples in the higher categories.

For CZ1-4, at least 60% of the samples show $CaCO_3$ content of less than 50 g/kg and many of the higher categories have no records. These data reflect the predominantly acidic nature of woodland soils outside of the Mediterranean region.

As expected, calcium carbonate levels are slightly more balanced in the Mediterranean regions (CZ7-9), reflecting the generally lime-rich parent materials, lower rainfall and higher temperatures that favour the retention of carbonates in the soil. However, the Mediterranean mountainous (CZ9) has no data in the highest category.

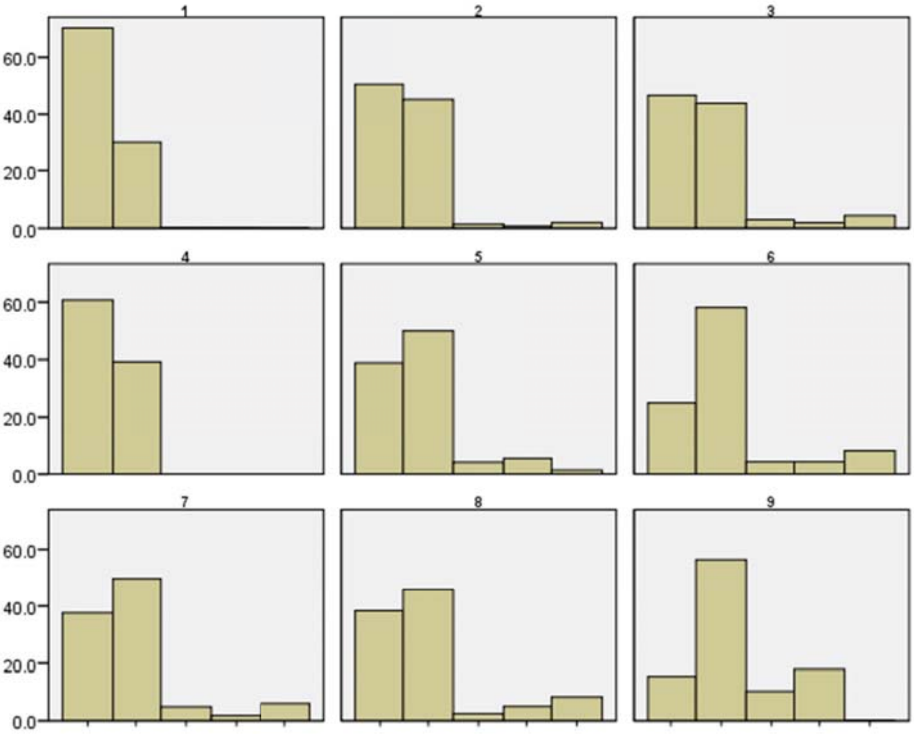


Figure 6.28 $CaCO_3$ content of mineral topsoils in woodlands in the EU for different climatic zones.

1: $CaCO_3$ <= 0.1 (g/kg); 2: >=0.1 and < 50; 3: >=50 and <100; 4: >=100 and <250; 5: >=250
(for climate zone names see Table 6.4)

6.4.6 Regional variability of topsoil total nitrogen content of woodlands

The variability of total nitrogen (N) in mineral woodland soils shows some interesting pattern with notable differences between the climatic regions, as shown in figure 6.29.

While most samples in the Boreal and Boreal to Temperate (CZ1), Sub-oceanic to sub-continental (CZ4) and Mediterranean semi-arid (CZ7) zones show generally low N levels, most climatic zones are characterized by woodland soils with medium to high levels of N.

Climate zones 2-3, 6 and 8-9 show a pronounced skewness towards higher N classes with more than 40% of the samples from the Atlantic, sub-oceanic, Temperate mountainous zones and Mediterranean temperate and sub-oceanic zones (CZ2, 3, 6 and 8) falling into the >3 g/kg category.

Only the Sub-continental (CZ5) zone shows a relatively even distribution of N levels.

The relatively large proportion of samples in the highest N category may signify the consequences of atmospheric N deposition on shrublands.

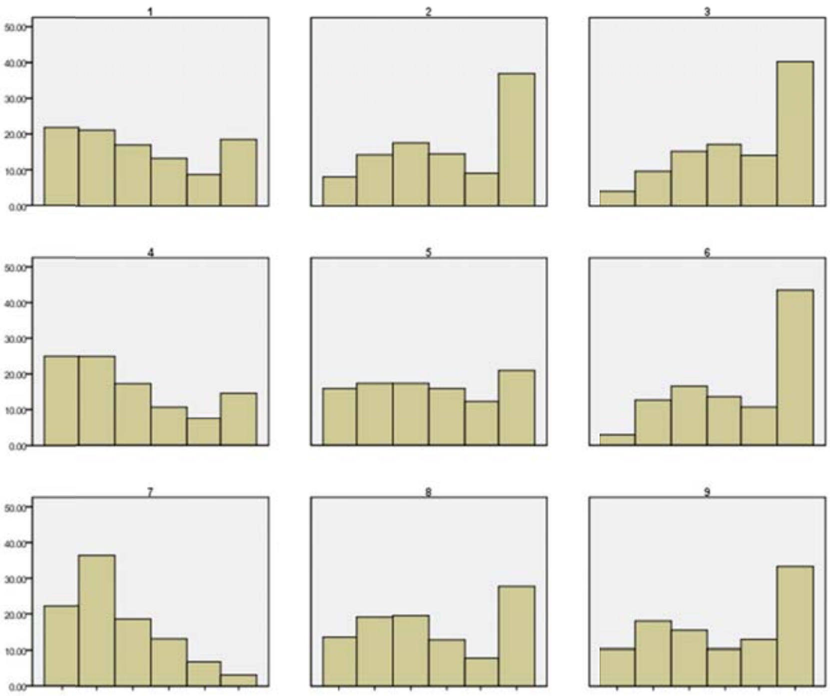


Figure 6.29 Nitrogen content of mineral topsoils in woodlands in the EU for different climatic zones.

in % of samples in classes; classes - 1: <1; 2: >=1 and <1.5; 3: >=1.5 and <2; 4: >=2 and <2.5;
5: >=2.5 and <3; 6: >=3
(for climate zone names see Table 6.4)

The establishment of numerical relationships between the total nitrogen content and other parameters (e.g. plant available mineral forms of nitrogen) in a harmonised manner for applications on regional to continental scale remains a task for future research.

6.4.7 Regional variability of topsoil phosphorus content of woodlands

By common consensus, phosphorus (P) levels in woodlands should be low and they are not normally subjected to fertilizer applications.

Analysis of the LUCAS topsoil database for P levels gives broadly similar characteristics in all climate zones with a strong skewness towards low values (Figure 6.30). In all regions, at least 75% of all samples are characterized by generally low levels of P (<40 mg/kg) with generally more than half the samples falling in the lowest category (apart from Sub-oceanic to sub-continental zone).

The proportion of samples falling in the highest P category is generally low or almost negligible in all zones apart from the Atlantic (CZ2).

Overall, P levels in woodlands are lower than those of grasslands and shrublands in all climate zones.

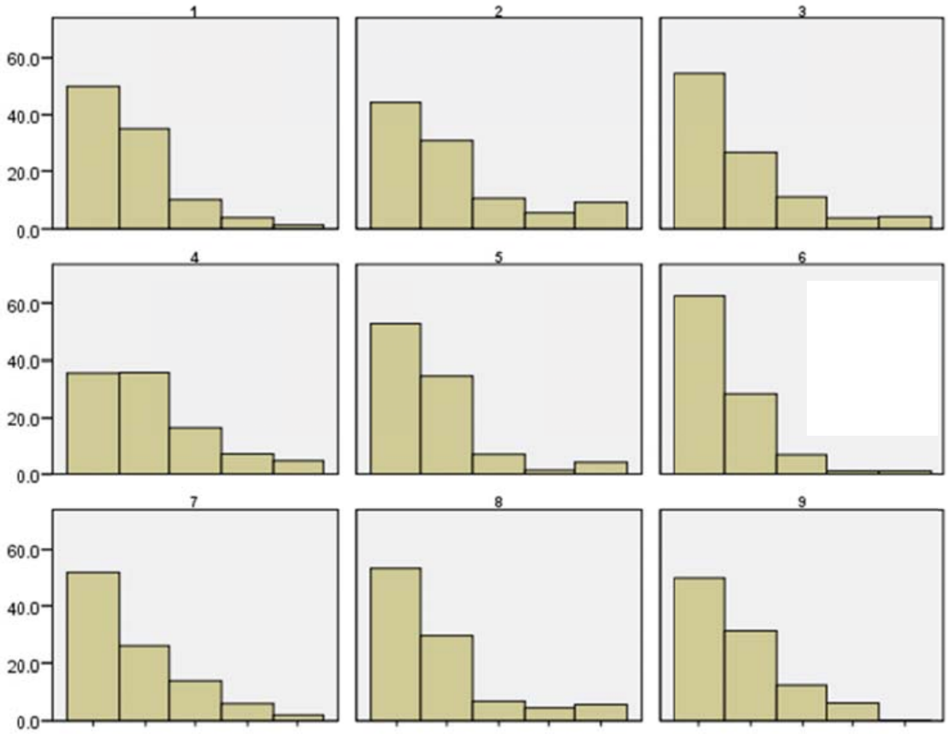


Figure 6.30 Phosphorus content of mineral topsoils in woodlands in the EU for different climatic zones.

in % of samples in classes; Classes - 1: <20 (mg/kg); 2: >=20 and <40; 3: >=40 and <60; 4: >=60 and <80; 5: >=80
(for climate zone names see Table 6.4)

6.4.8 Regional variability of topsoil potassium content of woodlands

Available K is determined either by clay content and mineralogy or by fertiliser inputs. Figure 6.31 shows that potassium (K) in woodland topsoils has three broad distribution patterns across the EU.

The first group (CZ1 & 4) depict soils with very low K levels: around 90% of the samples contain <100 mg/kg .

The second group (CZ2, CZ3, CZ5 & CZ6) also display a marked skewness towards the lower categories of K content, but display a higher proportion of samples in higher categories than the first group.

The third group corresponds to the Mediterranean region (CZ7-9) and is characterised by a broadly bimodal distribution with at least 30% of samples having low K values and more than 15% of samples having > 300 mg/kg, with significant proportions in the intermediate levels. This pattern is most pronounced in Mediterranean mountainous (CZ9) zone where 20% of the samples fall in the highest K category (> 400 mg/kg).

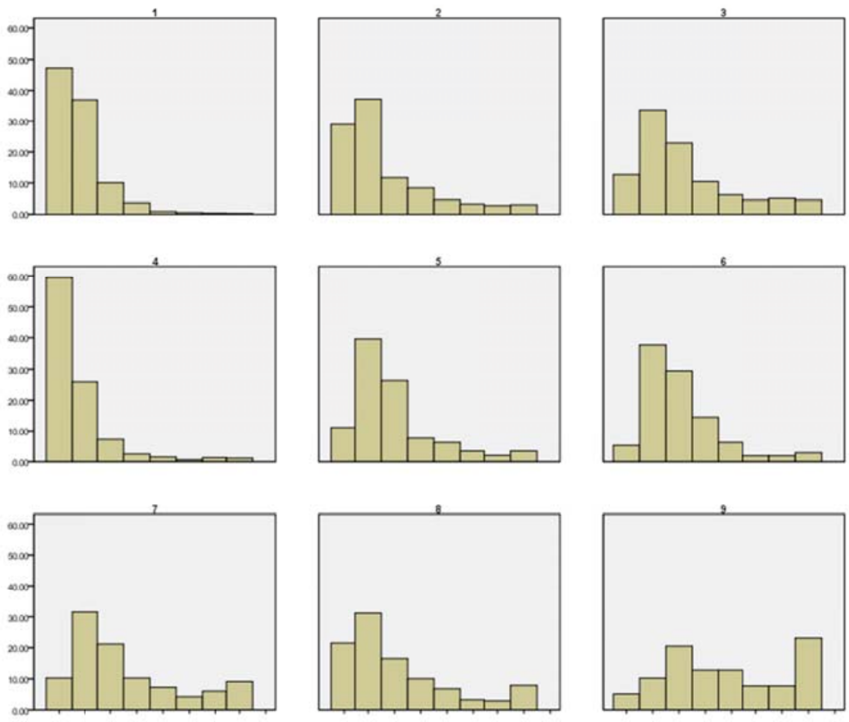


Figure 6.31 Potassium content of mineral topsoils in woodlands in the EU for different climatic zones.

% of samples in classes; Classes – 1: <50 (mg/kg); 2: >=50 and <100; 3: >=100 and <150; 4: >=150 and <200; 5: >=200 and <250; 6: >=250 and <300; 7: >=300 and <400; 8: >=400
(for climate zone names see Table 6.4)

6.5 Peat

Around 5% of the LUCAS dataset (1013 samples) are regarded as coming from peat soils (i.e. containing very little or even no mineral material). Organic soil is commonly known as peat (or Histosols in international soil classification schemes) and is formed through the accumulation of partially decayed vegetation in wetland conditions where water limits the levels of oxygen from the atmosphere thus slowing down rates of decomposition. Low temperatures also contribute to the formation of peat

Within the LUCAS survey, peat is recognised as occurring in peat bogs (H12), inland marshes (H11), peat extraction sites (U140 Mining and quarrying) and mire and swamp forests.

No peat samples were reported for the partly arid Subcontinental (CZ5), Mediterranean temperate and sub-oceanic (CZ8) or the Mediterranean mountainous (CZ9) zones.

In addition, no peat samples were reported for shrublands in the Sub-oceanic (CZ3), Sub-oceanic to sub-continental (CZ4), Temperate mountainous (CZ6) and Mediterranean semi-arid (CZ7) zones while no peat samples were reported for woodlands of the Mediterranean semi-arid (CZ7) zone.

Only a single sample was collected for Temperate mountainous grassland (CZ6) and Mediterranean semi-arid grassland (CZ7) while fewer than ten samples were collected for Sub-oceanic (CZ3) woodlands and grasslands.

While the absence of samples in specific cover types and climate zones may reflect the restricted sampling design, it also reflects warm and dry climatic conditions that generally do not favour the formation of extensive peat lands. Given the limited number of samples in many climate zones, the use of the LUCAS Topsoil Database for pan-European studies or assessments on peat lands may be problematic and should be restricted to specific regions where the number of samples is greater.

6.5.1 Regional variability of topsoil organic carbon of peat soils

The limited number of samples restricts the possibilities of making valid statistical comparisons between the various climatic zones. Data from the LUCAS soil survey show (Table 6.5) that mean values of organic carbon in toplayer of peat are generally consistently above 260 g/kg (values with limited number of samples are not considered).

The highest mean value was found in the shrublands of Atlantic zone (CZ2) followed by the woodlands of the Boreal and boreal to temperate zone (CZ1) although standard deviation values are high in all cases, generally reaching 25-30% of mean values.

Table 6.5. Soil organic carbon concentration (g/kg) in topsoil of peat in different climatic regions of Europe

Climate zone		Land use type	Peat soils		
No.	Name		mean	std	n
1	Boreal and boreal to temperate	WL	399	98	779
		SL	354	96	13
		GL	349	89	46
2	Atlantic	WL	325	106	36
		SL	402	78	14
		GL	358	92	50
3	Sub-oceanic	WL	236	37	7
		SL			
		GL	240	16	2
4	Sub-oceanic to sub-continental	WL	335	100	34
		SL			
		GL	368	81	19
5	Subcontinental, partly arid	WL			
		SL			
		GL			
6	Temperate mountainous	WL	260	49	11
		SL			
		GL	230		1
7	Mediterranean semi-arid	WL			
		SL			
		GL	81		1
8	Mediterranean temperate and sub-oceanic	WL			
		SL			
		GL			
9	Mediterranean mountainous	WL			
		SL			
		GL			

6.5.2 Regional variability of topsoil pH of peat soils

Analysis based on the LUCAS topsoil database shows that the high levels of organic compounds (i.e. acids) present in peat soils give a strong acidic reaction for grasslands (Figure 6.32), shurblands (Figure 6.33) and woodlands (Figure 6.34) of all climate zones.

Only grassland in the Mediterranean semi-arid zone (CZ7) shows conditions tending to neutral or alkaline. However, this is based on a single sample.

Less acid or even alkaline organic soils are also possible, especially in areas such as calcareous fens where groundwater that is rich in calcium and magnesium carbonates support a specific plant community (only a select group of plants can tolerate both high levels of calcium and waterlogging) or where sea or brackish water can reach.

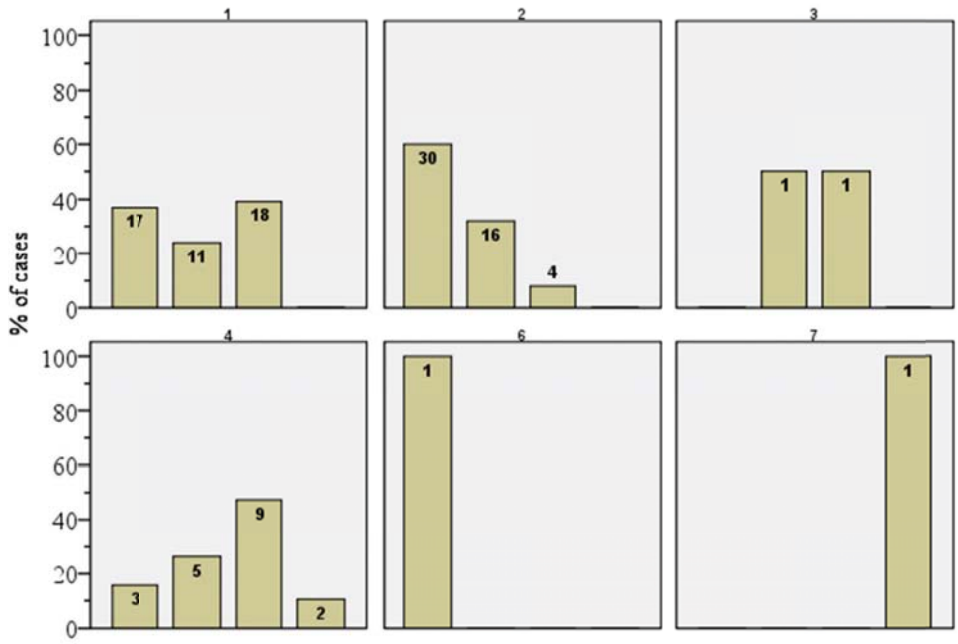


Figure 6.32 Percentage distribution of pH categories (1-3) in peat samples under grassland in the EU in six climatic zones (CZ1-4 & 6-7).
(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 – 7.2
numbers at the bars show sample size; (for climate zone names see Table 6.5)

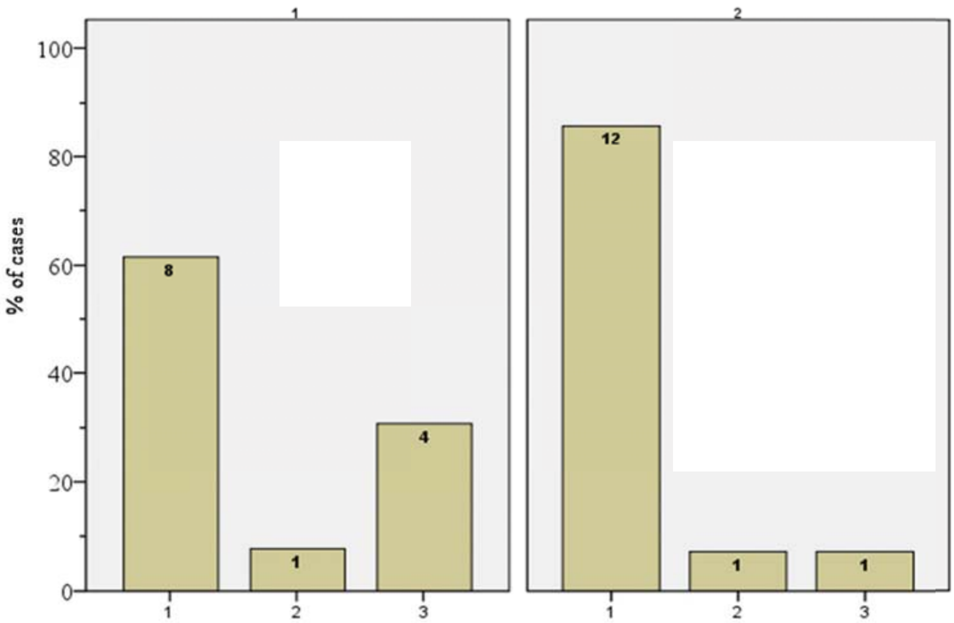


Figure 6.33 Percentage distribution of pH categories (1-3) in peat samples under shrubland in the EU in two climatic zones (CZ1-2).
(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 - 7.2
numbers at the bars show sample size; (for climate zone names see Table 6.5)

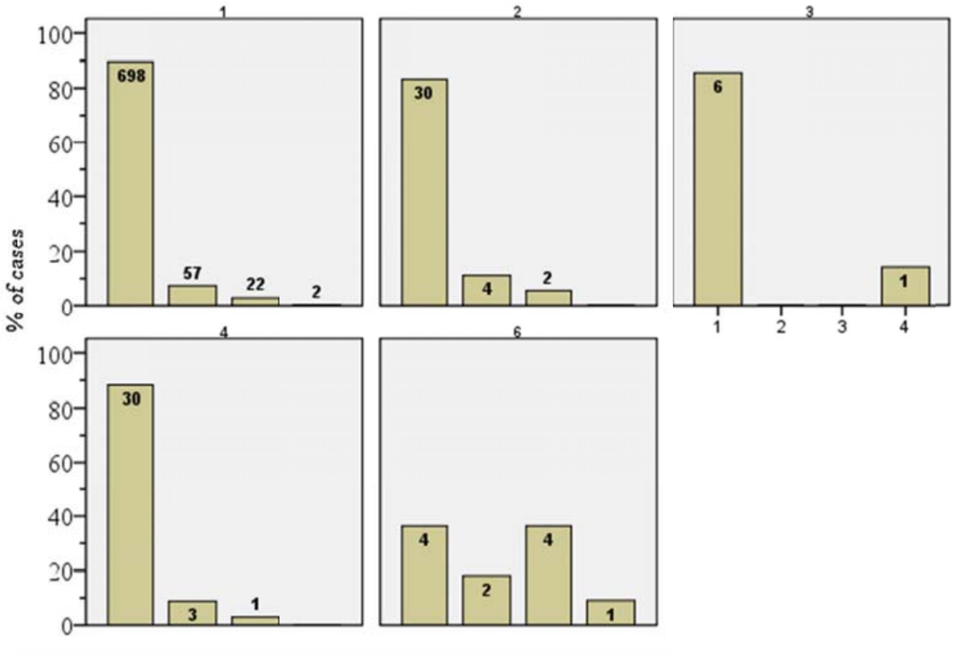


Figure 6.34 Percentage distribution of pH categories (1-4) in peat samples under woodland in the EU in five climatic zones (CZ1-4 & 6).
(pH categories: ; 1: =< 4.5; 2: 4.5 - 5.5; 3: 5.5 - 6.8; 4: 6.8 - 7.2
numbers at the bars show sample size; (for climate zone names see Table 6.5)

6.5.3 Regional variability of topsoil cation exchange capacity of peat soils

Cation exchange capacity (CEC) is the sum of exchangeable bases plus total soil acidity at a specific pH and is an indication of the ability of a soil to hold plant nutrients. However, measuring CEC in organic soils can be problematic.

