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LUCAS Topsoil Survey for the Western Balkans

Presentation of the dataset and results

Arias-Navarro, C., Vidojević, D., Zdruli, P., Islamaj, B., Scarpa, S., Yunta, F., Wojda, P., Jones, A.

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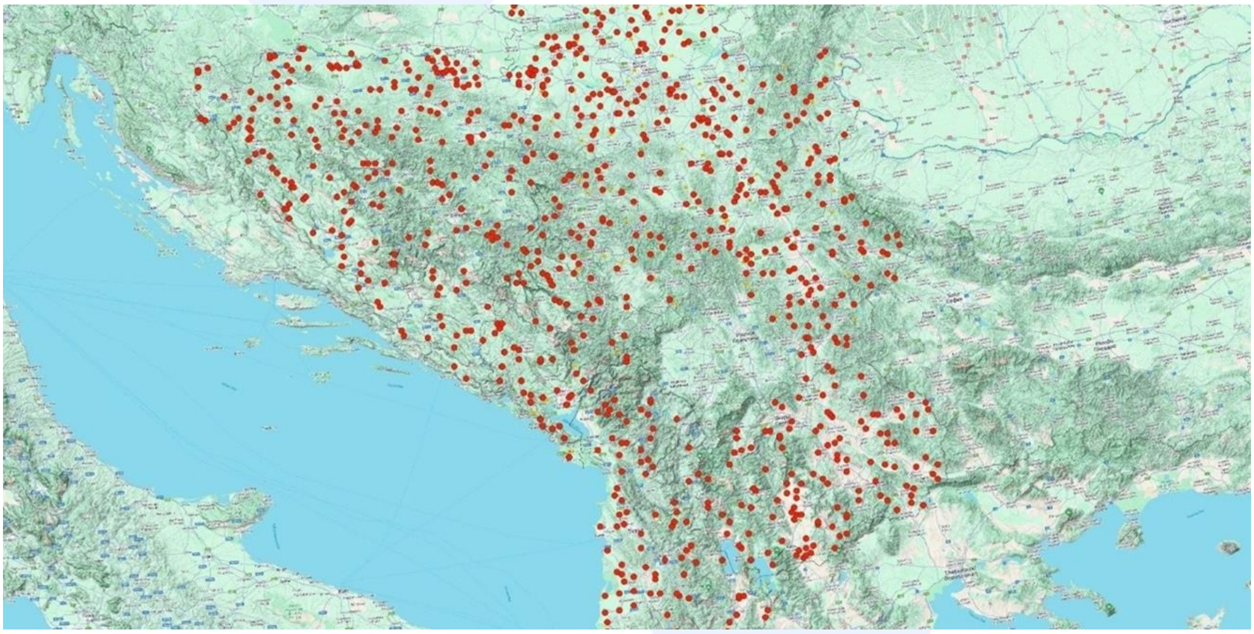

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Contents

Abstract

The European Union's focus on soil health is evident through initiatives like the Soil Mission "Soil Deal for Europe" under Horizon Europe, which aims to improve soil quality by creating 100 Living Labs and Lighthouses by 2030. The Soil Monitoring and Resilience Law further accentuates this goal, striving to reduce the prevalence of unhealthy soils, currently estimated at 60-70%. The Western Balkans face similar challenges but lack the comprehensive soil health data needed for effective interventions.

In 2015, the European Commission's Joint Research Centre (JRC), through the Enlargement and Integration Programme, extended the LUCAS Soil Module to the Western Balkans. This survey marked the first systematic soil sampling in countries like Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, and Serbia, collecting 1,015 soil samples. The dataset generated from this survey is crucial for understanding soil health and variability across the region.

The LUCAS Soil Module stands out as the only harmonized and regular soil data collection effort across the EU, essential for aligning Western Balkan countries with European standards, particularly under the EU enlargement policy led by the Von der Leyen Commission. It highlights the diverse soil types in the region, such as Serbia's fertile Chernozems and Albania's saline and sodic soils, offering insights into the spatial variability of soil properties relative to land cover types. Detailed laboratory analyses further reveal significant differences in soil attributes across climatic regions and land use types, providing a comprehensive understanding of the pressures facing these soils.

This report provides a detailed overview of the LUCAS database, emphasizing its importance to stakeholders interested in soil conservation, policy formulation, and agricultural productivity. Integrating soil health data from the Western Balkans into broader European initiatives offers an unparalleled opportunity to improve soil management in the region. This study marks an important step towards achieving healthier soils across the Western Balkans, contributing to the EU's overarching goal of improving soil health by 2050. Future research will build on this dataset to further explore soil-related challenges and inform policy measures that prioritize soil sustainability and resilience amid increasing environmental pressures.

Acknowledgements

This research was funded by the European Commission's Joint Research Centre (JRC) under the Enlargement and Integration Programme, which extended the LUCAS Soil Module to the Western Balkans. The work is part of the JRC portfolio for the Global Gateway and neighbourhood policy, specifically the SCENARIO project (Science for Enlargement, Arctic and International policy Options). The project monitors the alignment and implementation of the EU acquis in environmental sectors (air, soil, water, ecosystems) and climate and provides scientific input for the design and evaluation of pre-enlargement policies, with a focus on the green transition. It contributes to the EU's strategic agenda for the Western Balkans and to the broader objectives of the International Green Deal. The project is linked to the Western Balkans Innovation Agenda on Research, Education, Culture, Youth and Sport, a joint initiative involving the JRC, the Directorate-General for Research and Innovation and the Directorate-General for Education and Culture. Additional support was received from the EU Soil Observatory, also administered by the JRC.