CEC data from peat soils (Figure 6.35-6.37) in the LUCAS topsoil database show a strong inverse correlation to those of pH (Figures 6.32-34). As expected, the high organic matter levels and large surface area of the soil particles, give rise to high CEC values.

Although the number of samples is too low to make valid statistical comparisons, CEC values of peat soils are, in general, much higher than the mineral soils of croplands, grasslands, woodlands and shrublands.

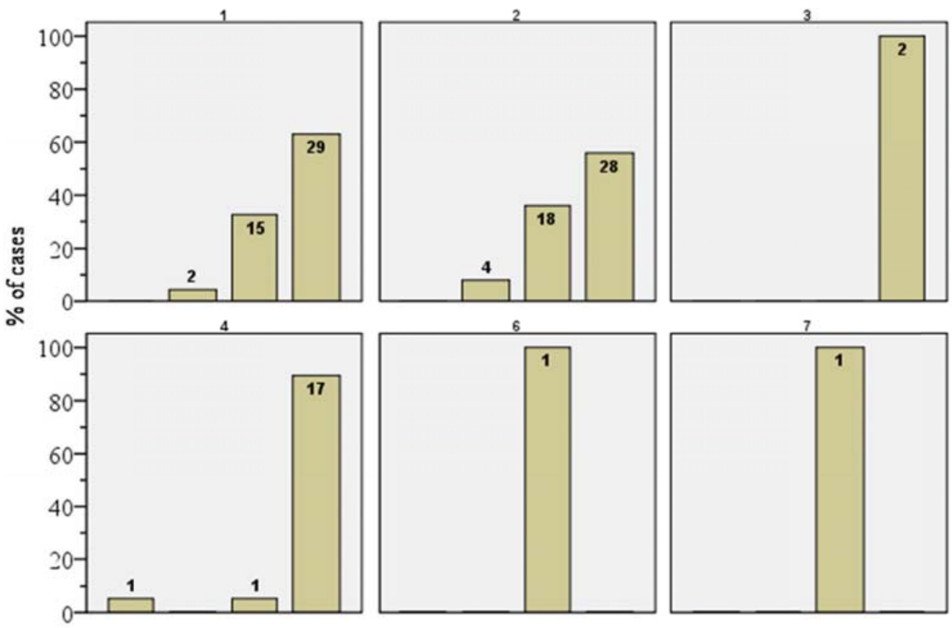


Figure 6.35 Distribution of cation exchange capacity categories (1-4) in peat samples under grassland in the EU in selected climatic zones (1-4, 6-7).
(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see table 6.5)

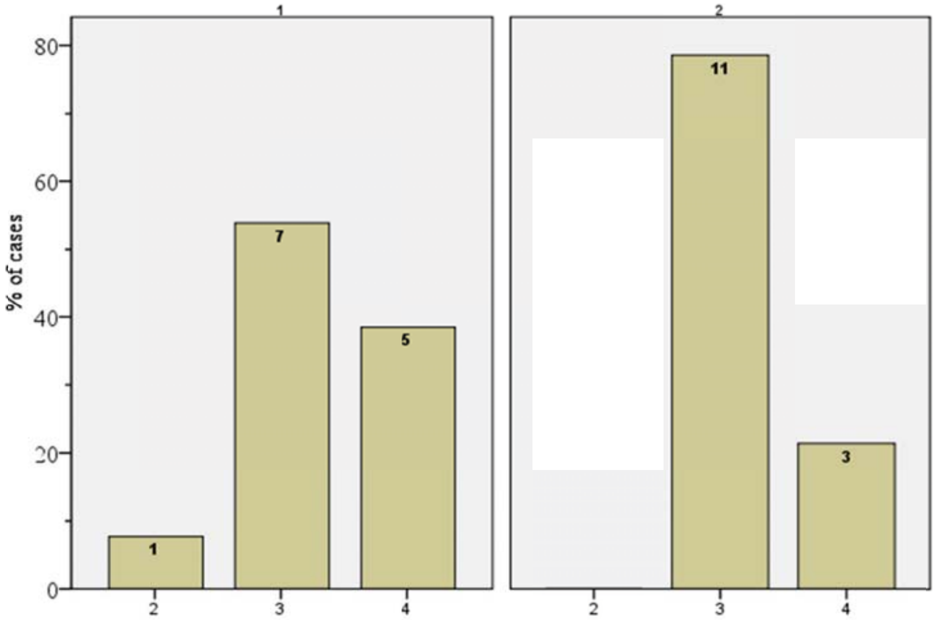


Figure 6.36 Distribution of cation exchange capacity categories (1-4) in peat samples under shrubland in the EU in two climatic zones (1-2).
(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see Table 6.5)

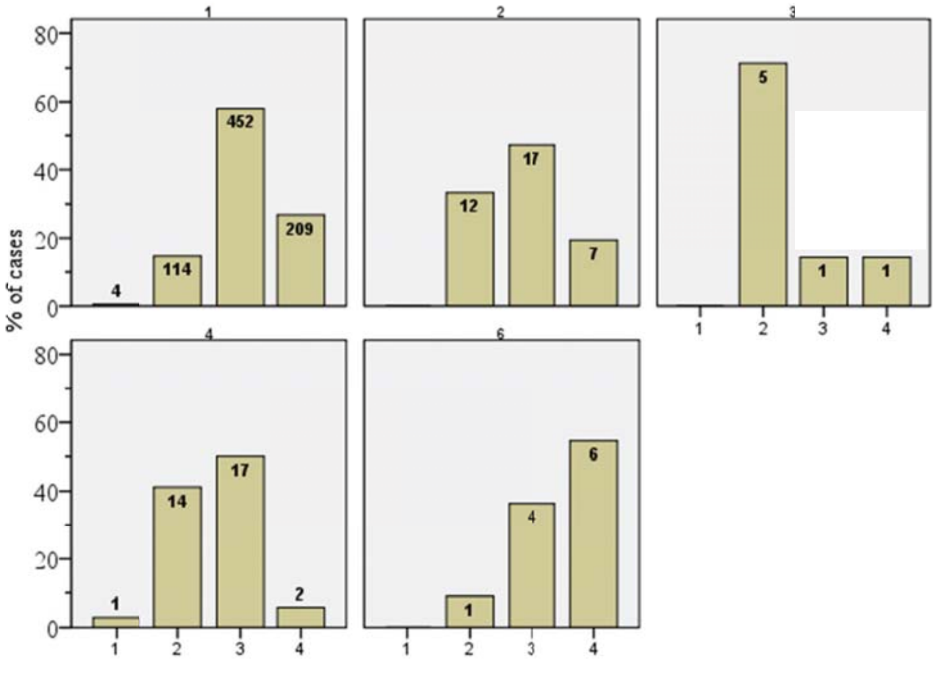


Figure 6.37 Distribution of cation exchange capacity categories (1-4) in peat samples under woodland in the EU in five climatic zones (1-4 & 6).
(Cation Exchange Capacity ranges; CEC in cmol(+)/kg; 1: <= 10, 2: 10-20, 3: 20-40, 4: >=40 numbers at the bars show sample size; for climate zone names see Table 6.5)

6.6 Organic-rich mineral soils

Within the LUCAS Topsoil Survey, 431 samples (around 2% of the dataset) are considered are representing organic-rich mineral soils. These samples have been identified as having a soil organic carbon content greater than 12% but less than 20% (see section 6.5). These limits reflect commonly used thresholds in soil science (e.g. FAO, WRB, soil taxonomy). In these samples, significant amounts of mineral matter were also present in the sample.

Organic-rich mineral soils generally reflect humid conditions and are often saturated with water for significant lengths of time (thus, inhibiting the decay of organic matter). Organic-rich soils are often referred to as possessing 'peaty' or humic topsoils. In general, the bulk densities and pH levels of organic-rich mineral soils tend to be lower than corresponding mineral soils. Porosity, water holding capacity and cation exchange capacity of organic-rich soils are also generally higher than mineral soils,

6.6.1 Regional variability of topsoil organic carbon of organic-rich soils

While the absence of samples in a specific climate zone zones may reflect the restricted sampling design, the distribution of samples also reflects the wet and humid climatic conditions that generally favour the formation of elevated levels of organic matter in soil.

Organic-rich mineral soils are mostly associated with woodlands and shrublands (in the Mediterranean mountainous zone (CZ9), a single sample was collected from a grassland).

The highest number of samples was collected in the Boreal and boreal to temperate zone (CZ1) while the least samples came from the Mediterranean semi-arid (CZ7) and Mediterranean mountainous zone (CZ9), with only a single sample from a woodland and a grassland site, respectively.

In addition, no samples were reported for shrublands in the Sub-oceanic to sub-continental (CZ4) or the partly arid Subcontinental (CZ5) zones.

In addition, only a single sample was collected for Sub-oceanic shrublands (CZ3), Temperate mountainous shrublands and grasslands (CZ6) and Mediterranean temperate and sub-oceanic grassland (CZ8).

Given the limited number of samples in many climate zones, the use of the LUCAS Topsoil Database for pan-European studies or assessments on organic-rich soils may be problematic and should be restricted to specific regions where the number of samples is greater. However, the following broad conclusions may be observed in Table 6.6.

Mean values of organic carbon in the topsoils of organic-rich mineral soils show considerable variation across the different climatic zones. Values in the Mediterranean region (layer of peat are generally consistently above 260 g/kg (values with limited number of samples are not considered).

The highest mean values were found in the shrublands of cool and humid climates of CZ1 and CZ2 (168 and 160 g/kg C respectively) while 159 g/kg C were found in the grasslands of the Sub-oceanic to sub-continental zone (CZ4). In general, woodlands show a consistent level of OC in all climate zones (approximately 150 g/kg C). In fact the mean level of OC in CZ1 is identical to that of CZ8 even through the climates are very different. In northern and western regions, comparable values are found for shrublands and grasslands, although for the latter two cover types, the values are lower in the Temperate Mountains and Mediterranean zones.

Table 6.6. Soil organic carbon concentration (g/kg) in topsoil of peat in different climatic regions of Europe

Climate zone		Land use	Peat soils		
No.	Name	type	mean	std	n
1	Boreal and boreal to temperate	WL	153	23	241
		SL	168	23	10
		GL	152	22	19
2	Atlantic	WL	157	22	21
		SL	160	22	7
		GL	151	22	39
3	Sub-oceanic	WL	149	23	15
		SL	128		1
		GL	143	27	10
4	Sub-oceanic to sub-continental	WL	146	22	21
		SL			
		GL	159	26	15
5	Subcontinental, partly arid	WL	156	25	3
		SL			
		GL	121	1	2
6	Temperate mountainous	WL	150	24	14
		SL	133		1
		GL	123		1
7	Mediterranean semi-arid	WL	157	28	3
		SL			
		GL			
8	Mediterranean temperate and sub-oceanic	WL	153	39	4
		SL	137	24	2
		GL	138		1
9	Mediterranean mountainous	WL			
		SL			
		GL	121		1

As expected, the OC of organic-rich mineral soils is markedly higher than all mineral soils from cropland, grassland, shrubland and woodlands by around 300% but around 50% of the value of peat soils.

6.7 C:N elemental ratio in topsoils of the European Union

Rannveig Anna Guicharnaud

The elemental ratio of carbon and nitrogen (C:N) of organic matter influences the rate of decomposition of soil organic matter (SOM) which in turns affects plant availability of C and N within soil systems. The main reason is linked to soil microorganisms C and N need for their metabolisms. For every part of N microbes will need 20 parts of C. When added soil organic material contains more N in proportion to C, excess N is released in to the soil solution and becomes available to plants. If, on the other hand, the organic matter contains less N in relation to C, soil microorganisms will immobilise soil N for their metabolisms and N will become temporarily unavailable to plants. The C and N plant availability is best demonstrated in the soil C: N elemental ratios. As well documented in the literature, when the soil ratio is ≤ 16, this is an indication of C limitation, when the C: N ratio is ≥16 this is an indication of N limitation.

C:N elemental ratios were calculated from the LUCAS soil dataset for all land cover groups (cropland, forest, grassland and bare land) and for different climatic regions (Boreal, Boreal/Temperate and Mediterranean). According to calculated C:N ratios, plant available N is generally not a limiting factor indifferent soil systems, with the exception of few forested areas, with C: N ratios rarely being over 16. Across the EU, soils appear to be C limited with C:N ratios being generally less than 16 (Figure 6.38)**.** No specific trend was observed between climatic regions (Figure 6.1).

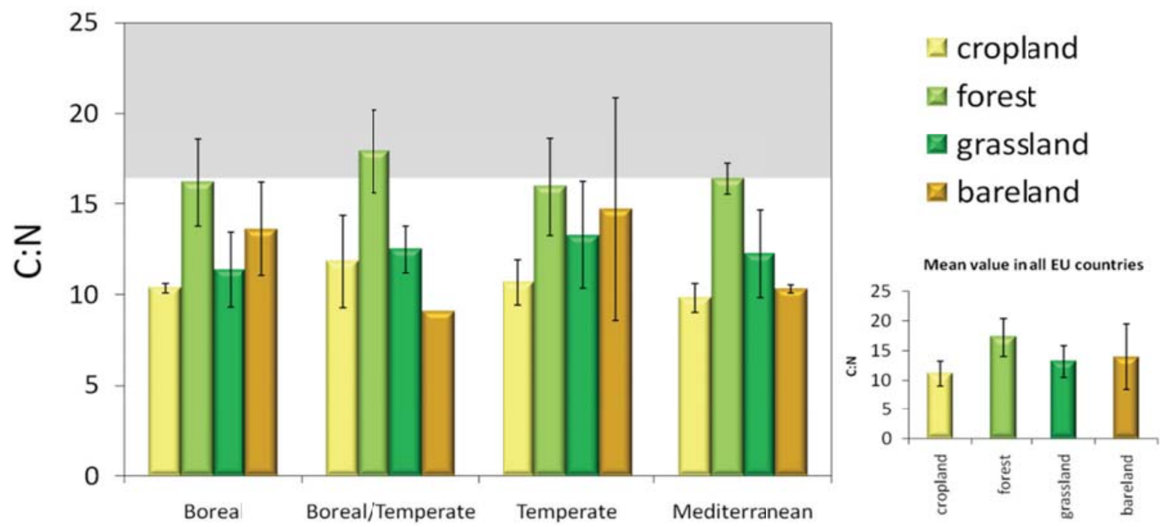


Figure 6.38 Columns represent C:N ratios in different climatic region and land cover groups in the EU. Columns are means obtained from LUCAS 2009 and error bars standard deviations of means.

6.8 Conclusions

As the first harmonised soil assessment across almost all Member States, the LUCAS topsoil survey resulted in a unique dataset that allows a series of comparative assessments to be made on the soil resources of the EU. The LUCAS dataset is enhanced by the associated information on land use/cover on the sampling locations. This report provides an overview of the survey methodology and resultant database and highlights some of the geographic tendencies in topsoil properties across the EU.

An important component of the LUCAS topsoil database is the library of multispectral properties. However, the analysis of multispectral properties was beyond the scope of this current study.

This initial general assessment of the database aimed to reveal the potential of the information it contains. These potentials are certainly unique from a scientific aspect but also for the formation of soil related policies in the EU.

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7. Interim results of continuous mapping topsoil properties of the European Union on a continental scale using LUCAS Soil data

7.1 Generating continuous soil maps from point observation and auxiliary information

Cristiano Ballabio

Digital Soil Mapping (DSM) deals with the production of continuous soil maps or maps of soil properties form heterogeneous data sources through the use of machine learning or statistical techniques. The most common task is to produce geographically continuous maps (i.e. maps covering the entire surface of a given region) from scattered point data. This is generally due to soil surveys providing a limited number of field observations, which are insufficient to estimate soil properties over large areas by simple averaging. For instance, the points of the LUCAS dataset have a minimum distance of 2 km (determined by the general LUCAS grid). However, it is not possible to consider the sampled point as representative of a larger area (the area over which the soil was sampled for any single observation), nor is it possible to average the value of several point to obtain an estimate for a region because a reasonably accurate estimation would require a quite high number of points, resulting in very large estimation surfaces.

An alternative approach to the problem of the estimation of soil properties from soil surveys is to establish a relation between the soil property of interest and a series of environmental covariates, representing a series of factors influencing soil formation. This approach follows the paradigm of soil science where the distribution of soil features is generally attributed to a series of interacting environmental factors driving soil development. This concept stems from the work of Vasily Dokuchaev who attributed changes in soil properties to both changes in geology and climatic or topographic conditions. Hans Jenny formalised this relationship in his famous equation S=f(CL, O, P, R, T, …), where soil properties S are defined as the combination of the effects of climate CL, organisms O, parent material P, relief R and time T while leaving the possibility to introduce additional variables in the equation. In spite of its formal appearance, Jenny's equation is purely qualitative and aims to describe a concept more rather than making effective predictions of soil properties. Nonetheless, since Jenny published his formulation, it has been used by soil surveyors as a qualitative expression for understanding the factors that may be help in producing the soil pattern within a region. Numerous researchers have taken the quantitative path and have tried to formalise this equation. Mostly through studies where one factor varies and the rest are constant, resulting in quantitative climofunctions, topofunctions, etc.

DSM follows the concepts expressed in Jenny's equation. However, instead of expressing an empirical relation, DSM aims to find an actual mathematical relation between soil properties and a combination of environmental features. This is usually achieved using a statistical regression procedure to relate a set of environmental features with a set of observed soil properties. Subsequently soil properties are extrapolated or interpolated from the fitted model for all the unvisited locations where the prediction is needed. In practice the DSM approach follows Hans Jenny's approach but establishes a quantitative relationship instead of a qualitative one.

Limitations in the sampling design and possible limitations in the modelling process may mean that procedures to develop continuous mapping of soil parameters may not capture all spatial variation. Consequently, certain areas may be subject to high uncertainty (see Fig. 7.2).

Regions that are above 1,000 m in elevation, peatlands and non-soil areas (e.g. urban, water, bare rock) have been excluded from the following maps.

7.2 Topsoil organic carbon content map

Delphine de Brogniez and Cristiano Ballabio

The measured organic carbon content of LUCAS soil samples is used to produce a map of topsoil organic carbon (SOC) content at European scale. The dynamic of the latter soil parameter is influenced by different factors such as climate (e.g. rainfall, temperature), vegetation cover, mineralisation rate, land management practices as well as soil physico-chemical properties.

In order to predict SOC it is necessary to establish a relation between measured SOC and independent variables (covariates) representing the above-mentioned factors. These variables must be available as continuous data layers so that to allow the prediction of SOC content at unsampled locations. Digital soil mapping through regression consists in fitting a statistical regression model between the soil property to predict and the value of the independent variables at the same locations. The soil property is then predicted at unsampled locations by applying the fitted model on the covariates.

In the present case study, a generalized additive model (thin-plate splines) was fitted using generalized cross-validation. Predictive environment variables used were CORINE2006[5] land cover, elevation and slope (SRTM derived), soil texture, temperature, ratio of rainfall and potential evapotranspiration also referred to as aridity index (WorldClim global climate database), geology (BGR geological map of Europe), net primary productivity (MODIS land-product), latitude and longitude. The overall model-fitting performance (adjusted-R2) is 0.46. The root mean squared error (RMSE) is 79.3 and the normalized RMSE is 13.5%.

The predicted SOC content is presented in figure 7.1.

[5] CORINE2006 was not available for Greece. The data of CORINE2000 were therefore used for the latter country since no change in the classification occurred between both datasets release.

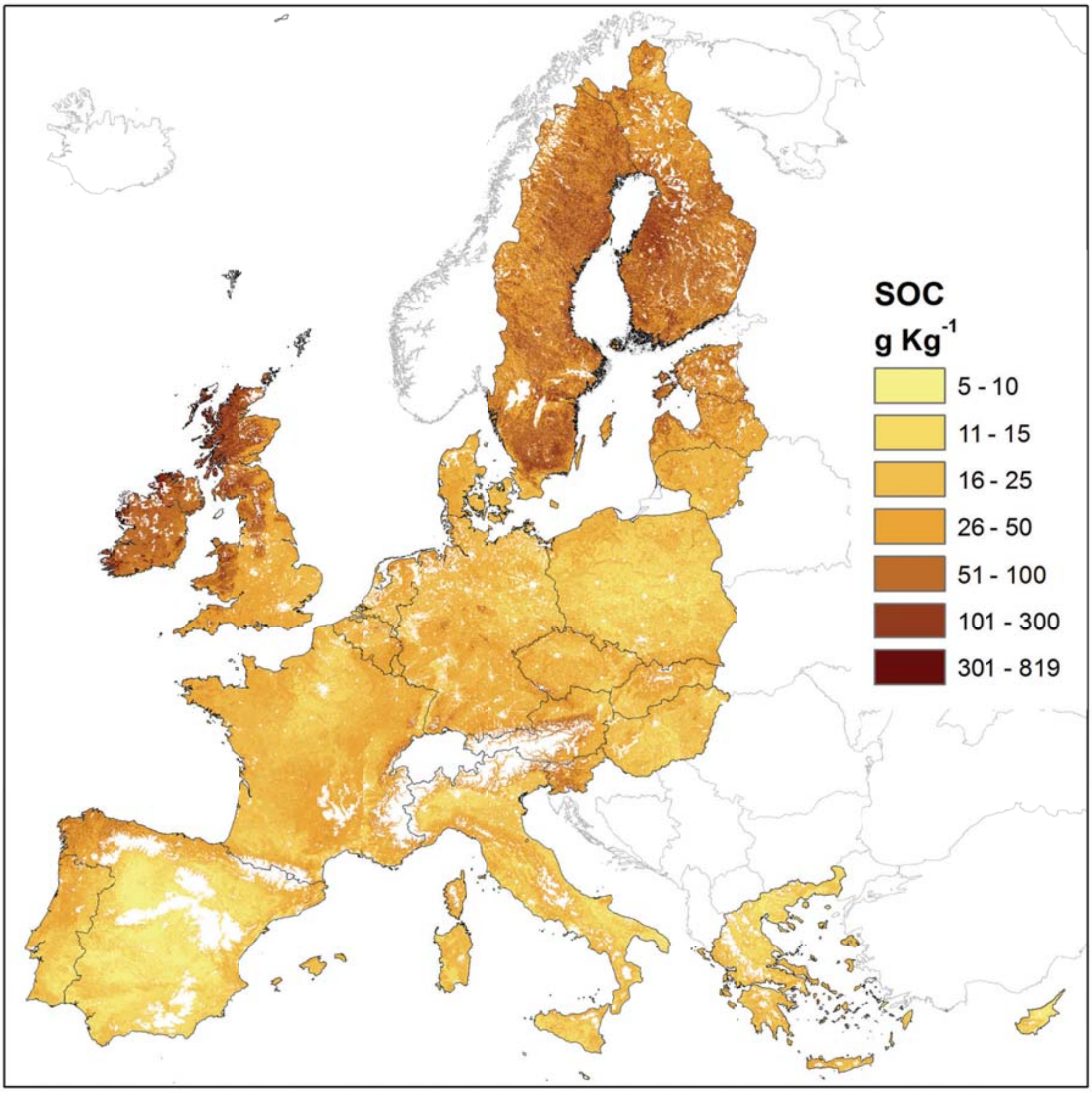

Figure 7.1 Predicted topsoil organic carbon content for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

Figure 7.2 represents the standard error of the model prediction. In other words, this map shows the theoretical range of deviation in the prediction made by the model (assuming a normal distribution of the errors). These values were calculated a posteriori, based on a Monte-Carlo simulations from a multivariate normal distribution using the estimated covariance matrix of the parameters. This standard error expresses the distribution of the SOC value for a certain combination of covariates (i.e. a pixel) as predicted by the regression model (created with the LUCAS dataset in this case).

We would like to emphasize that this map should, by no means, be interpreted as showing the prediction error for every pixel of the map. As a matter of fact, prediction error is calculated as the difference between a SOC measurement and prediction and could therefore only be obtained for the pixels where LUCAS samples were taken. The reader should also keep in mind that the LUCAS dataset is a sample of a much larger population (that is the soils of Europe).

A threshold of 50g·kg-1 standard error was chosen to discard areas that were either predicting outside the range of covariates or with too few samples. They are shown in red on the map (Figure 7.2).

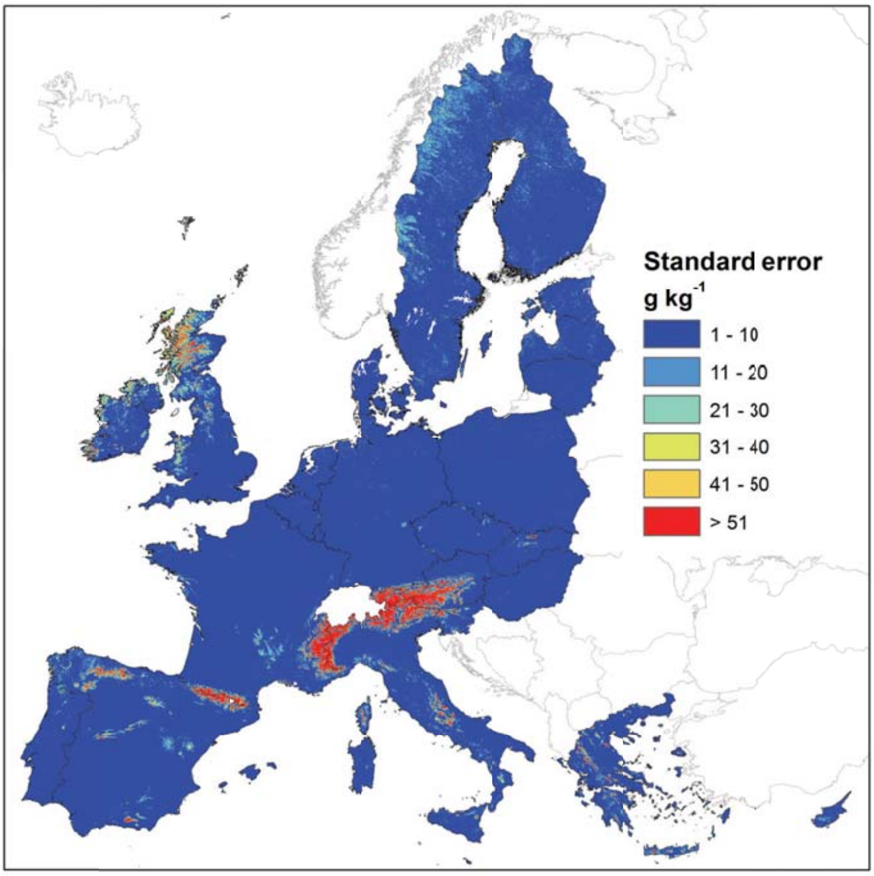

Figure 7.2 Standard error of the model prediction.

The above considerations on uncertainties related to spatial prediction of soil properties apply to all maps in chapter 7.

7.3 Topsoil pH maps

Cristiano Ballabio, Ciro Gardi and Yusuf Yigini

In order to obtain a continuous mapping of soil pH for the EU through the digital soil mapping approach, a set of continuously distribute covariates, highly correlated with pH, were selected. Soil vegetation dynamic was derived from remotely sensed data with a high temporal resolution (MODIS 16 days vegetation indexes: NDVI and EVI) which provide some information about the seasonal dynamics of vegetation over the EU.

In the present case study, a generalized additive model (thin-plate splines) was fitted using generalized cross-validation. Predictive environment variables used were elevation and slope (SRTM derived), ratio of rainfall and potential evapotranspiration also referred to as aridity index (WorldClim global climate database), net primary productivity (MODIS land-product), latitude and longitude, seasonal MODIS EVI and NDVI.

The overall model-fitting performance for the pH (adjusted-R2) is 0.76. The standardized error is 0.11.

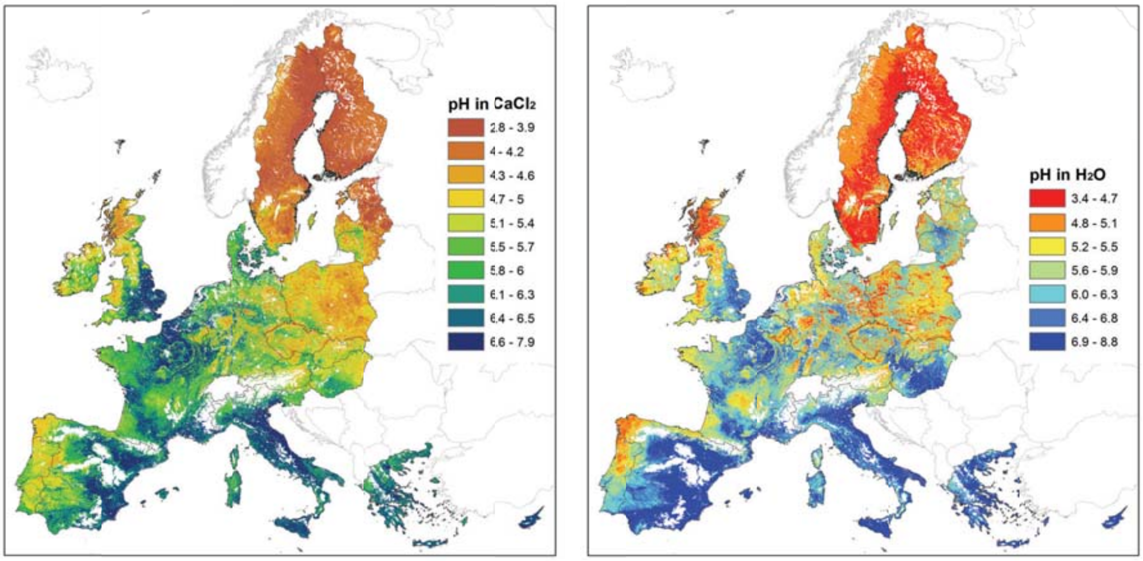

Figure 7.3 Predicted Topsoil pH maps for the EU based on the LUCAS Topsoil Database: measured in $CaCl_2$ (left) and H_2O (right).

(BG and RO are excluded – No Data).

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

7.4 Topsoil sand-, silt- and clay maps

Cristiano Ballabio

Soil sand-, silt- and clay content as measured (in %) in the samples of the LUCAS database were extrapolated to the full extent of the EU by means of a regression tree model using remotely sensed data as support covariates. The approach was to model soil particles as a dependent (in the statistics sense) variable, whereas the seasonal variation of vegetation cover was taken as an independent descriptor. Soil vegetation dynamic was derived from remotely sensed data with a high temporal resolution. In this case the data used was the MODIS 16 day vegetation indexes (NDVI and EVI) which provide some information about the seasonal dynamics of vegetation over Europe. As the vegetation dynamics is substantially controlled by climate, the difference in the plant growth and senescence cycle, once the climatic effect is removed, is substantially controlled by the soil available water content, which in turn is controlled by soil texture and soil organic matter content.

The regression model was then fitted using climatic data from the WorldClim global climate database, geomorphometric variables (elevation and slope) and MODIS derived vegetation indices. Vegetation dynamics was modelled using strictly concave splines to generate a prototype yearly cycle from the data collected over many years (2000-2008).

The model fitting resulted in very good performance metrics: fitting R2 = 0.6. The model was also tested using k-fold cross-validation (500 repetitions with a proportion of 0.2 validation/fitting instances) giving an R2 = 0.56. The standard error varies from 5.44 to 6.8%.

Since the three textural components (sand, silt and clay) are mutually correlated, the first prediction made was done on the textural component which could be predicted with the best accuracy, in this case sand. Thereafter each other component was predicted by constraining the sum of the three to be equal to 100.

Results of the digital mapping of the sand, silt and clay content are presented in Figures 7.4 - 7.6 respectively.

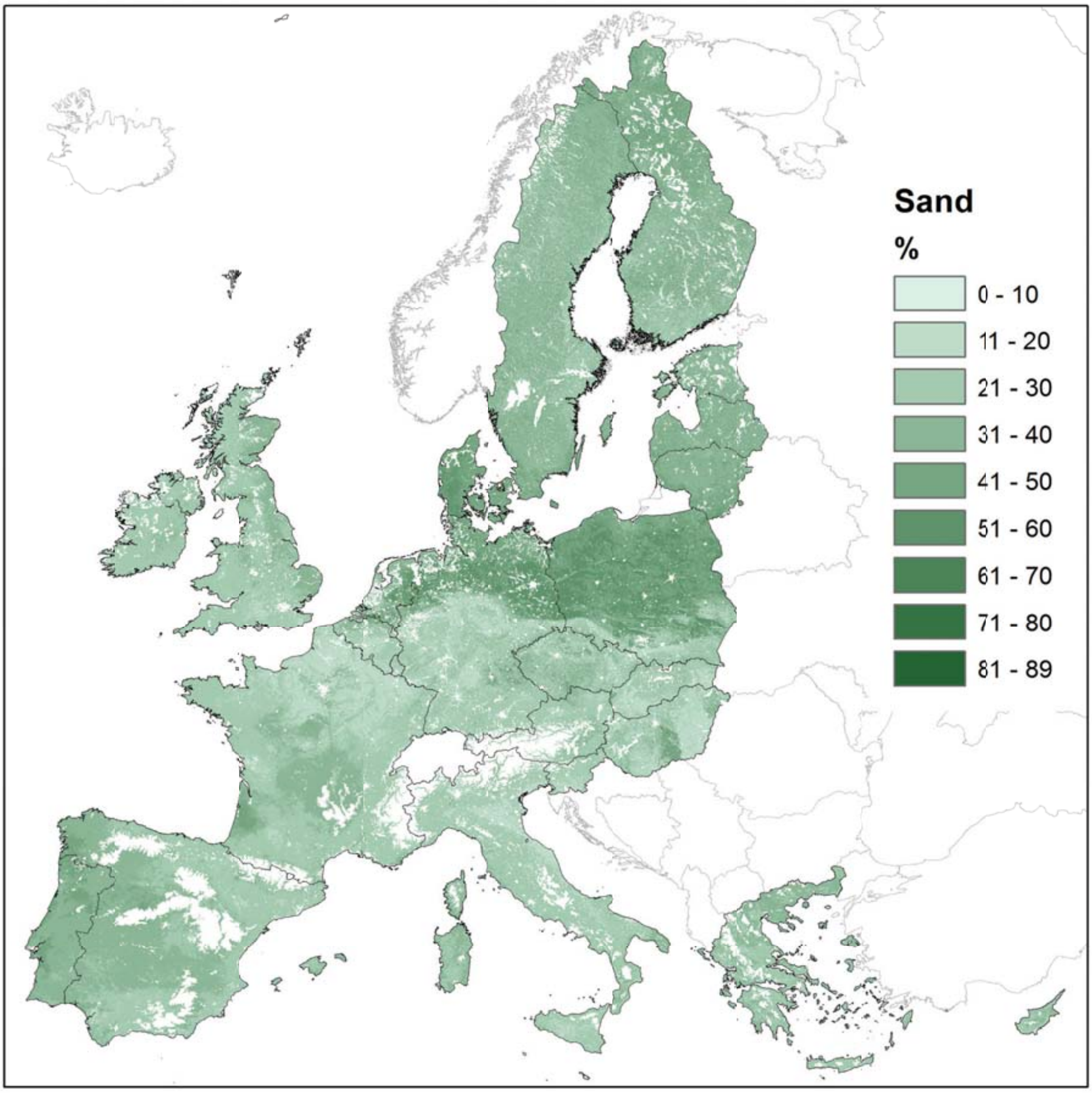

Figure 7.4 Predicted topsoil sand content (percentage) for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

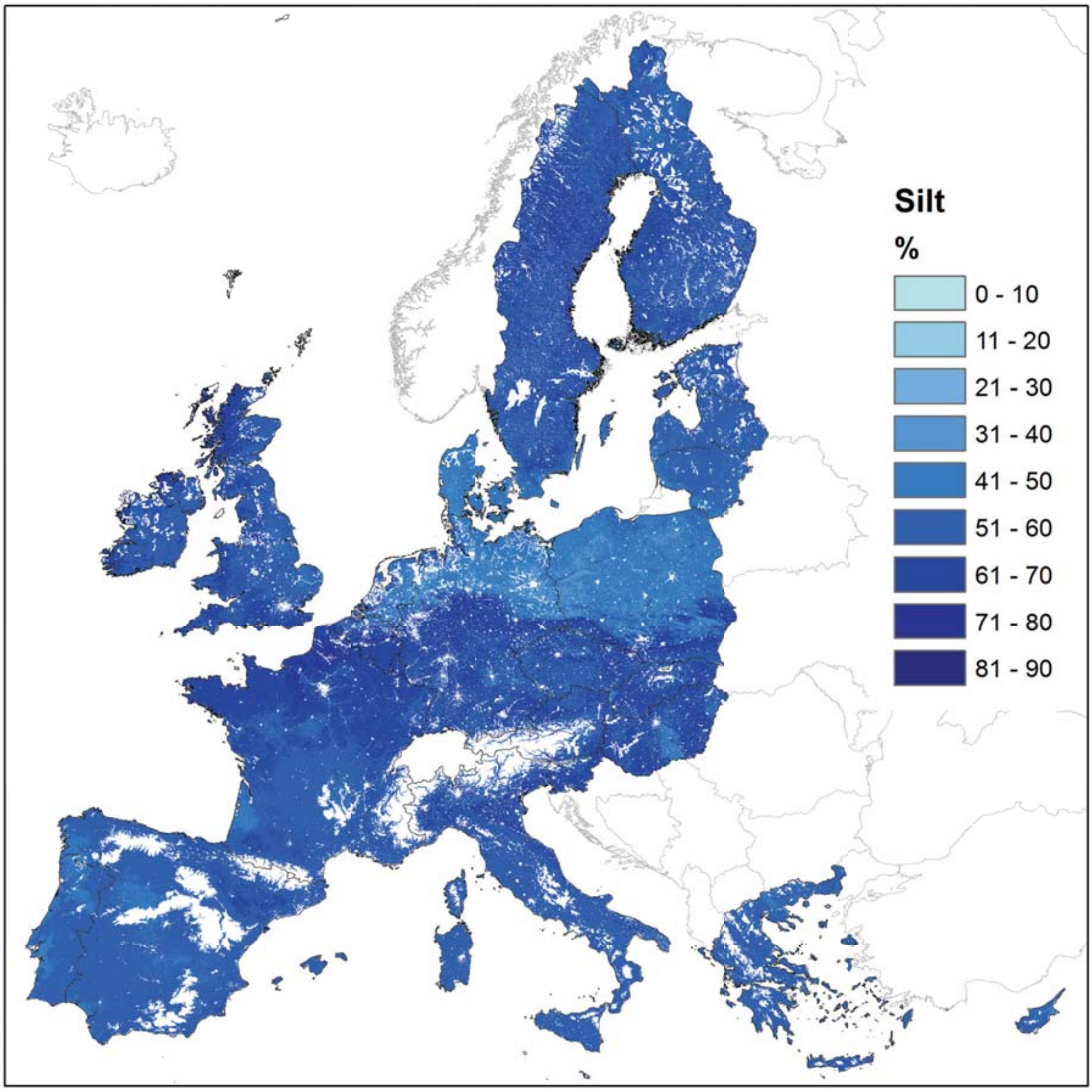

Figure 7.5 Predicted topsoil silt content (percentage) for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

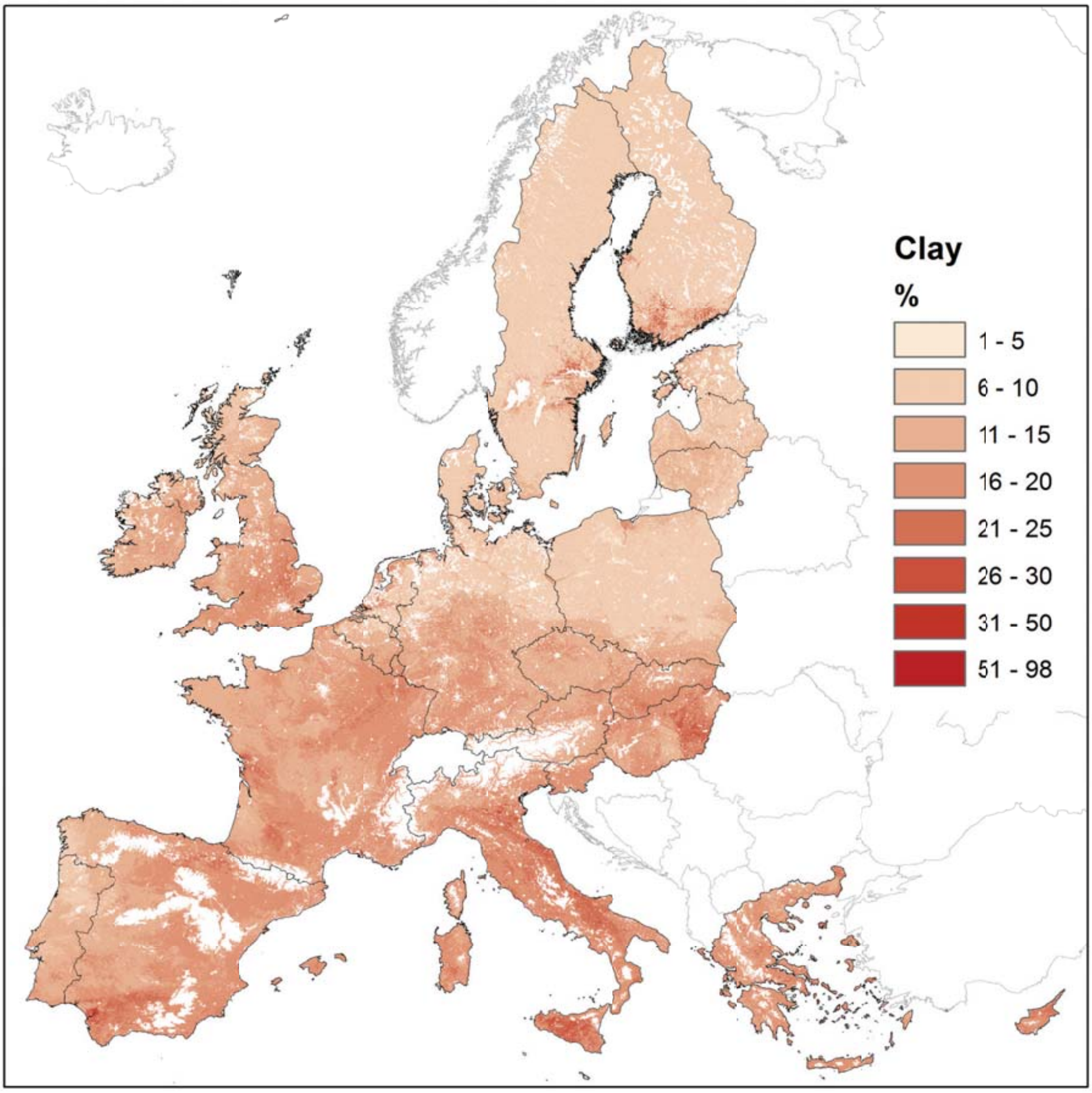

Figure 7.6 Predicted topsoil clay content (percentage) for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

The maps appear to be consistent with the main geological and geomorphological features of Europe. In particular the highest amounts of sand can be found in correspondence of the limit of the glacial/marine transgression associated with the last glacial maximum. Silt content is higher in correspondence with aeolian deposits, while clay is related to the geological nature of the substrate (e.g. presence of shales, glacial clays).