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Our sincere gratitude to everyone involved in the execution of Europe's Land Use/Cover Area Frame Survey (LUCAS). This survey is coordinated by Unit E4 of the Statistical Office of the European Union (EUROSTAT). The LUCAS Soil sample collection and laboratory analyses receive support from the Directorate-General for Environment (DG-ENV), Directorate-General for Agriculture and Rural Development (DG-AGRI), and Directorate-General for Climate Action (DG-CLIMA).

Finally, huge thanks to colleagues of the JRC Soil Team for their invaluable hands-on support during the survey preparation and in the analysis of the laboratory data. Specific mention should be made of the JRC Ispra Logistics Unit for their invaluable support in dealing with internal movement and storage of material and samples. Our thanks also go to the colleagues of the Western Balkans Soil Partnership for sharing their soil map shape files with the Regional Rural Development Standing Working Group in Southeast Europe (SWG). Special appreciation is given to Dr. Dusko Mukaetov, a university professor at the Institute of Agriculture - University "Ss. Cyril and Methodius" in Skopje, North Macedonia, for his invaluable support.

The JRC recognises the delay in the publication of these data and report. This was due to a range of administrative and technical issues beyond our control.

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1. Introduction

The health of soils has increasingly become a priority within the European Union (EU), underscored by the establishment of the Soil Mission "Soil Deal for Europe" under the Horizon Europe research program (Arias-Navarro *et al.*, 2023; Panagos *et al.*, 2024). This initiative aims to foster soil health by setting up 100 Living Labs and Lighthouses to guide the transition towards robust soil health by 2030. Additionally, the Soil Monitoring and Resilience Law (EC, 2023) seeks to implement specific targets for achieving soil health, which is crucial given the European Commission's estimation that 60-70% of EU soils are currently unhealthy (Arias-Navarro *et al.*, 2024a; Panagos *et al.*, 2024).

The Western Balkans face similar challenges but lack comprehensive, region-wide data on soil health (Arias-Navarro *et al.*, 2024b, 2025, 2026). Soil degradation is widespread, with varying degrees of soil health indicators across different countries. This situation is increasingly concerning given significant issues like declining soil organic carbon, severe soil pollution, urban expansion, and soil erosion. Such challenges underscore the vital need for precise and structured soil monitoring in aligning with EU standards and guiding sustainable land management practices (Vidojevic *et al.*, 2022; Zdruli *et al.*, 2022; Arias-Navarro *et al.*, 2024a; Belis *et al.*, 2024).

The LUCAS Programme is an area frame statistical survey organised and managed by Eurostat (the Statistical Office of the EU) to monitor changes in land use and land cover, over time across the EU. Since 2006, Eurostat has carried out LUCAS surveys every three years. The surveys are based on the visual assessment of environmental and structural elements of the landscape in georeferenced control points. The points belong to the intersections of a 2 x 2 km regular grid covering the territory of the EU. This results in around 1,000,000 georeferenced points. In every survey, a subsample of these points is selected for the collection of field-based information. In LUCAS 2009, about 235,000 points were visited across 25 Member States (Bulgaria, Cyprus, Malta and Romania were not included). Ten percent of these points were selected for the soil survey. At the end of the survey, soil samples were taken in about 20,000 points. In LUCAS 2012, the soil survey was conducted in Romania and Bulgaria, where circa 2,000 points were sampled. The details and outcomes of the 2009 and 2012 surveys are fully documented in Tóth et al. (2013). In 2015, the LUCAS survey was carried out in all EU-27 Member States (MS) plus UK. The 2015 survey was also extended through funding provided by the JRC's Enlargement and Integration Programme to Albania, Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, and Serbia (LUCAS WB 2015) following standard LUCAS protocols.

In total, 1015 locations were selected for sampling in the Wester Balkans. Soil samples were collected from a depth of 20 cm following a common sampling procedure. All samples were analysed for physical and chemical properties in a single laboratory using the same ISO analytical methods.

The main objectives of this report are to:

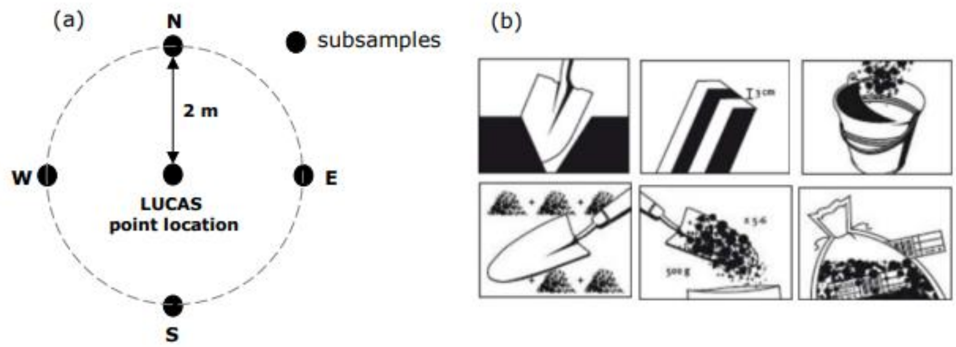
1. Present the dataset from the LUCAS WB 2015 Topsoil Survey.
2. Provide a detailed analysis of the survey results for the region.

Applying these objectives, the report seeks to establish a foundational database that supports further possible regular soil monitoring, facilitates cross-border comparisons, and aligns with broader EU environmental and agricultural policies. The analysis by Statistical Regions (SR) level 2, corresponding to the EU's NUTS 2 classification, offers a structured approach for future policy development, ensuring standardized regional comparisons and guiding targeted interventions to improve soil health in the Western Balkans.

2. LUCAS sampling methodology and laboratory analysis

In 2015, the sampling followed the standardised approach used in the EU surveys of 2009 and 2012. This method involved collecting a composite soil sample of roughly 500 grams, derived from five subsamples gathered at each LUCAS location using a spade. The initial subsample was taken at the precise geo-referenced point, while the remaining four were collected 2 meters away in the cardinal directions: North, East, South, and West (Figure 1a). Prior to subsample collection, large stones (exceeding 6 cm in diameter), vegetation debris, grass, and litter were cleared from the soil surface with a spade. As depicted in Figure 2b, a V-shaped pit was dug to a depth of 20 cm, and a 3-cm thick soil slice was extracted from one side. This slice was then trimmed to maintain a 3-cm width and placed in a bucket. This procedure was repeated for the other four subsample locations. The collected subsamples in the bucket were then mixed thoroughly with a trowel, and any remaining vegetation and stones were removed. A 500-gram portion of the mixed soil was subsequently taken with a trowel, put into a plastic bag, labelled, and designated as the composite sample. The soil samples were air-dried prior to sealing the bags. Further details can be found in (Jones *et al.*, 2020).

Figure 1. (a) LUCAS sampling schema and (b) summary of the sampling procedure



Source: Jones et al., 2020

The samples were then sent to a central laboratory where physical and chemical properties were analysed according to standard ISO methods (except for extractable Potassium). Table 1 shows the soil properties measured, together with the methods used (Jones *et al.*, 2020).

Table 1. Methods used for the analysis of physical and chemical properties in topsoil samples.

Soil properties	Method	Description
Coarse fragments	ISO 11464:2006	Sieving to separate coarse fragments (2-60 mm) from fine earth fraction
Clay, silt and sand contents	ISO 11277:1998 ISO 13320:2009	Sieving and sedimentation method Laser diffraction (in 2015 only)
pH in $CaCl_2$ and in H_2O	ISO 10390:2005	Glass electrode in a 1:5 (V/V) suspension of soil in H_20 and $CaCl_2$
Electrical conductivity	ISO 11265:1994	Metal electrodes in aqueous extract of soil
Organic carbon content	ISO 10694:1995	Dry combustion (elementary analysis)
Carbonates content	ISO 10693:1995	Volumetric method
Available Phosphorus	ISO 11263:1194	Spectrometric determination of P soluble in sodium hydrogen $CaCO_3$ solution
Total nitrogen content	ISO 11261:1995	Modified Kjeldahl method
Extractable potassium content	USDA−NRCS, 2004	Atomic absorption spectrometry after extraction with NH_4OAc
Cation exchange capacity	ISO 11260:1994	Using barium chloride solution to saturate samples and extract cations

Source: JRC analysis

As part of the quality control efforts, the effectiveness of the LUCAS sampling method for topsoil monitoring was evaluated, with a comprehensive analysis available in Fernández-Ugalde et al., (2020). The study concluded that using the LUCAS spade sampling technique is an effective and economical approach for monitoring topsoil on a regional or continental scale. However, it highlighted the need for improved management of litter removal in woodland areas and more consistent control of sampling depth across all land cover classes.

3. Soil data evaluation

This process aims to ensure the accuracy, completeness, and consistency of the data. The validation focused on two main aspects of the data: compliance and conformity. Compliance involves ensuring the data format aligns with the LUCAS 2015 call for tender specifications. Conformity examines the data content, including the identification and registration procedures, as well as the application of pedological criteria within the LUCAS WB 2015 survey. For more detailed information, refer to Jones et al. (2020).

3.1. Agreement of the data format with the specifications of the call for tender for laboratory analysis in LUCAS 2015

The information of each soil sample is linked to its Soil ID in the dataset, so that soil information can be attributed to a monitoring point in the LUCAS 2015 database of Eurostat through the Soil ID. Soil properties are ordered in columns in the dataset as indicated in the technical specifications. Data of soil properties are expressed in pertinent units and with the number of decimals requested in the technical specifications. The laboratory added two extra columns to the dataset with Client ID (i.e. internal identification of samples in the laboratory) and country of origin of soil samples.