7.5 Topsoil nitrogen content and C:N ratio maps

Cristiano Ballabio

Nitrogen (g kg^{-1}) and the C:N ratio of the LUCAS samples was extrapolated to the full extent of the EU by mean of a regression tree model using remotely sensed data as support covariates. Given the high correlation between SOC and nitrogen content, the approach applied was similar to the one presented in section 8.1. In this case, nitrogen was considered as the independent variable, whereas the seasonal variation of vegetation, mineralisation rate, land management practices as well as soil physical and chemical properties cover were taken as an independent descriptor. Soil vegetation dynamic was derived from remotely sensed data with a high temporal resolution (MODIS 16 day vegetation indexes: NDVI and EVI) which provide some information about the seasonal dynamics of vegetation over Europe.

In the present case study, a generalized additive model (thin-plate splines) was fitted using generalized cross-validation. Predictive environment variables used were elevation and slope (SRTM derived), ratio of rainfall and potential evapotranspiration also referred to as aridity index (WorldClim global climate database), net primary productivity (MODIS land-product), latitude and longitude, seasonal MODIS EVI and NDVI.

The overall model-fitting performance for the nitrogen content (adjusted-R2) is 0.701. The standardized error is 0.264.

The overall model-fitting performance for the C:N ratio (adjusted-R2) is 0.603. The standardized error is 4.67.

The predicted nitrogen content and C:N ratio are presented in figures 7.7 and 7.8.

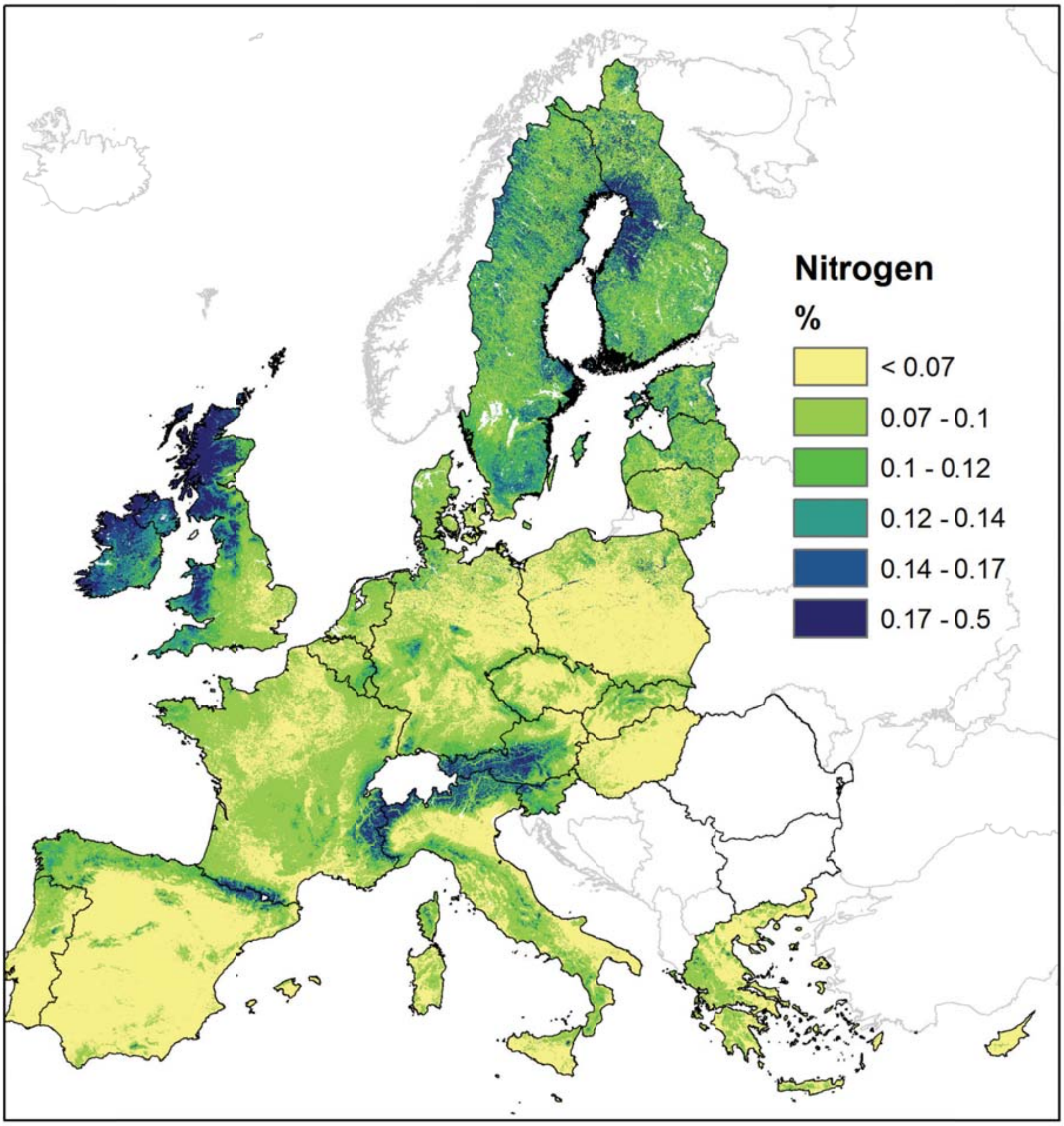

Figure 7.7 Predicted topsoil nitrogen content for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

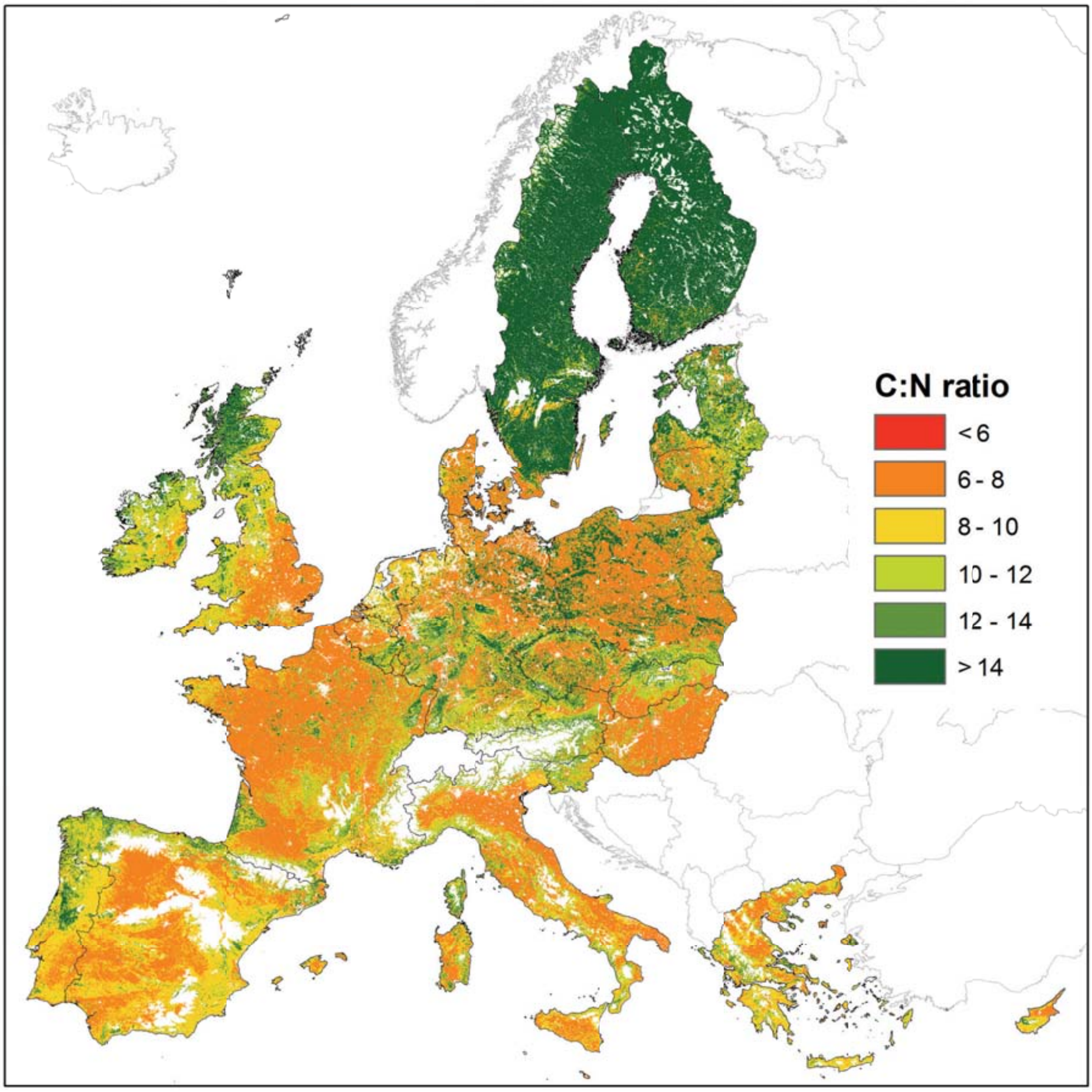

Figure 7.8 Predicted topsoil C:N ratio for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

7.6 Topsoil calcium carbonate map

Cristiano Ballabio

Calcium carbonate ($CaCO_3$) measured (in mg kg^{-1}) in the samples of the LUCAS database was extrapolated to the full extent of the EU by mean of a regression tree model using remotely sensed data as support covariates. The approach was similar to the one used to derive soil texture.

The regression model was then fitted using climatic data from the WorldClim global climate database, geomorphometric variables (elevation and slope) and MODIS derived vegetation indices. Vegetation dynamics was modelled using strictly concave splines to generate a prototype yearly cycle from the data collected over a nine year period (2000-2008).

The model fitting resulted in very good performance metrics: fitting R^2 = 0.77. The standard error is 42.9.

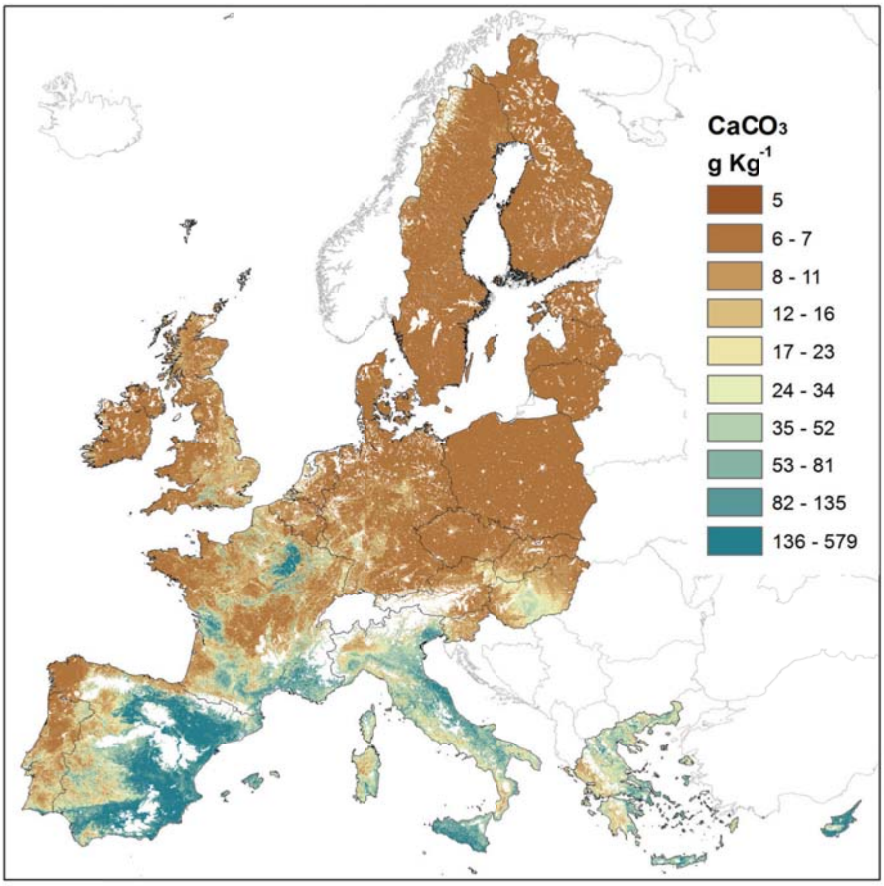

Figure 7.9 Predicted topsoil $CaCO_3$ content for the EU based on the LUCAS Topsoil Database.

Please note that areas above 1000 m and peatlands have been masked out. Also, the map is a preliminary product and reflects the specific sampling design (see Chapter 2.4) and possible limitations in the modelling process (e.g. weak covariates). It is worth bearing in mind that the characteristics of the topsoil (i.e. the uppermost 20 cm) may be very different to those deeper in the soil body. Consequently, certain areas have been mapped with high uncertainty.

8. Spatial analysis of soil properties of the European Union

8.1 Estimation of topsoil organic carbon stock of the European Union and its Member States for the reference year of 2009

Gergely Tóth, Cristiano Ballabio, Delphine de Brogniez and Tamás Hermann

8.1.1 Introduction

Soil organic carbon (SOC) concentration is a site specific soil characteristic, which is attributable to soil-forming factors such as climate, vegetation, parent material and land use.

Pedotransfer rules (PTRs) are techniques to estimate SOC concentration in situations where direct measurements are not available, or not adequate for spatial representation on the required scale. PTRs developed to characterise SOC levels of European soil types (EC 2003) were combined with climate and land use data by Jones et al. (2004) to derive spatial estimates of topsoil SOC content on a continental scale for Europe. The resulting spatial dataset, the so-called OCTOP data serves as the main information base on topsoil carbon content for various purposes to date. Although validation of the OCTOP data were performed using regional datasets, only with the availability of the LUCAS Soil data a full understanding of the model performance became feasible. Initial analyses of the model validity of OCTOP by Tóth (2011) and Panagos et al. (2012) described regional variation in its estimation inaccuracy. According to Tóth (2011), the model performance of OCTOP has a systematic error in relation to climatic patterns. Panagos et al. (2013) has added detailed data – based on analysis of SOC content in administrative units - to support this argument.

Digital soil mapping applies geostatistical processes of georeferenced data from different sources to derive continuous maps of soil properties. Brogniez and Ballabio (2013; Chapter 7.2 of this report) present a map of topsoil organic carbon concentration based on LUCAS point measurements and auxiliary information (land use, texture, climate, terrain characteristics).

The objective of our current study is to make use of the measured LUCAS topsoil SOC data to derive estimates for organic carbon stocks of topsoil (uppermost 20 cm) in the European Union. Two approaches were followed for the estimations. The first approach based its calculations on the SOC concentration values within distinct climate zones derived from the OCTOP map of Jones et al. (2004) and the measured LUCAS Topsoil data in the same climate zones. Statistical differences between the estimated (OCTOP) and measured (LUCAS) concentrations were used to estimate SOC stocks for each climatic zones of the EU for the year 2009. In the second approach, topsoil SOC estimates were made on the bases of the continuous map presented by Brogniez and Ballabio (2013).

8.1.2 Spatial datasets used

i. Organic carbon data

a) The OCTOP raster dataset (Jones et al. 2004) was used as primary input layer for the statistical analysis and spatial calculations.

b) Measured SOC data from the LUCAS points was used for comparative assessment with the OCTOP data on 19969 points and to establish correction measures for predicting SOC stocks.

b) The Topsoil Organic Carbon Content map of de Brogniez and Ballabio (2013) published in this report (Chapter 7.2) has been utilised for estimating topsoil SOC stocks for the EU and its Member States.

ii. Land use data

The CORINE (CO-oRdination of INformation on the Environment; JRC-EEA 2005) land cover database was used to select the extent of croplands (annual and permanent), grassland and forest for the analyses. The CLC database provides information on land cover in European countries, including member states of the European Union (JRC-EEA, 2005). CORINE Land Cover data from two years (2000 and 2006) was used. Basic mapping units of the CLC databases (2000 and 2006) are 25 ha in size displayed on a map of 1:100,000 scale or 100 m resolution. Each data cell is classified according to the dominant land cover type or by the mixture of land covers.

iii. Climate data

Climatic zonation based on the 35 climatic areas of Hartwich et al. (2005) served as spatial units for SOC assessments on the continental scale. Regrouping of the Climatic Areas was performed to create climatic zones (Chapter 6, Figure 6.1).

iv. Topsoil bulk density data

Spatial data on different topsoil '*packing density*' (PD_TOP) is available from the European Soil database (ESDB; EC 2003). Bulk density values are derived from this packing density data using the equation proposed by Jones et al. (2003). Jones et al. provides numeric relationships between packing density and bulk density values, conditioned by clay content and quantify the meaning of qualitative categories of packing density for mineral soils. For the special cases of Histosol areas, mean bulk density value (0.32 g/cm^3) of Histosols in the EU-HYDI database (Weynants et al. 2013) was used. It is worth noting, that with new data on bulk densities the accuracy of estimations can be considerably increased.

v. Soil typological units

The Soil Geographical Database of Eurasia (SGDBE) from the European Soil Database (ESDB; EC 2003) was used as the soil information source to separate areas with Histosols and other soil in this study.

8.1.3 Methods and results

Two methods were tested simultaneously to derive estimates for topsoil (upper 20 cm) organic carbon stocks of the European Union for the baseline year of 2009.

The first method used the OCTOP map (Jones et al. 2004) as an underlying continuous spatial dataset. To date OCTOP has been the only available dataset to characterise SOC in the soils of Europe. To estimate the differences between predicted (OCTOP) and measured (LUCAS) SOC concentrations were established for main climatic zones (Figure 6.1.1) and land cover classes (e.g. annual croplands, permanent croplands, grassland and woodland). These coefficients indicate differences between estimated regional SOC concentration values of the OCTOP raster data and those derived from measured LUCAS Topsoil data. OCTOP-based SOC stocks by climatic regions and land uses were calculated using SOC concentration values of the OCTOP raster and the bulk density raster. For areas of Histosols - as delineated from the ESDB - a separate bulk density value (0.32 g/cm^3) was applied. OCTOP-based stock estimates were modified by the coefficients (by climate region and land use; for Histosols separately) to arrive to an estimated SOC stock for the European Union for the baseline year of 2009. To establish topsoil SOC values for areas other than cropland, grassland and woodland, the average concentrations estimated for these land use types were used.

According to the estimations, organic carbon stock in the topsoil of the 25 EU Member States which participated in the 2009 LUCAS Topsoil Survey come to a total of 54.5 gigatonnes. Based on the combination of LUCAS data and OCTOP map and including an estimate for Bulgaria and Romania - based on the proportional land area of these countries within the EU and in the climate zone they located - the total topsoil SOC stock of the EU in the year 2009 and can be estimated as 56.9 gigatonnes. Over 70 % of this stock is in the Boreal and Atlantic regions.

The second method – based on digital soil mapping - used the topsoil organic carbon map presented by Brogniez and Ballabio (2013; see Chapter 7.2 of this report) in combination with the bulk density raster created using the above described methodology. SOC stock estimates using the second approach are presented for the Members States of the European Union that were covered by the LUCAS survey in 2009. Table 8.1 presents the result of the estimations for individual countries. Based on the country specific figures (and considering the land area and soil conditions of Bulgaria and Romania) topsoil (uppermost 20 cm) organic carbon stock of the European Union is estimated as 51.9 gigatonnes using the digital soil mapping approach.