3.2. Identification and registration of samples in LUCAS WB 2015

The LUCAS soil points in the five Western Balkans countries were identified by unique Point IDs. Topsoil samples collected in LUCAS points were identified by Soil IDs. The JRC creates these Soil IDs. In each LUCAS survey, surveyors randomly assign these Soil IDs to the samples when collected. Each sample is double packed with twin labels that have the same Soil ID. At each LUCAS point, surveyors document agro-environmental observations by filling in a field form and by taking photographs. Surveyors must indicate the Point ID and the Soil ID in the field form. All the data is then stored in the Data Management Tool (DMT) managed by Eurostat. Therefore, every topsoil sample has a double identification: the Soil ID and the Point ID. The Soil ID is used to identify the samples in the laboratory and provides the soil data, whereas the Point ID is used to give the field data and link information from different LUCAS surveys. Overall, 955 samples were taken in LUCAS WB 2015 across the region.

3.3. Evaluation of soil data and pedological criteria in LUCAS WB 2015

The limits of detection of the analytical methods were used to filter the data of soil properties and highlight the presence of values outside possible ranges in the dataset. Table 2 gives an overview of these outsider values in the dataset.

Table 2. Summary of outsider values per soil property in the dataset of the LUCAS WB 2015 survey.

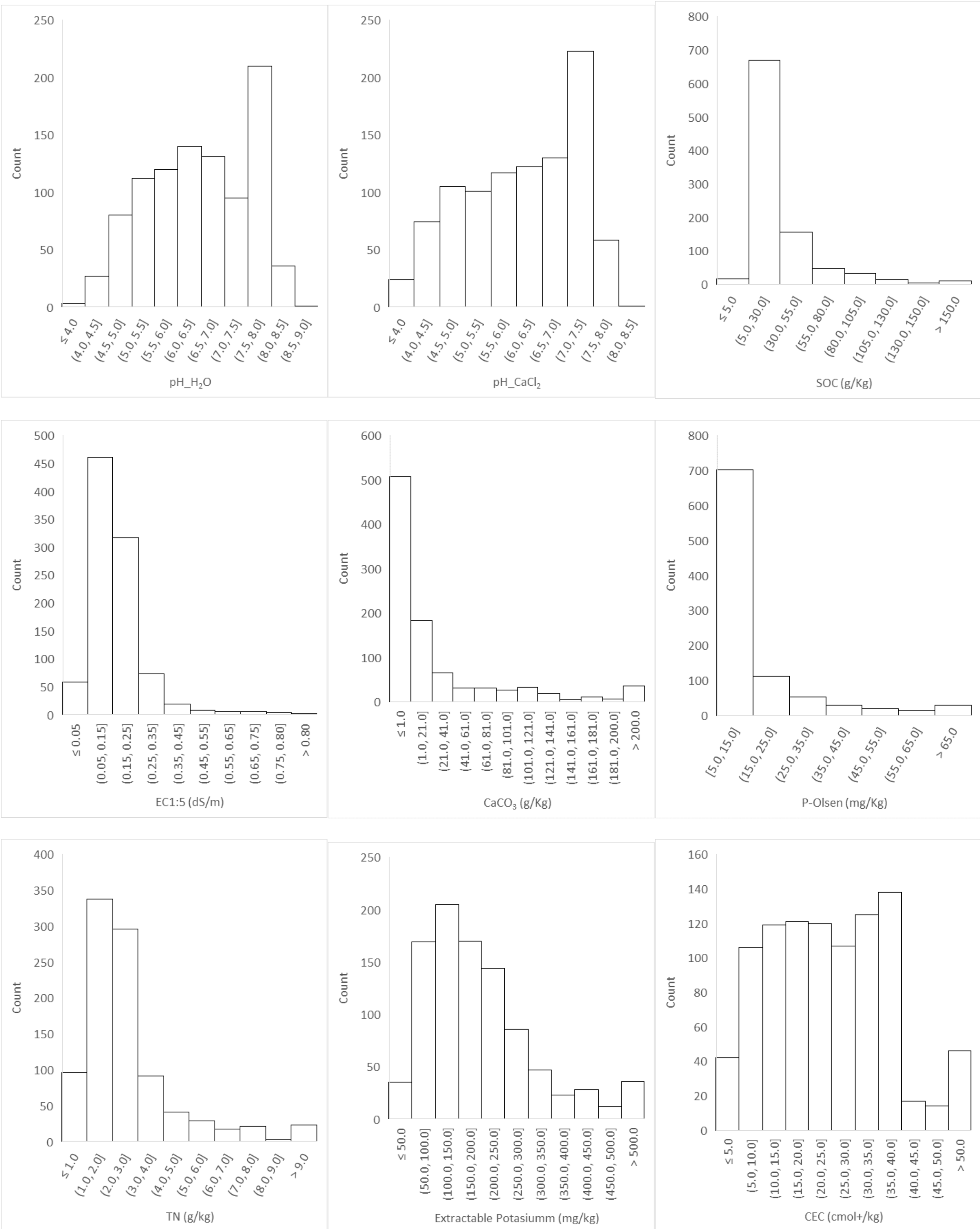
Soil parameter	**LOD[1]**	**Range actual values**	**N samples <LOD[1]**	**% of the data**
pH-$CaCl_2$	2–10	3.3 - 8.2	0	0
pH-H_2O	2–10	3.77 - 8.89	0	0
Electrical conductivity (mS m^{-1})	0.1	2.13 - 251	0	0
Organic carbon (g kg^{-1})	2.0	1.7 - 195.1	1	0.1
Carbonates (g kg^{-1})	1.0	0 - 764	338	35
Available phosphorous (mg kg^{-1})	10.0	0 - 245.7	579	60
Total nitrogen (g kg^{-1})	0.2	0.2 - 19.6	2	0
Extractable potassium (mg kg^{-1})	10.0	26.5 - 3536.4	0	0
Cation exchange capacity (cmol+ kg^{-1})	2.0	0 - 104.9	11	1

[1] LOD: limit of detection

Source: JRC analysis

The distribution of the soil samples for each of the soil indicators is shown in the Figure 2. The distribution of the experimental data for each soil parameter can be used to show a general picture of the soils in the WB. Most of the pH values (measured in water) are between 4.0 and 8.5. But it is important to highlight as more than 20% of the soil samples (247 points) could be labelled as highly alkaline as they have pH values above 7.5 and it could be directly related to carbonates content. Most of the soil samples show low levels of salinity as more than 90% of the samples show electrical conductivity values below 0.5 dS/m when measuring diluted EC. In general terms, soil samples from WB show a low content of SOC as around 50% of them have a content below 20 g kg^{-1} and only 34 soil samples have a SOC content above 100 g kg^{-1}. The 60% of the soil samples have extractable phosphorus content below LOQ (Table 2) and around 30% with concentrations below 30 mg P kg^{-1} that could be negatively affecting optimal crop development.

Figure 2. Distribution of the soil samples for the WB for each soil indicator: pH(H_2O); pH($CaCl_2$), Soil Organic Carbon (SOC), Electrical conductivity (EC1:5); Carbonates ($CaCO_3$), available phosphorus (P-Olsen), total nitrogen (TN), extractable potassium, and Cation Exchange Capacity (CEC) .



Source: JRC analysis

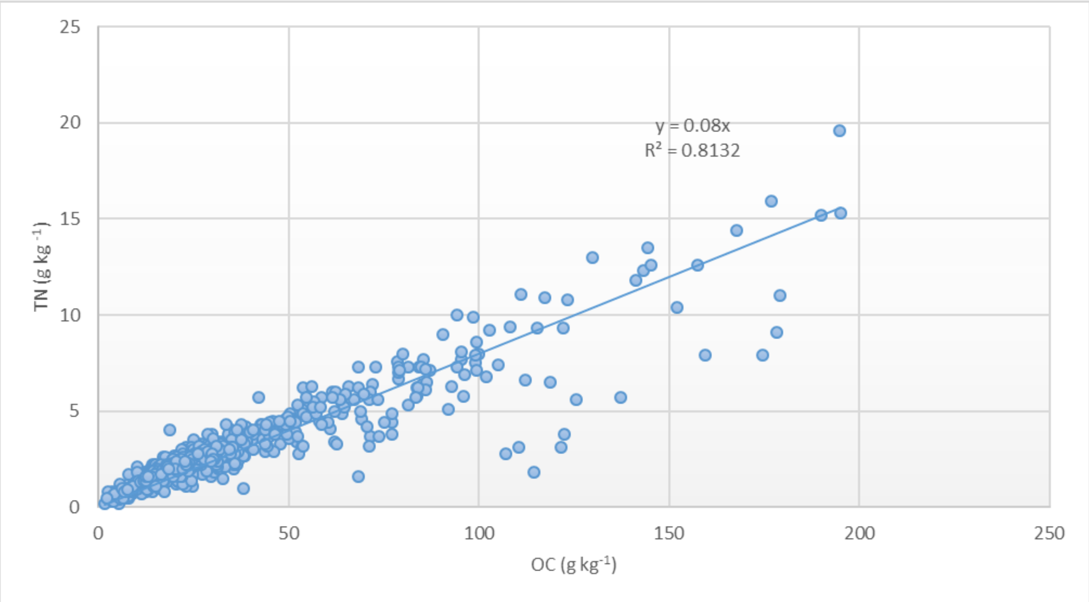
The ranges of values reported for soil properties are within reasonable limits for soils in the region. There are several points were values for $CaCO_3$ are missing and this is due to the use of the value "0" to indicate the absence of $CaCO_3$ in soil samples with pH<7. There are also values marked with "0" for P-Olsen, which is expected due to the type of land cover or land use where no chemical fertilisation is applied, resulting in naturally low P levels. Since we are measuring P-Olsen (not total P), low concentrations are anticipated.

A range of correlations between soil properties were assessed for verifying coherence of the raw data from the pedological point of view. These correlations include:

— **Correlation between OC and N**

A close relationship exists between OC and N levels in soil. The higher the OC concentration, the greater the N concentration could be (Figure 3). The soils in the LUCAS WB 2015 have an average C-to-N ratio of 10.64, with a variation of ±3.86 (Figure 3).

Figure 3. Relation between OC and N in the whole dataset.