8.1.4 Conclusions

Two methods were applied to estimate organic carbon stocks of the topsoil in the European Union. One method based its estimations on the OCTOP map of Jones et al. (2004) and the measured SOC concentrations of the LUCAS Topsoil survey, while the other method is based on the SOC concentrations derived using digital soil mapping techniques. The first and the second method resulted estimates of 56.9 and 51.9 gigatonnes of SOC stock for the uppermost 20 cm of soil, respectively. Considering the uncertainties in both estimation methods (e.g. varying areal share of soils with different SOC concentration within climatic zones (first approach) or reliability of the spatial model (second approach), under sampling of wetlands and peatlands) but also the similarities of the results, the topsoil (upper 20 cm) SOC stocks of the EU in 2009 can be assumed to be between 50 and 60 gigatonnes. Further studies are necessary to establish accurate measures. In such studies, apart from increasing the reliability of spatial SOC concentration estimates of continuous SOC map layers, increased accuracy of soil bulk density information has to play a major role.

Table 8.1. Estimates of soil organic carbon stocks in the topsoil of EU Member States, as derived from the digital topsoil organic carbon map of the EU (De Brogniez and Ballabio 2013)

Member State	**Total SOC stock of the topsoil** (Gigatonnes in top 20 cm)	**Mean SOC concentration*** (g/kg)	**STD of SOC concentration*** (g/kg)
Austria	0.85	44	16
Belgium	0.25	34	14
Czech Republic	0.51	25	8
Denmark	0.56	53	9
Estonia	0.72	65	15
Finland	10.45	131	24
France	3.74	28	11
Germany	2.76	30	9
Greece	0.6	21	7
Hungary	0.55	23	6
Ireland	1.95	130	44
Italy	1.78	26	14
Latvia	0.92	52	15
Lithuania	0.75	42	10
Luxembourg	0.02	33	9
Netherlands	0.24	28	13
Poland	1.65	20	10
Portugal	0.6	26	11
Slovakia	0.33	28	10
Slovenia	0.2	43	11
Spain	2.47	20	13
Sweden	12.59	124	32
United Kingdom	3.86	69	49

**Mean SOC values and standard deviation figures for countries are solely for orientation purposes, they have very limited scientific meaning.*

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8.2 Applicability of LUCAS Soil data to improve predictions of soil water retention in the EU

Melanie Weynants and Gergely Tóth

8.2.1 Introduction

Pedotransfer functions (PTFs) are a useful tool to predict soil hydrological properties where no such data are available. Especially, for large scale studies, they can provide information on the soil hydrological behaviour that can be used as input for hydrological models.

Pan-European PTFs predicting the parameters of Mualem-van Genuchten model (van Genuchten, 1980) were developed in the 1990's in the framework of HYPRES project (Wösten, Lilly, Nemes, & Bas, 1999). According to the available input data, the user has the choice between a class PTF based on the FAO texture classes or a continuous PTF based on the silt, clay, organic matter contents and the bulk density. Both PTFs are widely used and it is worth wondering how they perform on pan-European datasets in terms of expected accuracy and geographical reliability.

8.2.2 Datasets and pedotransfer functions

The Soil Geographical Database of Eurasia (SGDBE) (Lambert, et al., 2003) is part of the ESDB (European Commission Joint Research Centre, 2003). It provides a harmonized set of soil parameters covering Eurasia and Mediterranean countries at scale 1:1,000,000. Information in SGDBE is available at the Soil Typological Unit (STU) level, characterised by attributes specifying the nature and properties of soils. These properties are estimated either by expert judgment or derived from a set of pedotransfer rules (PTR), in the form of categorical data. For mapping purposes, the STUs are grouped into Soil Mapping Units (SMUs) since it is not possible to delineate each STU at the 1:1,000,000 scale.

The Land Use/Land Cover Area Frame statistical Survey (LUCAS), launched in 2001, aims at monitoring the land cover and land use at the European Union level with a harmonized methodology. The survey is conducted every three years at geo-referenced positions on a regular 2 x 2 km grid. During the 2009 survey, a subset of about 21000 points, sampled in 23 member States, included an assessment of the topsoil (0-30 cm). The points were selected to be representative of the European Union soils, stratified according to topography and land use. Physicochemical analyses were conducted in a central laboratory, providing a coherent assessment of soils from 23 member States (EU-27 except Cyprus, Malta, Bulgaria and Romania).

The two datasets (SGDBE and LUCAS-soil) differ in several ways. The first covers a larger area (Europe and Russia) and provides information on typical soil profiles, but this information is in the form of categorical estimations. The second gives measured information for the topsoil at specific points. Both can be used for predicting the soil hydrologic properties using pedotransfer functions (PTF). However the outputs will be different.

HYPRES PTFs (Wösten, Lilly, Nemes, & Bas, 1999) predict the parameters of functions describing the soil water retention and unsaturated hydraulic conductivity curves (the so-called Mualem-van Genuchten). Two types of PTFs are available. A class PTF based on the soil texture classes and a continuous PTF based on the soil silt, clay, organic matter contents and its bulk density. Only the first can be applied on SGDBE because this dataset does not contain continuous values. The second can be applied on LUCAS-soil dataset, but first the particle size distribution has to be transformed and the bulk density needs to be estimated using another pedotransfer function.

8.2.3 Methods

Sandy and silty materials have no unique definition. In LUCAS Topsoil database, the cut-off value of the diameter of particles between the two materials is 63 µm while HYPRES PTFs uses 50 µm. The cumulative particle size distribution was therefore transformed using cubic spline interpolation (Hollis et al, 2006).

Bulk density is an entry parameter of the HYPRES continuous PTF. Since it was not measured in LUCAS Topsoil survey, this factor was estimated based on a multiple regression calibrated and validated on subsets of the HYPRES database.

HYPRES PTFs were applied on both SGDBE and LUCAS-soil and the results were compared at two different pF values (pF = $\log_{10}(-h)$, with h the suction head [cm]).

8.2.4 Results

Figure 8.1 shows differences between water contents at pF 2.5 (-333 cm of water column) obtained by running HYPRES continuous PTF on the LUCAS Topsoil dataset and HYPRES class PTF on dominant STU. The dominant STU is the most represented STU in the SMU overlaying the LUCAS point. Seven classes of differences are shown as well as both their spatial distribution and their density distribution (surfaces are proportional to the number of instances). Small differences (between -0.03 and 0.03 in water content) are the most numerous (24%). They are closely followed by the next classes of differences: about 20% of the points show differences between -0.1 and -0.03 and again about 20% between 0.03 and 0.1. The remaining 36% of the points show differences larger than 0.1 in absolute value. However this comparison encompasses both the differences of texture between the two datasets and the differences due to the use of the class and continuous PTF. In Figure 8.2 and Figure 8.3, the two effects are separated.

Figure 8.2 shows the differences between water contents at pF2.5 estimated with HYPRES class PTF on LUCAS and on the dominant STU. This shows the effect of the differences in texture values between the two datasets. 47% of the points show small differences (between -0.03 and 0.03 of water content), 11% show medium differences (between 0.03 and 0.1 in absolute value), 27% show large differences (between 0.1 and 0.25 in absolute value) and 8% show very large differences (more than 0.25 in absolute value).

The spatial distribution of the differences is very contrasting. Very large differences are mainly observed in Northern Europe (Sweden, Finland, Estonia, Latvia, Lithuania, Ireland, etc). Of course, this comparison is based on the dominant soil typological unit (STU) in each soil mapping unit (SMU) and does not consider the other STUs in the SMU. Nevertheless, using the dominant STU is a common approach used for mapping purposes, when the mapped variable cannot be averaged between STUs. This shows the limitations of the SGDBE and the potential of LUCAS Topsoil database for estimations of the soil hydraulic properties across Europe. However, as the LUCAS Topsoil Survey is a point dataset, it needs to be interpolated to be applicable for continuous mapping purposes.

Figure 8.3 shows the differences between water contents at pF2.5 estimated on LUCAS-soil with the continuous and the class HYPRES PTFs. This illustrates the effect of using a class or a continuous pedotransfer function. 38% of the points show small differences (between -0.03 and 0.03 in water content). For 31% of the points, the continuous PTF results in smaller (difference less than -0.03) water contents than the class one. For 29%, it is the contrary (difference greater than 0.03). Hence, only 40% of the points show very small differences. Nevertheless, no point shows very large difference (greater than 0.25 in absolute value). This illustrates the impact of using a class or a continuous PTF. This does not mean that the continuous is more correct: these data do not allow us to evaluate the validity of one or the other PTF. It shows that using a continuous PTF generates more variability in the hydraulic properties, which might be closer to reality.

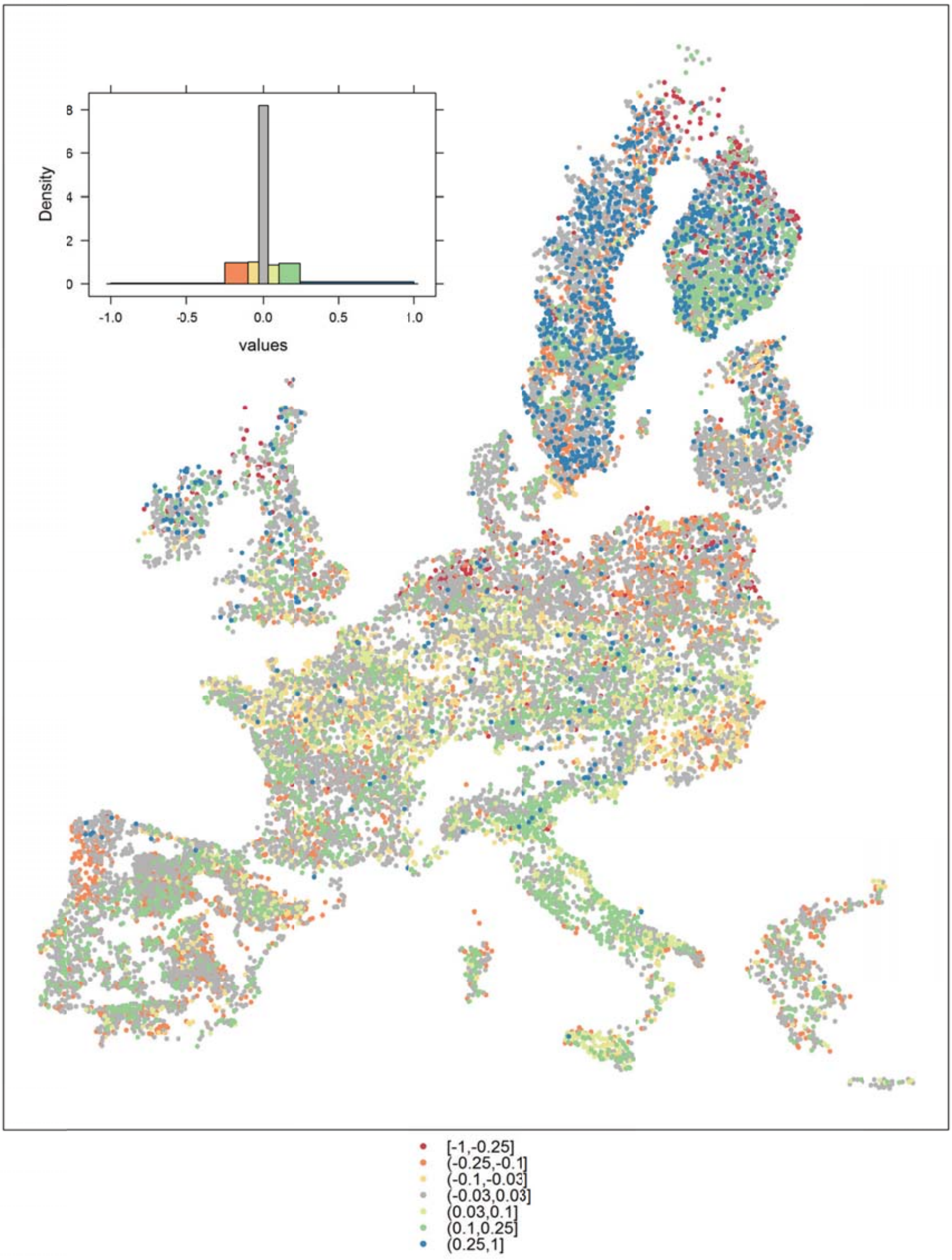

Figure 8.1 Differences between water contents at pF2.5 obtained with LUCAS (cont. PTF) and the dominant STU (class PTF).

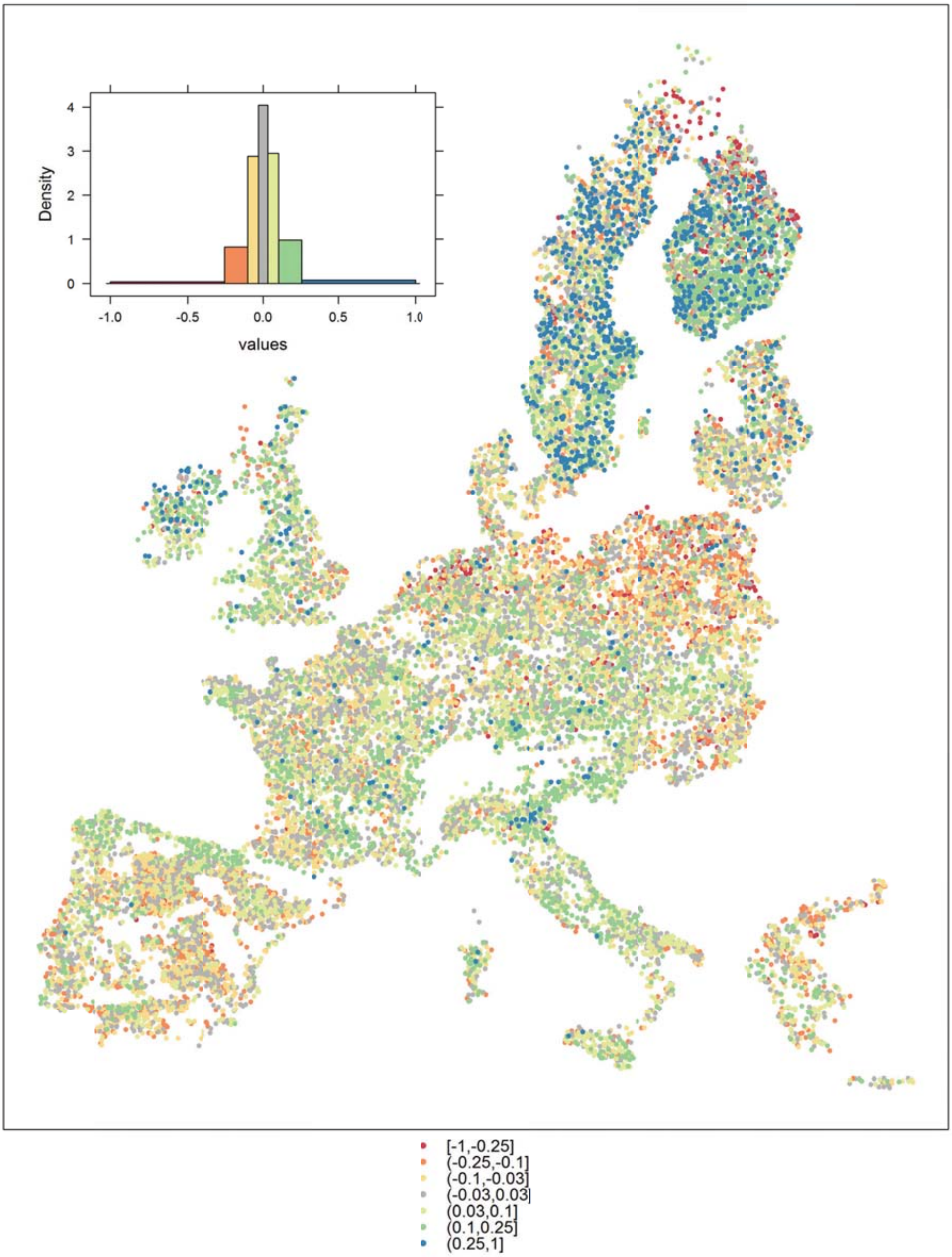

Figure 8.2 Difference between water contents at pF 2.5 obtained with LUCAS (class PTF) and the dominant STU (class PTF).

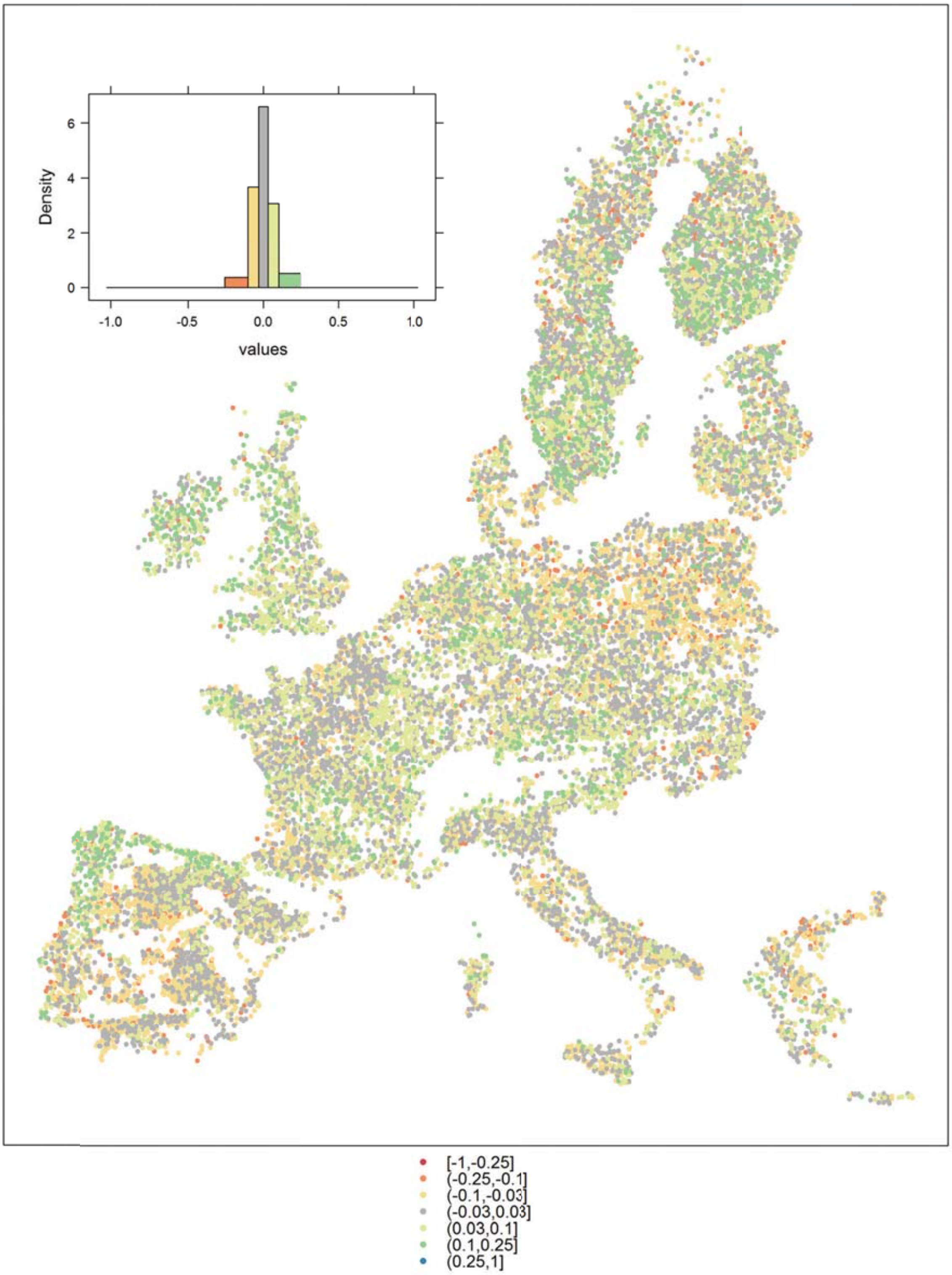

Figure 8.3 Differences between water contents at pF 2.5 obtained with the continuous and the PTF class on LUCAS.

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8.3 Soil erodibility estimation of the EU using LUCAS point survey data

Panos Panagos, Katrin Meusburger, Christine Alewell and Luca Montanarella

8.3.1 Introduction

Soil erosion caused by water is a multivariate phenomenon and can be attributed to a number of basic agents, which may also trigger erosion in combination. One of the most widely used soil erosion models is the USLE which predicts the long term average annual rate of soil erosion on a field slope based on a multiplicative formula of rainfall erosivity, soil erodibility, slope, crop management and support practices. In most studies, the estimation of soil erodibility is restricted by limited data availability and the regionalisation technique elaborated by Van Knijff et al. (2000). This method is based on the five textural classes of the European Soil Database at a scale of 1:1,000,000 (ESDB) (Panagos, 2006). According to Pérez-Rodríguez et al. (2007), current soil maps do not provide sufficient information to assess soil erodibility. Thus, the use of interpolation techniques in combination with spatially distributed field data allows for a better representation of the soil erodibility.

The main objective of this communication is to assess the soil erodibility in terms of K-factor (Wischmeier and Smith, 1978) for the EU using the 2009 LUCAS Topsoil survey.

8.3.2 Method for estimation of K-Factor

The K-factor is a lumped parameter that represents an integrated average annual value of the soil profile reaction to the processes of soil detachment and transport by raindrop impact and surface flow (Renard et al., 1997). Consequently, the K-factor is best obtained from direct measurements on natural plots (Kinnell, 2010). However this is an infeasible task on a national or continental scale. To overcome this problem, measured K-factor values have been related to soil properties. The most widely used relationship is the soil-erodibility nomograph of Wischmeier and Smith (1978) that defines the following equation:

$$K = ((2.1\ 10-4\ M1.14\ (12-OM) + 3.25\ (s-2) + 2.5\ (p-3))/100)*0.137 \qquad [1]$$

where OM is organic matter(%), s is the soil structure class, and p is the permeability class. M is the textural factor: percentage silt + fine sand fraction content multiplied by 100 – clay fraction. K is expressed in SI units of t ha h ha^{-1} MJ^{-1} mm^{-1}.