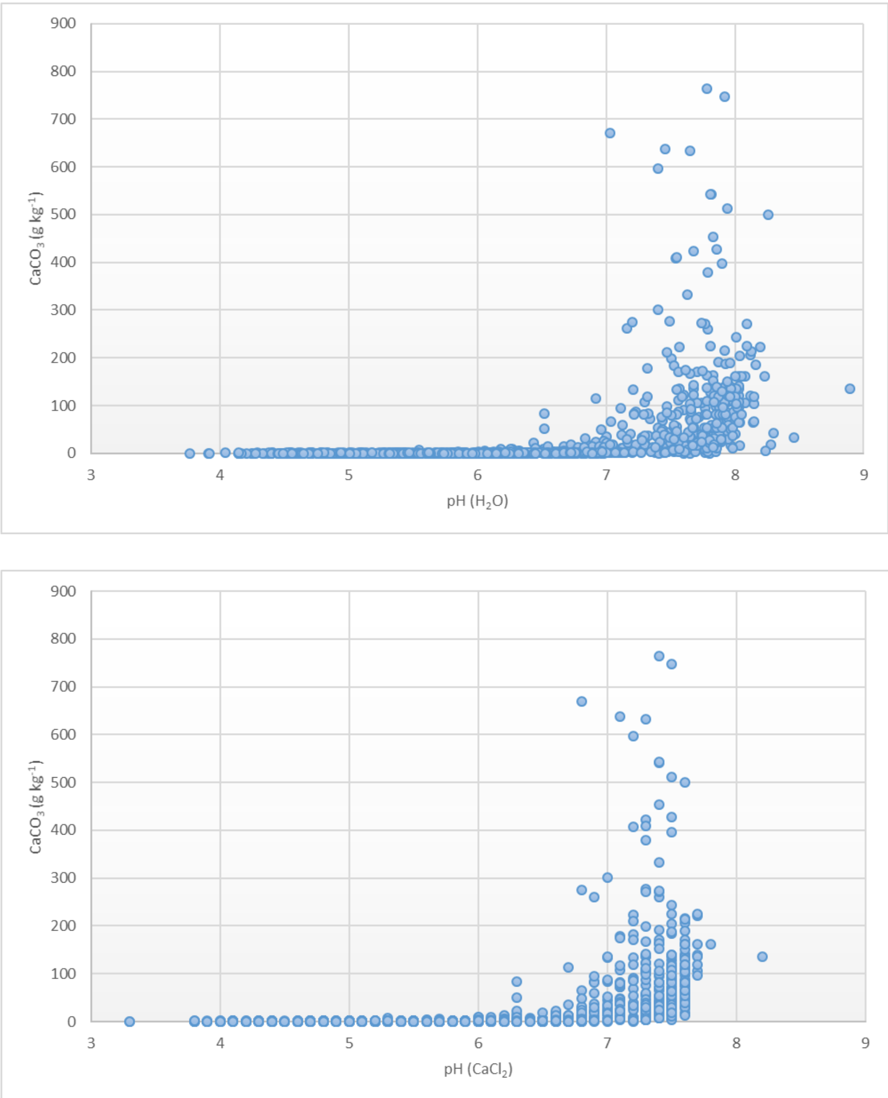


Source: JRC analysis

— **Correlation between pH and $CaCO_3$**

pH is a measure of the acidity or alkalinity in the soil. Soil pH can be measured in H_2O and in $CaCl_2$. Typically, the pH of a $CaCl_2$ solution is 0.5 to 0.9 units lower than the pH of water. However, in the dataset there are two exceptions where the pH of $CaCl_2$ is higher than the pH of water. Soils with a high Anion Exchange Capacity (AEC), such as andosols, where the AEC dominates the Cation Exchange Capacity (CEC). In these soils, the pH measured in $CaCl_2$ can be higher than the pH measured in water. Soils have common pH values in H_2O between 3.5 and 9.0. Carbonates should not be present (or the concentrations should be very low) in soils where pH is below 7, as its solubility is pH dependent, and it does not form under acidic conditions. In accordance with this criterion, Figure 4 shows (i) that pH in H_2O ranges between 3.7 and 8.9 while pH in $CaCl_2$ ranges between 3.8 and 7.6 in all LUCAS WB 2015 samples, and (ii) that soil samples with pH around 7.0 – 8.2 have the greatest contents of carbonates.

Figure 4. Relation between pH and carbonates ($CaCO_3$) in the whole dataset: (upper panel) pH-H_2O, (lower panel) pH-$CaCl_2$