The erodibility factor was calculated for each LUCAS topsoil point and interpolated to create a map using the inverse distance weighting (IDW) method due to the limited availability of significant covariates on a European scale. The IDW method is based on the assumption that the soil erodibility at an un-sampled point is a distance weighting average of soil erodibility values of the nearby sampling points (in this case 20). The IDW method can yield a prediction for variables with a very high spatial variability (Angulo-Martinez et al., 2009). The quality of the interpolation was tested on an subset of 25% of the data.

8.3.3 Results and Discussion

The K-factor values (t ha h ha^{-1} MJ^{-1} mm^{-1}) obtained by using equation [1] range between 0.013 and 0.087 with a mean value of 0.041 and a standard deviation of 0.013. The IDW interpolation with a power parameter of 2 performed best (R2 adjusted=0.81) to interpolate LUCAS point data to a soil erodibility map of Europe (Figure 8.4). Visually, the spatial pattern of high soil erodibility follows in large parts the distribution of loess in Europe (Haase and Fink, 2007).

Comparison of K-factors between countries (Table 8.2) illustrates that there is a degree of stratification since Mediterranean countries (Italy, Spain, Greece, and Portugal) have mean K-factors between 0.039 and 0.042 (t ha h ha^{-1} MJ^{-1} mm^{-1}). The highest mean values are found in central European countries (Belgium, Slovakia, Luxembourg, Czech Republic, Austria and South Germany) where mean values range between 0.047 and 0.054. Finally, a part of northern Europe (Denmark, Netherlands and North Poland) and the Baltic States (Latvia, Estonia and Lithuania) show the lowest mean values ranging less than 0.039. The coefficient of variation, expressed as a ratio between standard deviation and mean value, illustrates the dispersion of K-factor values inside the country. Ireland, Austria and Slovakia showed low variability while the highest ones are found in Netherlands, Germany and Poland.

The LUCAS dataset enables an unbiased overview of soil erodibility over Europe. However, it should be kept in mind that, depending on the region, K-factors obtained from field measurements may differ considerable from K-factors deduced from the empirical equation [1]. For a global assessment, IDW proved to be suitable. However, in-depth analysis of potential covariates and geo-statistical methods in order to interpolate the 22,000 points will be a future research question.

8.3.4 Data availability

The soil erodibility data are available to download as raster files in the European Soil Data Centre (ESDAC) electronic platform allowing modellers to use the K-factor for their regional, national or European applications.

Public users are able to access the data for free (no cost) by accepting the license agreement which is the proof that the user agrees with the conditions about data use. ESDAC has established a username/password automatic authentication mechanism for users who have registered to download the data. Registration is a simple process through a web form requesting the name of the user, their organisation, E-mail address, country of origin and purpose for which the data will be used.

Most ESDAC data are used for research purposes (modelling, research projects, PhDs, publications, etc.), followed by policy making and implementation of studies/assessments (Panagos et al., 2013).

8.3.5 Conclusions and applications

The proposed dataset has the significant advantage that it is derived from a first ever pan-European soil sampling campaign. The data harmonisation is guaranteed since samples have been collected in a systematic manner during the same period and analysed by a single certified laboratory. The current study offers an enormous improvement in the precise estimation of K-factor on European level comparing with past methodologies which have derived this attribute based only on five textural classes and relatively coarser scale.

The ESDAC, as the single information focal point for soil data in Europe, provides the soil erodibility data to a vast majority of scientists for soil erosion applications. In case of European or national applications, the soil erodibility data can be used as it is. At local or regional scales, where soil data are missing, the K-factor estimation is offered as an input layer for interpolation using other covariates. In case of local assessments where erodibility data are available from local soil databases, the present study can be proposed as supplement for cross validating the local K-factor estimation.

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Table 8.2. Descriptive statistics of K-factor for European Union countries based on the LUCAS point survey (t ha h ha^{-1} $MJ^{-1}mm^{-1}$)

Country	Mean	Max.	Standard Deviation	Coefficient of variation
Austria	0.047	0.070	0.010	0.204
Belgium	0.054	0.078	0.013	0.247
Czech Republic	0.047	0.076	0.012	0.250
Denmark	0.031	0.054	0.008	0.276
Estonia	0.039	0.073	0.013	0.345
Finland	0.040	0.084	0.013	0.329
France	0.045	0.081	0.012	0.280
Germany	0.040	0.077	0.014	0.349
Greece	0.040	0.073	0.010	0.261
Hungary	0.044	0.074	0.014	0.316
Ireland	0.039	0.064	0.007	0.182
Italy	0.042	0.077	0.011	0.267
Latvia	0.039	0.077	0.011	0.279
Lithuania	0.040	0.081	0.011	0.268
Luxembourg	0.048	0.058	0.012	0.254
Netherlands	0.035	0.064	0.013	0.364
Poland	0.034	0.081	0.013	0.389
Portugal	0.039	0.080	0.012	0.302
Slovakia	0.049	0.068	0.011	0.218
Slovenia	0.045	0.067	0.011	0.232
Spain	0.041	0.087	0.011	0.258
Sweden	0.043	0.085	0.013	0.301
United Kingdom	0.040	0.078	0.011	0.270

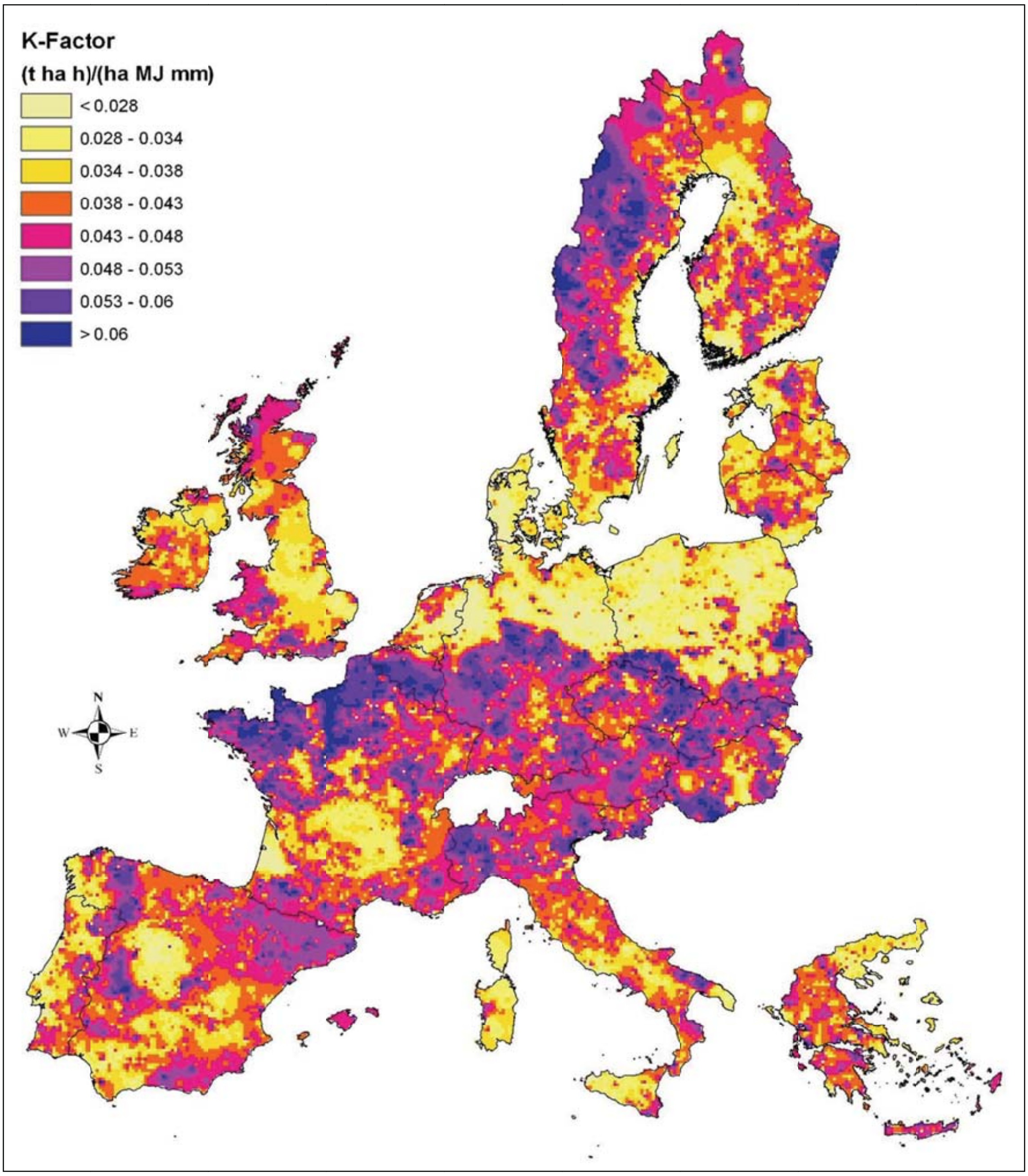

Figure. 8.4 Predicted soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}) across the European Union based on the monograph of Wischmeier and Smith (1978).

9. Prediction of SOC content by Vis-NIR spectroscopy at European scale

Marco Nocita, Antoine Stevens, Gergely Tóth, Bas van Wesemael, Luca Montanarella

9.1 Introduction

Soil organic carbon (SOC), a main component of global carbon cycle, plays also a major role in regulating and maintaining ecosystem functions, including atmospheric exchanges of CO_2. Global soil resources, in their current state have a high potential to sequester atmospheric carbon totalling around 78 Pg of C, or 1 Pg C yr^{-1} (Lal and Follett, 2009). Therefore, there is a clear and increasing demand for the monitoring of carbon levels in soils, particularly on agricultural land, as it is the prime space for SOC to be increased through adequate management practices (Lal et al., 2004). The cost of the traditional soil information system still limits the monitoring of soil properties at large scale, and must be overcome with inexpensive and accurate SOC assessment methods (Conant et al., 2010). Laboratory Visible (Vis, 400-700 nm) and near-infrared (NIR, 700-2500 nm) diffuse reflectance spectroscopy (DRS) has shown to be an efficient and not invasive tool for the rapid and cheap prediction of SOC (Islam et al., 2003). Since the 80's many scientists have used Vis-NIR DRS to accurately predict SOC content. This technique was mostly applied in the laboratory (Dalal and Henry, 1986; McCarty et al., 2002). However, Vis-NIR DRS has been also used in the field with portable spectrometers (Morgan et al., 2008; Stevens et al., 2008) with promising results.

However the level of accuracy of SOC predictions achieved by soil spectroscopy at large scale did not meet the accuracy found at local or field scale studies. The LUCAS topsoil samples were scanned with a Vis-NIR spectrometer in the same laboratory. The scope of our research was to predict SOC content at European scale using the LUCAS spectral library coupled with a modified local PLS (l-PLS) multivariate regression method. The general concept is that most regression surfaces can be fitted locally using linear models (Naes et al., 2001). Basically, a group of predictors similar to the sample to be inferred is chosen from a large spectral library and a specific equation is computed to predict every analyzed sample (Shenk et al., 1997). The advantage of local regressions is based on the accuracy obtainable with specific calibrations covering the spectral complexity of soils, and thus the high non-linear effects of a large database (Gogé et al., 2011). Genot et al. (2011) used the correlation coefficient between spectra as similarity index to select the homogenous group of predicting samples for each unknown sample. The l-PLS was modified to include other potentially useful covariates (geography, texture, etc.) to select the group of predicting neighbours. We believe that the application of l-PLS might favour a more accurate prediction of SOC due to the ability of l-PLS to account for the non-linearity of spectral signal compared to a global approach.

9.2 Methodology

The Vis-NIR reflectance was measured using a FOSS XDS Rapid Content Analyzer (NIRSystems, INC.), operating in the 400-2500 nm wavelength range, with 0.5 nm spectral resolution. Every sample was scanned twice and the mean was considered for subsequent analyses.

Several pre-processing techniques, commonly used in soil spectroscopy, were applied: transformation of absorbance (A) spectra into reflectance ($(1/10^A)$) and continuum removal (Clark and Roush, 1984), standard normal variate (SNV) and multiplicative spectral correction (MSC), Savitzky-Golay smoothing with a window size of 50 and 2nd order polynomial (Savitzky and Golay, 1964), first and second derivatives (Rinnan et al. 2009).

Local partial least square regression (l-PLS) was chosen to develop the SOC prediction models. The dataset was divided in mineral and organic soils (FAO, 1998) due to the extremely diverse spectral response of the two classes. Moreover, mineral soils were split in cropland, grassland, and woodland soils according to land cover classes of LUCAS database in order to improve the SOC prediction of soils with different characteristics. For each subset, a training (70%) and test (30%) group were created to calibrate and validate the SOC prediction models. Training and test data were selected using the Kennard-Stone algorithm (Kennard and Stone, 1969)

The LOCAL algorithm was developed to select samples from a spectral library that are spectrally similar to the unknown sample (Shenk et al., 1997). The predictors are then used to calibrate a specific prediction model for the unknown sample. The stability of a prediction model is function of the soil variability coverage of a spectral library. In the LOCAL algorithm the selection of the predicting neighbours is controlled by the correlation coefficient between the spectra of the predictors and the spectrum of the unknown sample. The algorithm used in this study proposed a modification of the selecting process of the predictors adding sand content or geographical coordinates to spectral similarity as co-variables to calculate the correlation coefficient between the predictors and the unknown sample.

9.3 Results and discussion

The LUCAS dataset and the SOC distribution

The distribution of points per country was not proportional to the total country area (Figure 9.1). For example, Italy was characterized by a sampling density that was much lower than in France.

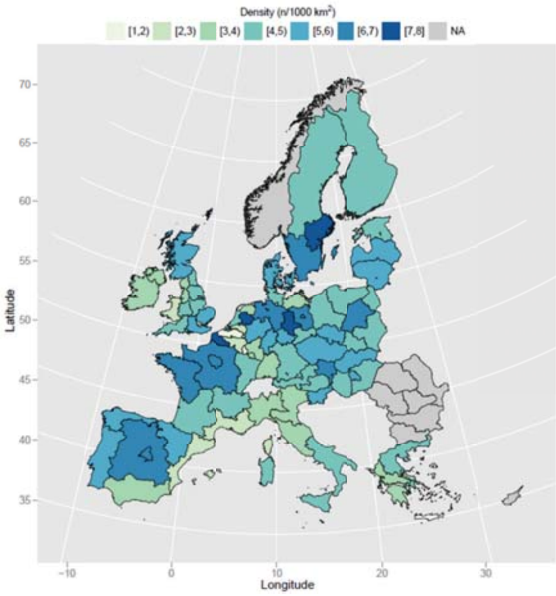

Figure 9.1 LUCAS sampling density by NUTS1

As expected, the SOC content was high in organic soils and much lower in cropland, grassland and woodland soils (Table 9.1). For the three classes of mineral soils, the minimum and maximum SOC contents were similar while the mean SOC resulted in a known trend with higher SOC content in woodland soils than grassland and cropland soils. Grassland soils showed double the mean SOC content of cropland soils. This confirms the ability of grassland to sequester much more carbon than disturbed soils under cropland that are more exposed to soil organic matter (SOM) degradation.

Table 9.1. Statistics of SOC content by subsets

		SOC (g C kg^{-1})					
Subsets	N*	Min	Q25	Median	Mean	Q75	Max
Cropland	8731	0.1	10.3	14.3	17.6	20.5	193.9
Grassland	4096	0.1	16.0	26.6	33.4	41.8	199.2
Woodland	5040	0.1	19.8	34.2	46.4	59.1	198.8
Organic	1104	168	296.4	401.0	385.7	474.4	586.8

*figures based on partial dataset

Table 9.1 shows a significant difference of samples number (N) among the subsets. This represents a weakness of LUCAS dataset confirmed by the skewed-to-the-right distribution of SOC content (Figure 9.2). The majority of the samples have a SOC content lower than 50 g C kg^{-1}. The biggest problem was caused by the organic soils which have a SOC content range between 168 and 586 g C kg^{-1}, but very few samples covering the range. Woodland soils are also characterized by unfavourable ratio of samples to SOC content, while cropland and grassland presented a stricter SOC range and better sample density. The distribution showed in figure 9.2 was an important variable conditioning the SOC content prediction results.

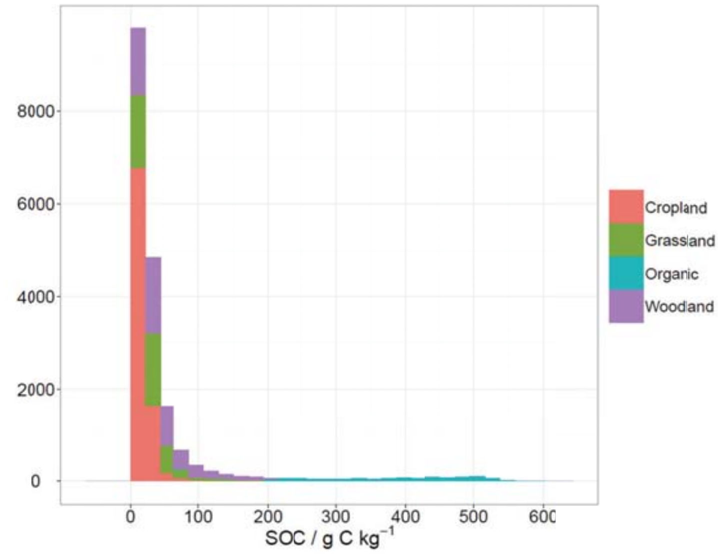

Figure 9.2. Histogram of SOC content of LUCAS dataset

SOC predicted versus observed

The accuracy achieved by the l-PLS to predict SOC of cropland soils were remarkable (Fig. 9.3). The RMSE of 3.9 g C kg^{-1} using only spectral similarity to choose the predictors was not expected and it compared well with several studies inferring SOC using laboratory spectra at local scale (Morgan et al., 2009; Xie et al., 2011). Figure 9.3 shows the decreasing accuracy of SOC predictions for mineral soils with the increased observed SOC content. This was caused by the insufficient number of samples beyond 80 g C kg^{-1} in the training set. The l-PLS was not able to guarantee stable calibrations if the variation of soil types and SOC content was not covered by a proportionate sampling density. The error registered for soils under cropland (3.6-3.9 g C kg^{-1}) was much lower than the RMSE of soil under grassland (7.2-7.9 g C kg^{-1}) and woodland (11.9-13.8 g C kg^{-1}). This was due to the weaker calibrations caused by the lower sampling density and the higher SOC range of grassland and woodland soils, which presented a complexity of the soil matrix more important than the more disturbed and easier to sample cropland soils. These results reflect the accuracy obtained by (i) Shepherd and Walsh (2002) - R^2 of 0.80, (ii) Brown et al. (2006) - RMSE of 7.9 g C kg^{-1}, and Terhoeven-Urselmans et al. (2010) - RMSE of 9.1 g C kg^{-1}, who predicted SOC using global spectral libraries. The accurate predictions were confirmed by the relative RMSE (RMSE / mean observed SOC) of cropland, grassland, and woodland soils (Fig.9.4). The results indicated a relative RMSE of about 0.2 g C kg^{-1} for cropland soils in the range 15-30 g C kg^{-1} and a progressive increase moving towards 105-120 g C kg^{-1}. A decrease from 0-15 to 60-75 and a successive increase towards 120-135 g C kg^{-1} was registered for grassland soils, while an exponential decrease from 0-15 to 105-120 g C kg^{-1} characterised woodland soils. Although the absolute RMSE of grassland and

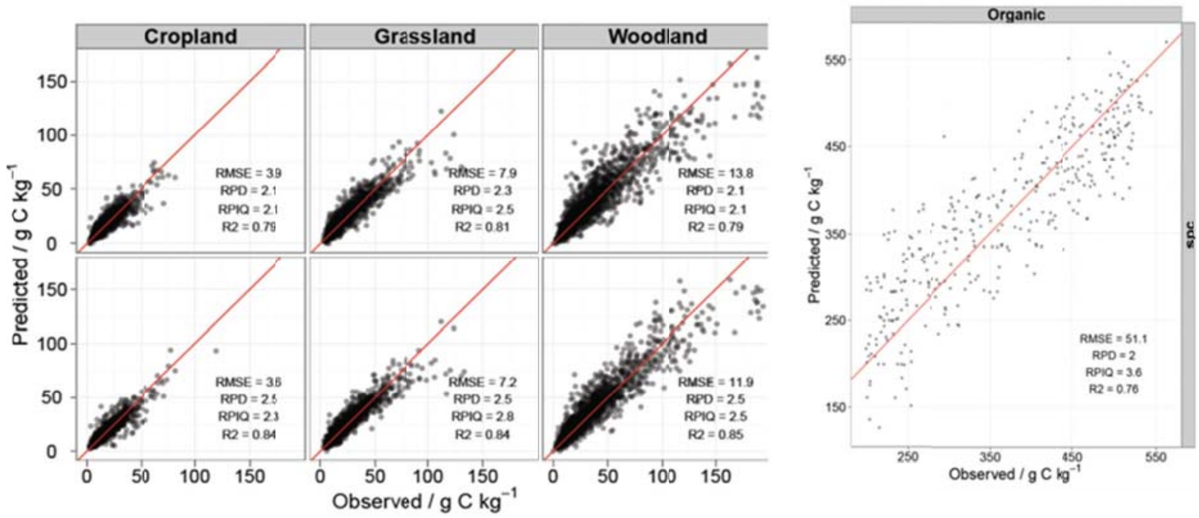

Figure 9.3 Predicted vs. observed values of SOC using spectral distance (spc) or adding sand content (spc+sand) in the LOCAL algorithm for the selection of predicting neighbours. Red line (1:1)

woodland was higher than cropland soils (Fig. 9.3), the relative RMSE showed that, if the error is normalized controlling the variable "sampling density", the accuracy of the prediction models was comparable for all mineral soils.