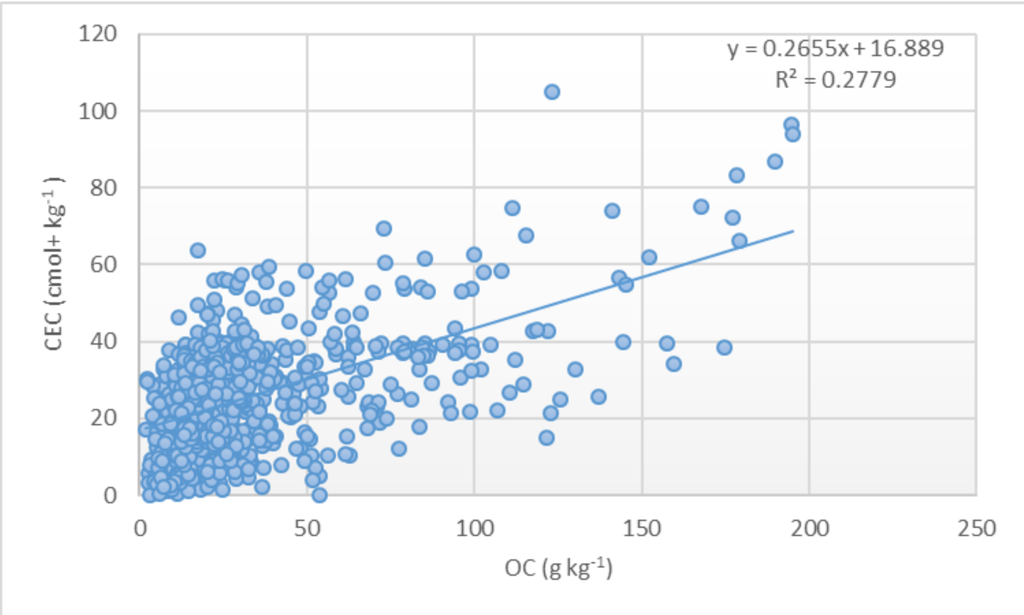


Source: JRC analysis

— **Correlation between CEC and clay and OC**

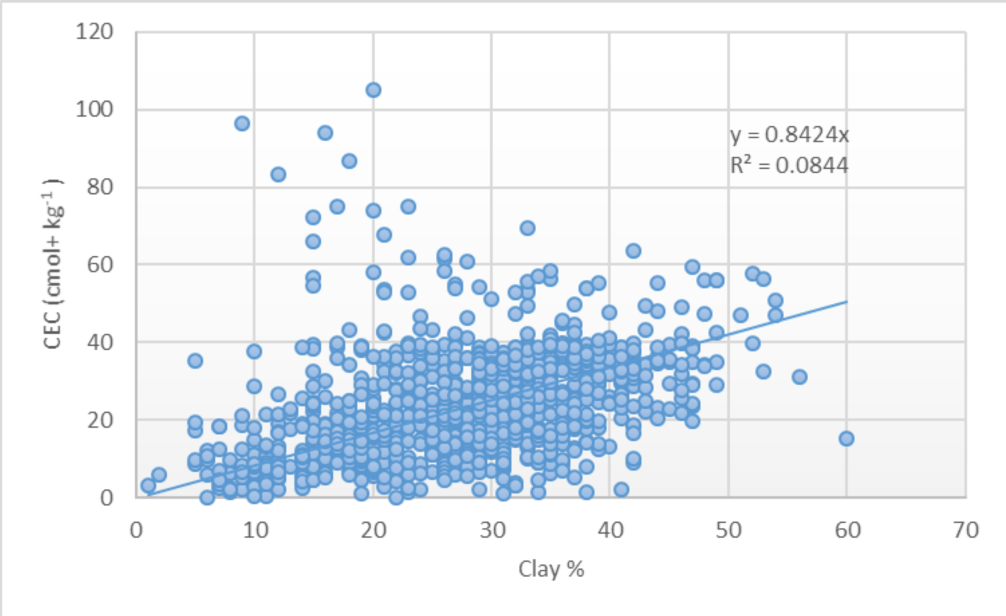
Cation exchange capacity (CEC) is the total capacity of soils to hold exchangeable cations. Soils with higher organic matter content and/or clay tend to have greater CEC, because organic matter and clay minerals have negatively charged sites on their surfaces where cations are adsorbed by electrostatic force. Similar to the findings from the LUCAS 2015 study for the EU (Jones *et al.*, 2020), Figure 4 illustrates a positive, albeit not strong, correlation between OC and CEC, as well as between clay content and CEC (Figure 5). This is because soil CEC is influenced not only by OC and clay content but also by the degree of decomposition of organic matter and the mineral composition of the clay fraction. Additionally, soil pH affects CEC. The presence of other functional groups, such as amides, in organic matter—particularly in humic acids—and in clays that do not impact CEC (like kaolinites and illites) can easily account for the lack of a strong correlation between CEC and organic carbon-clay content. It's also noteworthy that clay-rich soils tend to retain more organic carbon (Morton, 2005; Wang et al., 2003).