Organic soils were predicted with a RMSE of more than 50 g C kg^{-1} (Fig.9.3), but the RPIQ of 3.6 was the highest recorded, showing a very good prediction ability of the model. The improvement of the SOC predictions for organic soil should pass by the increase of the sampling density, with the awareness that the level of accuracy will never be the same observed for mineral soils, due to the saturation of SOM absorption features beyond 120 g C kg^{-1}.

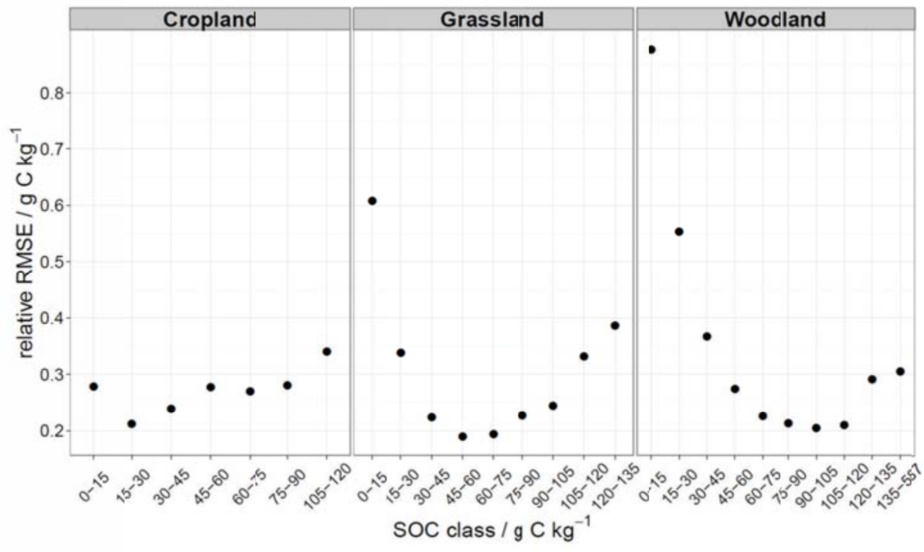

Figure 9.4. Relative RMSE by SOC classes

9.4 Summary and expected impact

The research presented here represents a novel use of Vis-NIR diffuse reflectance spectroscopy scenario due to the statistical approach, culminating in the development of a new l-PLS regression algorithm, and the analysed data, characterized by the largest continental harmonised spectral library.

This research proved that Vis-NIR spectroscopy is a valuable tool to predict SOC at regional or continental scales. The results highlight the need to invest in the creation of harmonised spectral library, based on sampling strategies that are able to cope with soil type variation, and characterised by standardised laboratory protocols. The transformation of Vis-NIR DRS from a pure research discipline into a reference operational method could promote the development of stable and representative calibrations as support of airborne and satellite-borne hyperspectral remote sensing research for SOC monitoring.

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10. LUCAS soil data in the ESDAC Web-Tool for Soil Point Data

Marc van Liedekerke

The European Soil Data Centre (ESDAC) of the European Commission manages soil related data at European level. Its flagship product is the European Soil Database, developed jointly with partners in participating countries and is the only harmonised coverage of digital soil information for Europe. This database, along with many other European soil related data, can be downloaded from the ESDAC (http://eusoils.jrc.ec.europa.eu/data.html).

Many key datasets can also be visually inspected through an online application. The **ESDAC Map Viewer** uses standard web map serving technology that offers the user a view of, and navigating functionalities through, European datasets. Over the last few years, the ESDAC has acquired a number of point-based soil datasets that technically could not easily be integrated in the ESDAC Map Viewer since the standard technology did not offer the possibility to easily customise special functionality required when visualising such point data. Therefore, a dedicated spatial data application was designed and implemented with the objective of giving access to the point soil data in ESDAC through one single web-based tool. Currently, this tool incorporates the LUCAS and BioSoil point data sets and a web mapping interface to these two data sets for viewing and querying;

The viewer is currently visible only within the European Commission intranet and has been tested on major Internet browsers. Eventual access to the general public will be provided through an accepted licence agreement.

Figure 10.1 illustrates the ESDAC Map Viewer, featuring on the right side the navigation buttons and the selection of Layers. For this figure, the user has zoomed in on the region around Belgium and included the ancillary layer of ‘Rivers’ and the layer expressing the soil type according to the WRB scheme. As can be seen, the user can select from a wide range of layer types: soil threats (e.g. erosion, compaction), texture, parent material, etc.

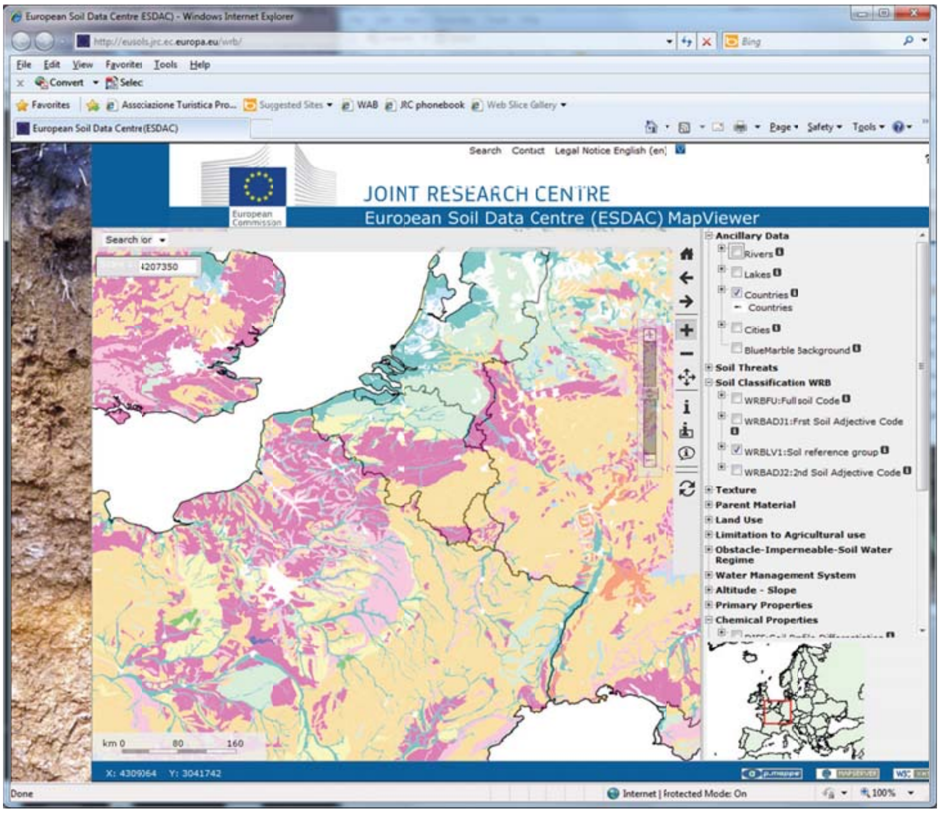


Figure 10.1 The ESDAC Map Viewer.

Figure 10.2 shows the entry page of the ESDAC webtool for soil point data. The navigation and query functionality are not standard and have been custom designed.

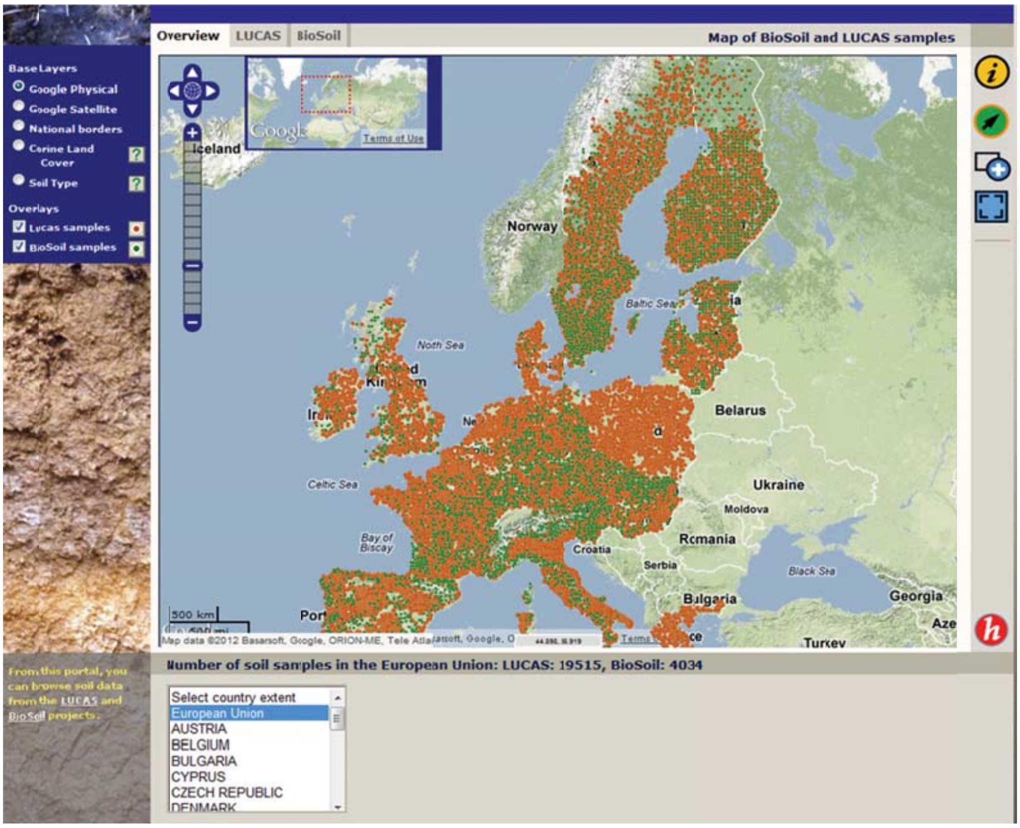


Figure 10.2 Entry page of the ESDAC webtool for soil point data.

On **top** of the page, there are a number of tabs: one tab provides an overview of all locations for which there are point data for all included datasets (here LUCAS and BioSoil) and one tab per included dataset to access further detail.

To the **left**, there is a Map Layer Selector for five base layers, one of which can be shown as backdrop to the point data, and for selecting or deselecting the point location layers associated to the datasets included.

To the **right** are buttons to select a Map Tool. The selected tool is indicated by an orange ring. These tools allow spatial navigation (panning and zooming) and for obtaining further information through the "I" button. When zooming, a context map in the left corner shows the location that the user has navigated to. Zooming in combination with Google map and satellite layers is useful to observe the geographical context of point samples. When the "I' button has been selected and the user clicks on the map, the data for the point that is closest to the click of each dataset is shown (see Figure 10.3).

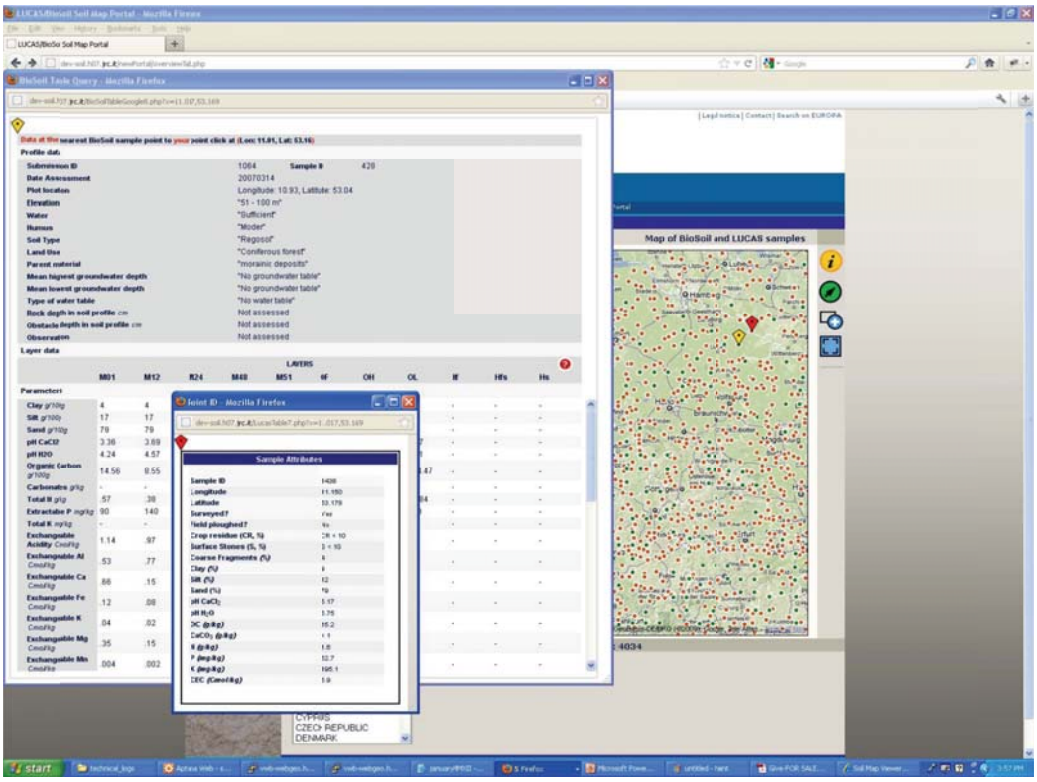


Figure 10.3 Pop-up information for the points that are the closest to a mouse-click location, for each dataset.

To the **bottom** of the web-tool page, a country selector allows the user to concentrate on one country: the map zooms to the country, which is outlined by a thick blue border.

LUCAS data

Selecting the LUCAS Tab allows a user to concentrate only on the LUCAS data. Additional functionality to the interface is added and all the points from other datasets are removed (see figure 10.4). At the bottom of the window, a selector menu of properties associated to the LUCAS point data is added, and if a country had been or is selected, additional buttons appear to the right.

By selecting the LUCAS country attribute table button to the right (see Figure 10.5), a table with LUCAS data for all the LUCAS points in the selected country are shown. This table is interactive: the rows (points) can be sorted for each data field; selecting a row (point) highlights the corresponding point on the map; multiple rows can be selected; by selecting an already selected row, the point is removed from the map; by closing the attribute data window, all selected points are removed from the map. By selecting the KML button to the right, the user can save the LUCAS points for an individual country as a KML file for further use with applications such as GoogleEarth.

By selecting a **property** from the properties selector (no matter the map extent) a map is created which shows the property values for the LUCAS points present in the extent, with appropriate legend. Figure 10.6 illustrates the selection of ‘clay’ for the area of, and around, Belgium.

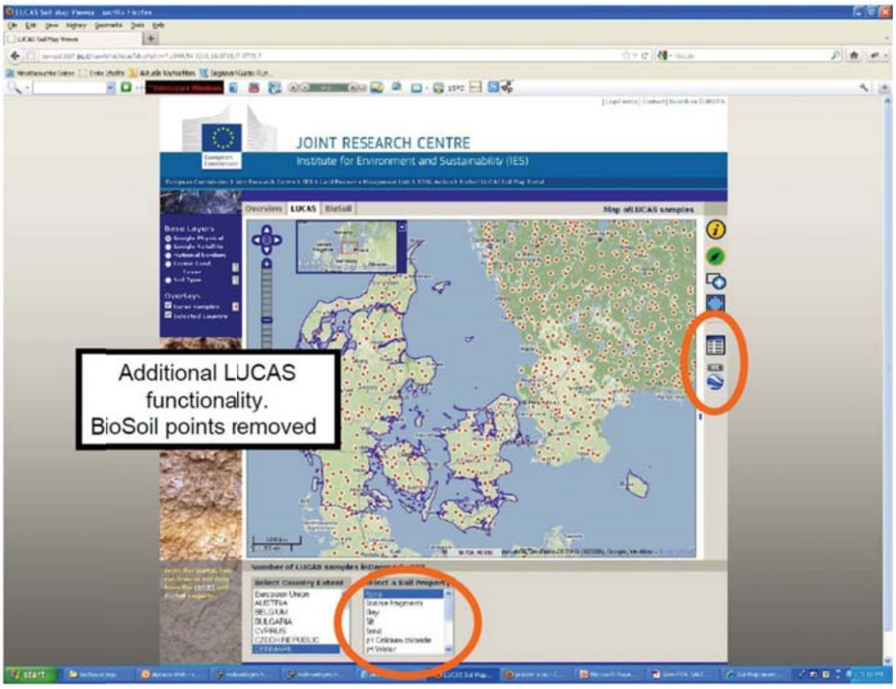


Figure 10.4 Selecting the LUCAS tab and a country (Denmark).

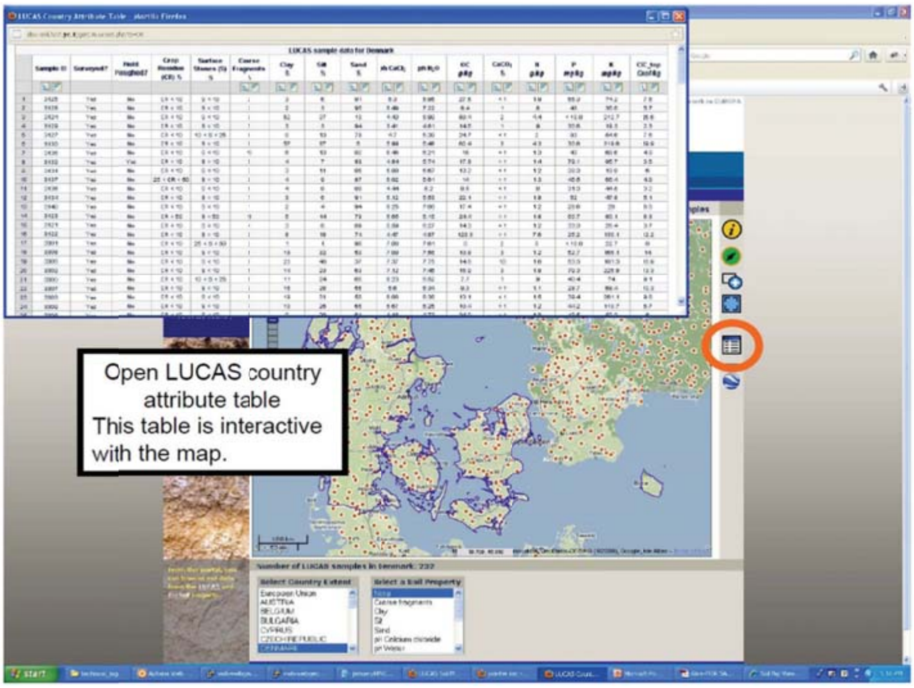


Figure 10.5 Selecting the LUCAS country attribute table button (for Denmark).

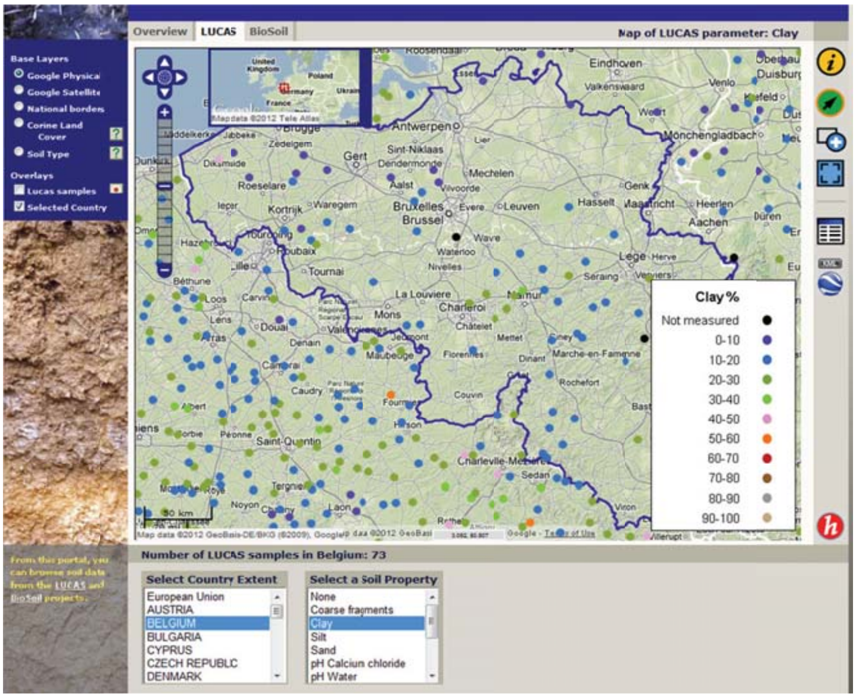


Figure 10.6 Selection of a LUCAS soil property and corresponding map.

When the 'I' information button is selected and a LUCAS point on the map is clicked, the tool returns the LUCAS data for the point along with thumbnails of photographs that were taken at that location. By clicking the thumbnail a photo of large dimension appears (see figure 10.7), allowing better contextualisation of the data.

BioSoil data

The ESDAC web-tool can incorporate other point data that are of a different nature compared to the LUCAS data but it requires an adaptation of the interface under the tab associated to the other data. To illustrate this feature, a brief presentation of the extended functionality required for the BioSoil data is given. For each BioSoil data point there are data pertaining to the point (as a whole) and data for the various layers analysed for the point. To show the data for a point in a table in numerical or textual format, requires only the proper layout and formatting. To show a map of point values, a similar approach as described for LUCAS data can be taken. However, to show a map pertaining to the values of a layer for a set of points, additional selection functionality has been added.

Figure 10.8 shows a 'point property selector' to the right of the country selector (just as for LUCAS) and additional two selector windows at the right bottom, to select a layer and a property of the layer that needs to be shown on a map. The point attribute selector is mutually exclusive with the other two selectors, as both data cannot be shown on one map. Figures 10.9 and 10.10 illustrate these concepts respectively.

As for the LUCAS example, the 'attribute table' button to the right appears when a country is selected: an attribute table pops up with point data for all the LUCAS points in the country selected. Again, the table is interactive meaning that, when clicking on a row, not only the corresponding point on the map is highlighted, but also a new table pops up that shows all data for the layers connected to the associated point. A last interesting feature, included when a country is selected, is the Parameter Matrix Table button: this shows the number of points for which parameters have been sampled per layer and can guide the user in the intelligent selection of combinations for attributes and layers (see Figure 10.11).

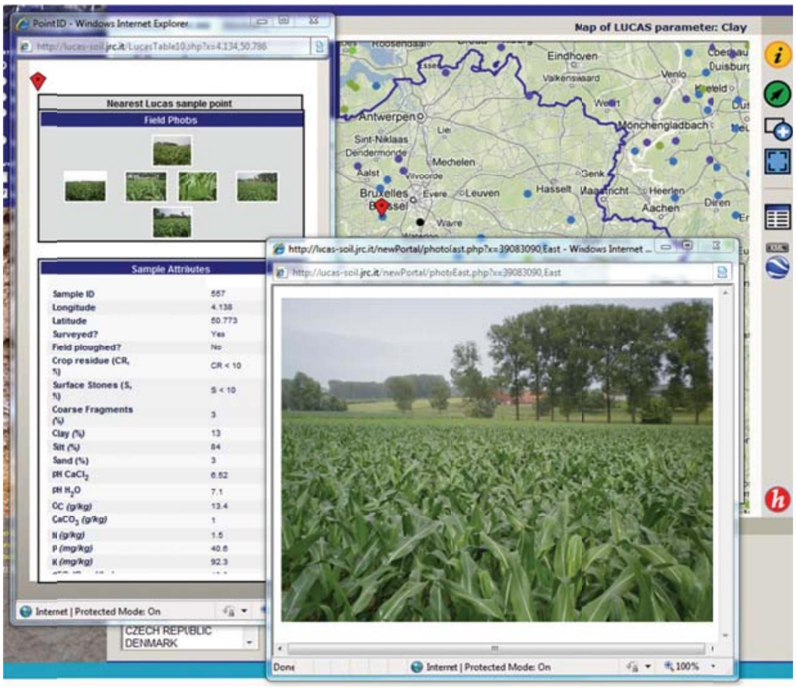


Figure 10.7 Data and photographs for a selected point.

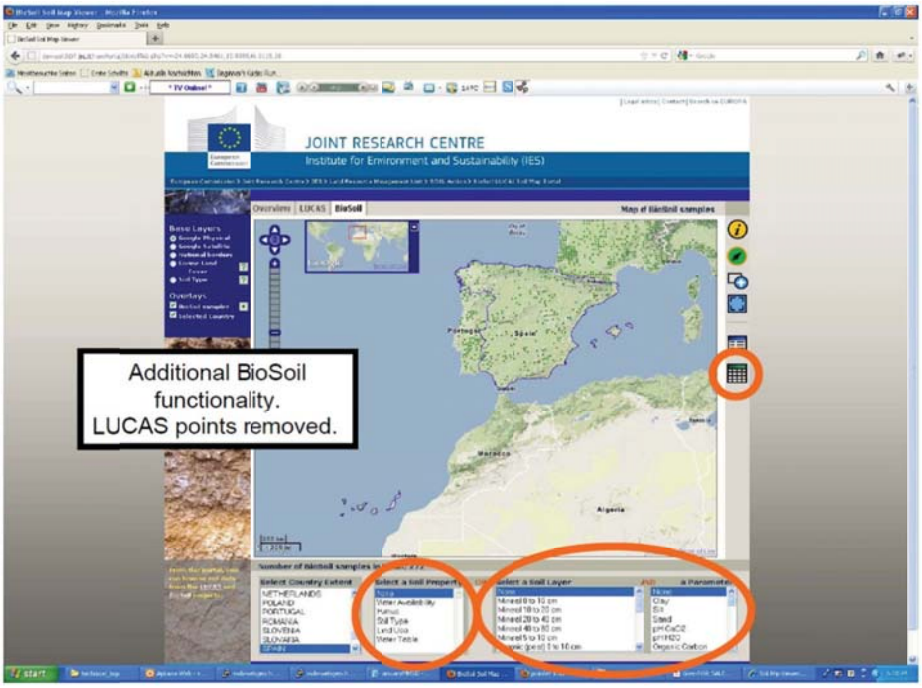


Figure 10.8 The BioSoil viewer tab.

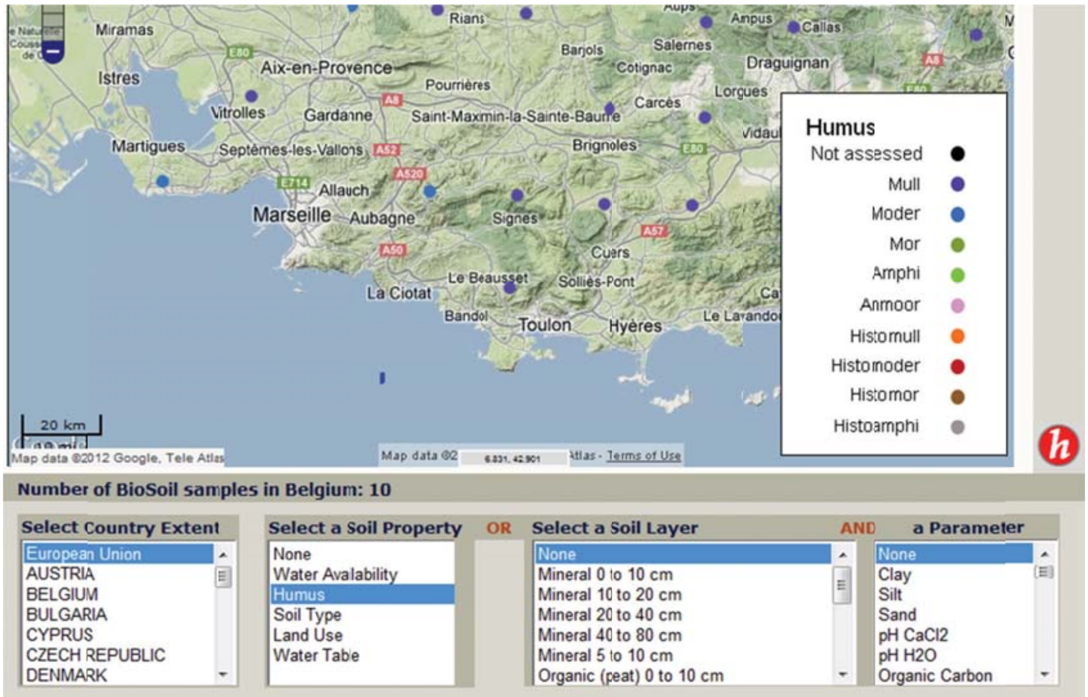


Figure 10.9 The BioSoil viewer tab: map for humus type at a point.

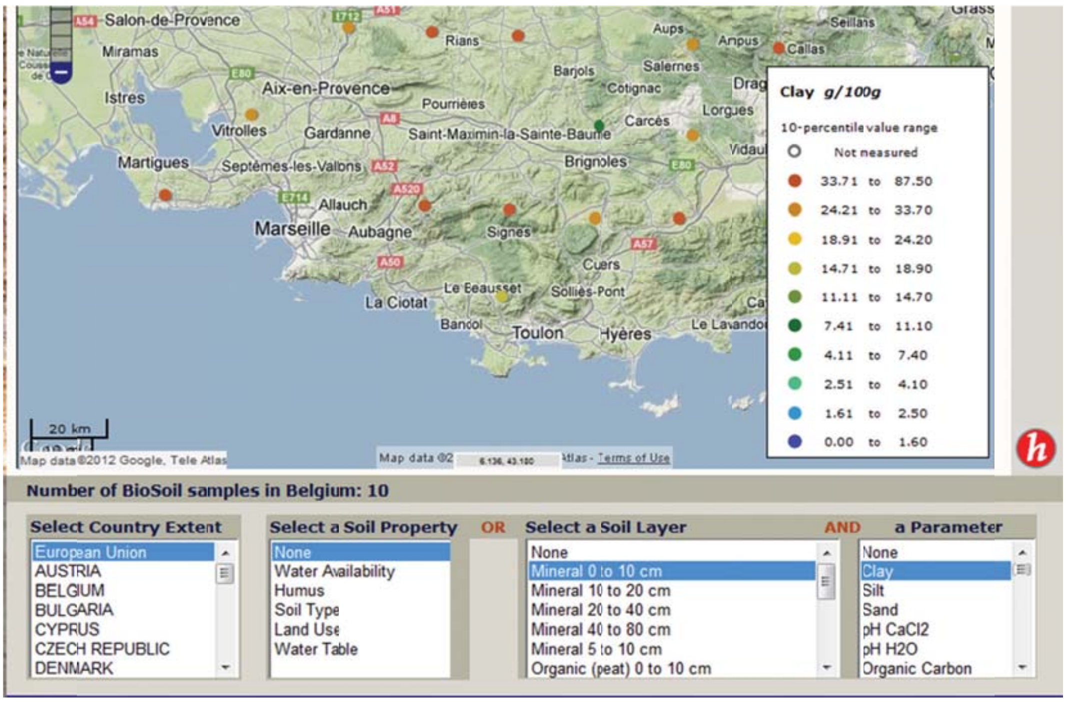
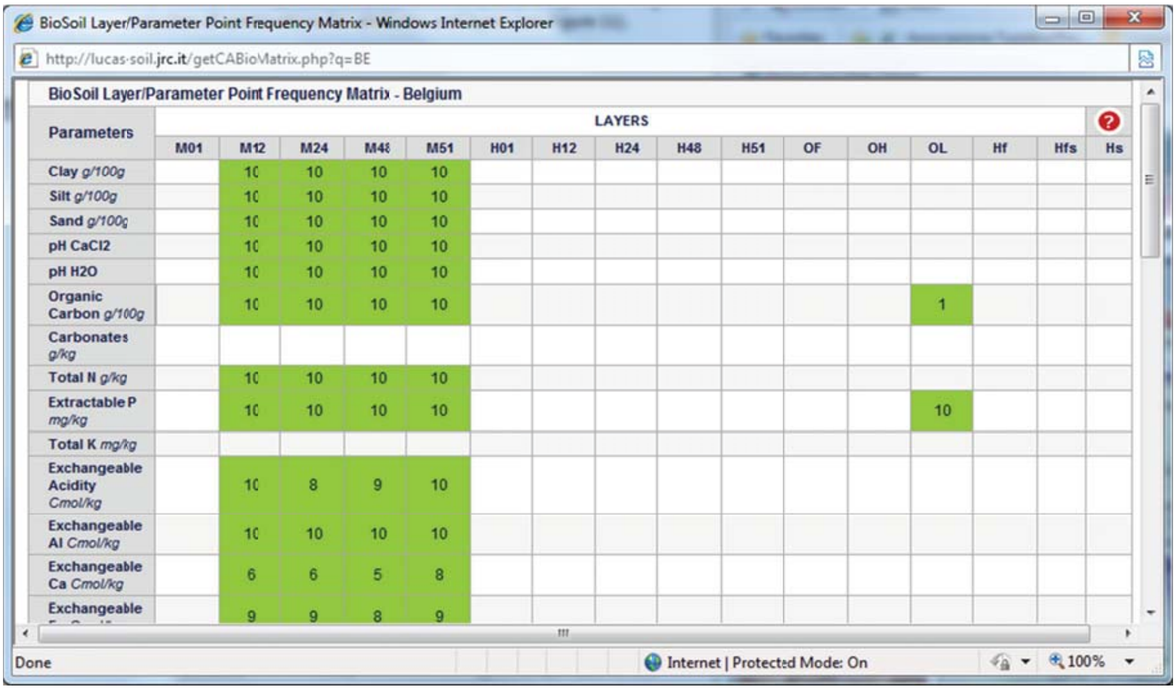


Figure 10.10 The BioSoil viewer tab: map for clay at the mineral layer from 0 to 10 cm.



Parameters	LAYERS														
	M01	M12	M24	M48	M51	H01	H12	H24	H48	H51	OF	OH	OL	Hf	Hfs	Hs
Clay g/100g		10	10	10	10											
Silt g/100g		10	10	10	10											
Sand g/100g		10	10	10	10											
pH CaCl2		10	10	10	10											
pH H2O		10	10	10	10											
Organic Carbon g/100g		10	10	10	10								1			
Carbonates g/kg																
Total N g/kg		10	10	10	10											
Extractable P mg/kg		10	10	10	10								10			
Total K mg/kg																
Exchangeable Acidity Cmol/kg		10	8	9	10											
Exchangeable Al Cmol/kg		10	10	10	10											
Exchangeable Ca Cmol/kg		6	6	5	8											
Exchangeable		9	9	8	9											

Figure 10.11 The BioSoil Parameter Matrix Table for Belgium.

ESDAC web-tool architecture

The application is hosted on a Linux Apache HTTP Server and its general architecture is illustrated in Figure 11.12. Some information of its components is given here. All LUCAS and BioSoil point data were transformed and imported from their native format into an Oracle Spatial Database.

OpenLayers is used to give better map interaction than would be available using MapServer alone. This is particularly so for zooming and panning. In addition, OpenLayers communicates with MapServer directly and serves layers as web mapping services (WMS). As it is written in JavaScript, elements are accessible via the Document Object Model via their IDs, which allow customisation of the web interface.

AJAX (Asynchronous JavaScript and XML) is an extension of JavaScript that allows in-page communication between a client web page and the web server. PHP is a server-side programming language that allows database connection/query and dynamic web page creation/update. The two combine to allow in-page update with information held on the server, which previously was achievable only by opening a new browser window. There are two databases in use. The main one holds all of the LUCAS and BioSoil data, as well as views linking the geometry and attribute tables, and derived tables holding statistics computed from the parameters. These pre-computed tables are used so that the user does not have to wait for on-the-fly queries to run. Another database holds the 153,000 field photos as Binary Large Objects (JPEGs), which are called by the LUCAS tab's point query interface. All of the photos are held both in full resolution, and as thumbnails.

The map portal works by rendering maps layers that are defined in MapServer mapfiles. In these mapfiles, each layer contains a DATA line, which either queries a vector table on the Oracle Spatial database, or a raster image on the server file system.

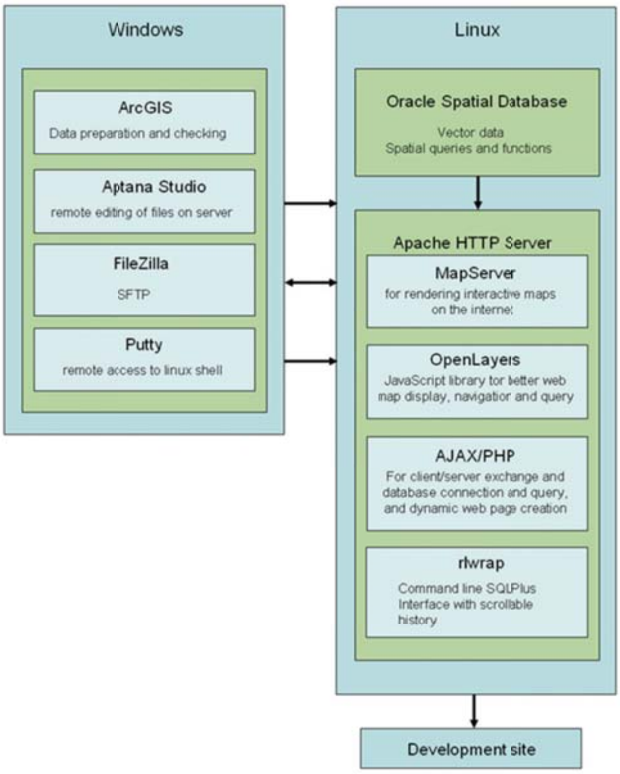


Figure 10.12 General ESDAC web-tool architecture.

The main PHP/HTML page receives the map extent coordinates and an array index referring to the country selected. These are passed as URL parameters between the tabs, thereby maintaining the current extent when tabs are changed. It links to the OpenLayers libraries, the Google API, and stylesheets. It also establishes the overall interface format. On loading the main page into the browser, the init() function is called from the OpenLayers JavaScript file. The OpenLayers JavaScript file renders all of the map layers, which are defined in MapServer mapfiles. It also provides the various mapping, pan and zoom tools seen on the interface. It also passes point click coordinates, which are passed to various functions in the JavaScript function file.

The JavaScript function files contain numerous functions that communicate with the database server, and use parameters passed to open popup windows containing attribute tables and to map the LUCAS and BioSoil properties and parameter values. The DOM is used to dynamically add, remove and customize the interface. For each tab (Overview, LUCAS, BioSoil), a number of JavaScript function files are defined, specific for each tab.

The layers that are defined in the MapServer Mapfiles determine which data are mapped and what legend colours/symbols are to be applied to the data features (mostly LUCAS and BioSoil point data in this case). They also define if/how symbols are rendered at different scales.

Outlook

The web-tool is still under development and work is in progress to add other ESDAC soil point data.

11. Overall conclusions and implications for future LUCAS Topsoil Surveys

With almost 20,000 samples, the 2009 LUCAS Topsoil Survey is the first attempt to build a consistent spatial database of the soil cover across twenty-five Member States of the European Union (Bulgaria and Romania were surveyed in 2012) based on standard sampling and analytical procedures. These data are further complemented by supporting information on land use practices and land cover, and the changes in these conditions.

Preliminary analysis of these data (presented in this report) show that there are significant variations in soil properties between different land cover types and different climatic zones. The LUCAS database provides an excellent baseline to assess changes in topsoil characteristics across the EU. Digital soil mapping techniques have been used to generate preliminary maps of soil characteristics across the EU. However, further investigation is needed to assess their validity. Limitations in the sampling design and possible limitations in the modelling process may mean that procedures to develop continuous mapping of soil parameters may not capture all spatial variation. Consequently, certain areas may be subject to high uncertainty.

It should be stressed that there is a bias in the sampling design towards arable land. Around 43% of all samples were collected from croplands. The corresponding area of croplands for the EU-24 is approximately 34%.

Some soil types (e.g. saline, shallow, urban, peat soils in the Mediterranean region) and some land cover types (e.g. areas under nature protection, wetlands, highlands, urban soils and natural grasslands) are likely to be under represented. Sampling density in these regions should to be increased.

With an additional 25% survey points figures on most land uses can achieve the same reliability for European scale assessment as for croplands.

The characteristics of the topsoil (i.e. the uppermost 20 cm) may also be very different to those deeper in the soil body. On a limited number of the surveyed locations - which are representative from a pedological viewpoint - full soil profile descriptions would be essential to allow the assessment of the dynamics of soil resources in Europe.

With some additional simple field and laboratory measurements (e.g. soil resistance against penetrometer, electric conductivity for salt content determination), the scale of soil quality descriptions can be considerably enlarged with little additional resource.

European Commission

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Abstract

In 2009, the European Commission extended the periodic Land Use/Land Cover Area Frame Survey (LUCAS) to sample and analyse the main properties of topsoil in 23 Member States of the European Union (EU). This topsoil survey represents the first attempt to build a consistent spatial database of the soil cover across The EU based on standard sampling and analytical procedures, with the analysis of all soil samples being carried out in a single laboratory. Approximately 20,000 points were selected out of the main LUCAS grid for the collection of soil samples. A standardised sampling procedure was used to collect around 0.5 kg of topsoil (0-20 cm). The samples were dispatched to a central laboratory for physical and chemical analyses. Subsequently, Malta and Cyprus provided soil samples even though the main LUCAS survey was not carried on their territories. Cyprus has adapted the sampling methodology of LUCAS-Topsoil for (the southern part of the island) while Malta adjusted its national sampling grid to correspond to the LUCAS standards. Bulgaria and Romania have been sampled in 2012. However, the analysis is ongoing and the results are not included in this report.The final database contains 19,967 geo-referenced samples.

This report provides a detailed insight to the design and methodology of the data collection and laboratory analysis. All samples have been analysed for the percentage of coarse fragments, particle size distribution (% clay, silt and sand content), pH (in $CaCl_2$ and H_2O), organic carbon (g/kg), carbonate content (g/kg), phosphorous content (mg/kg), total nitrogen content (g/kg), extractable potassium content (mg/kg), cation exchange capacity (cmol(+)/kg) and multispectral properties. Subsequently, heavy metal content is being analysed but the result are not yet available and thus not included in this report.

Based on the results of the survey, the regional variability of topsoil properties within the EU has been assessed and a comparative soil assessment of European regions and countries is presented. A series of predictive maps have been prepared using digital soil mapping methodologies that show the variation of individual parameters across the EU. In addition, the data have been used in studies to determine the SOC stock of the uppermost 20 cm of soil in the EU. While the LUCAS approach is designed for monitoring land use/land cover change, potential bias in the sampling design may not necessarily capture all soil characteristics in a country. Finally, a customised application has been developed for web browsers that allow users to view and query the LUCAS dataset in a variety of ways.

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