Figure 5. Relation between OC and CEC



Source: JRC analysis

Figure 6. Relation between Clay and CEC



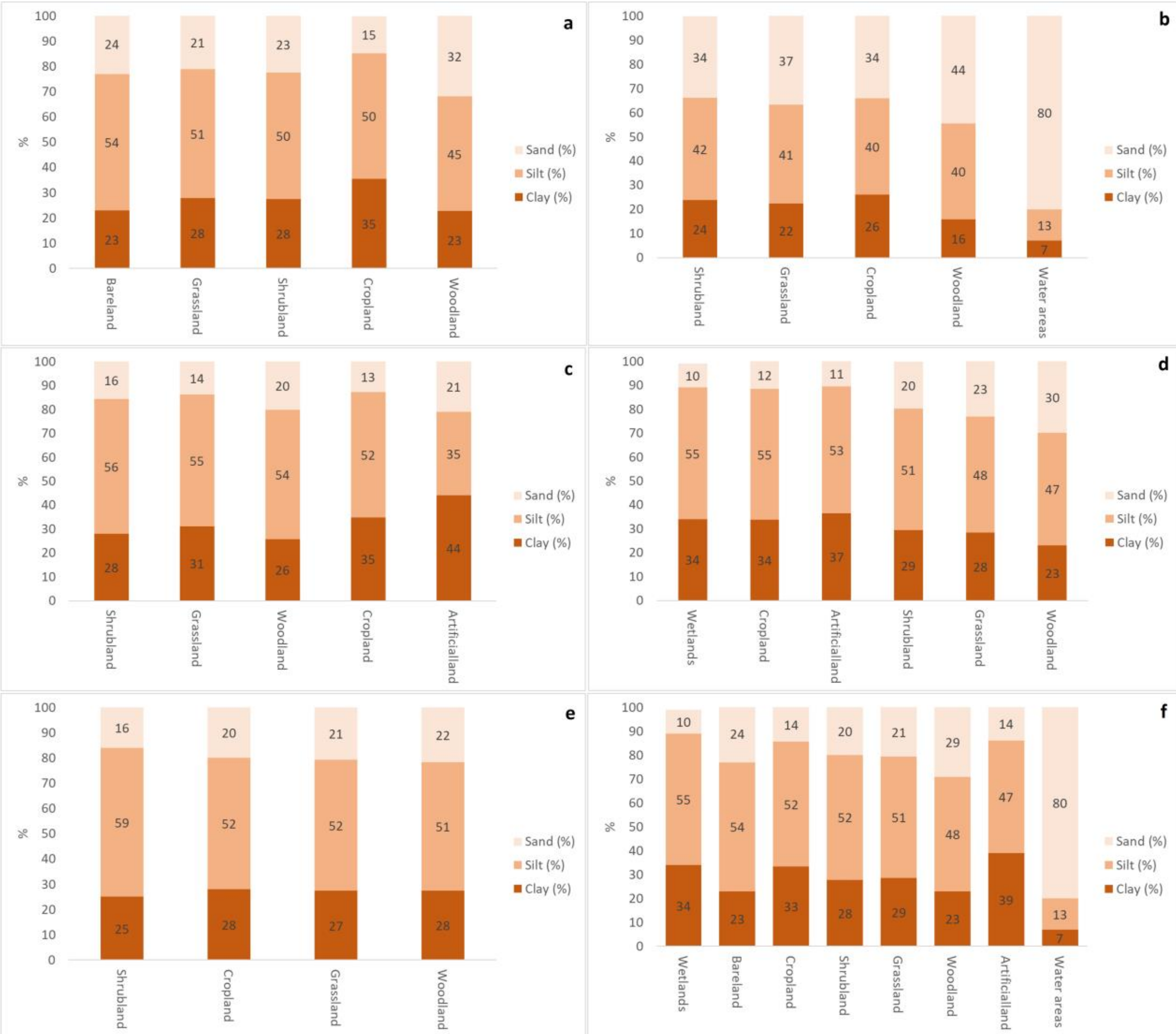
Source: JRC analysis

— **Coherence of particle size distribution data**

Mineral fraction <2 mm in soil can be split in three size fractions: sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm). In the LUCAS WB 2015 survey, these three fractions were measured in all the soil samples, and the sum of the three fractions shall be equal to 100 %.

The Figure 7 shows the content of clay, silt, and sand across different land uses in several Western Balkan countries. In Albania, the highest clay content is found in cropland (35.5%), while the lowest is in woodland (22.7%). Silt content is relatively uniform, with bareland having the highest (54%), and woodland has the highest sand content (31.9%). In Bosnia and Herzegovina, silt content is relatively high across all land uses (it could be used as an indicator of soil erosion), with shrubland having the highest (56.5%). Sand content is lowest in cropland (12.8%). For Montenegro, shrubland has the highest silt content (59%), and sand content is fairly consistent, with woodland having slightly more (21.8%). In North Macedonia, woodland has the lowest clay content (15.8%) and the highest sand content (44.4%). Silt content is consistent, around 39-42% for most land uses. In Serbia, silt content is uniformly high (around 50%). Overall, silt is consistently the dominant soil component in most land uses, and sand content varies significantly. Additional investigations are needed because fewer than three soil samples were collected from soils located in artificial lands, wetlands, barelands, and water areas. These insights provide a clear view of soil texture variation based on land use in the Western Balkans, crucial for agricultural planning and environmental management.

Figure 7. Distribution of clay, slit and sand content (%) for each of the land use classes reported in the LUCAS 2015 database in the Western Balkans for a) Albania, b) Bosnia and Herzegovina, c) Montenegro, d) North Macedonia, e) Serbia and f) overall mean values.



Source: JRC analysis

Overall, the raw soil data followed the expected trends for assessed correlations. Thus, it can be concluded that the data is coherent from the pedological point of view.

4. The LUCAS WB 2015 Topsoil dataset

4.1. Structure and description of the dataset

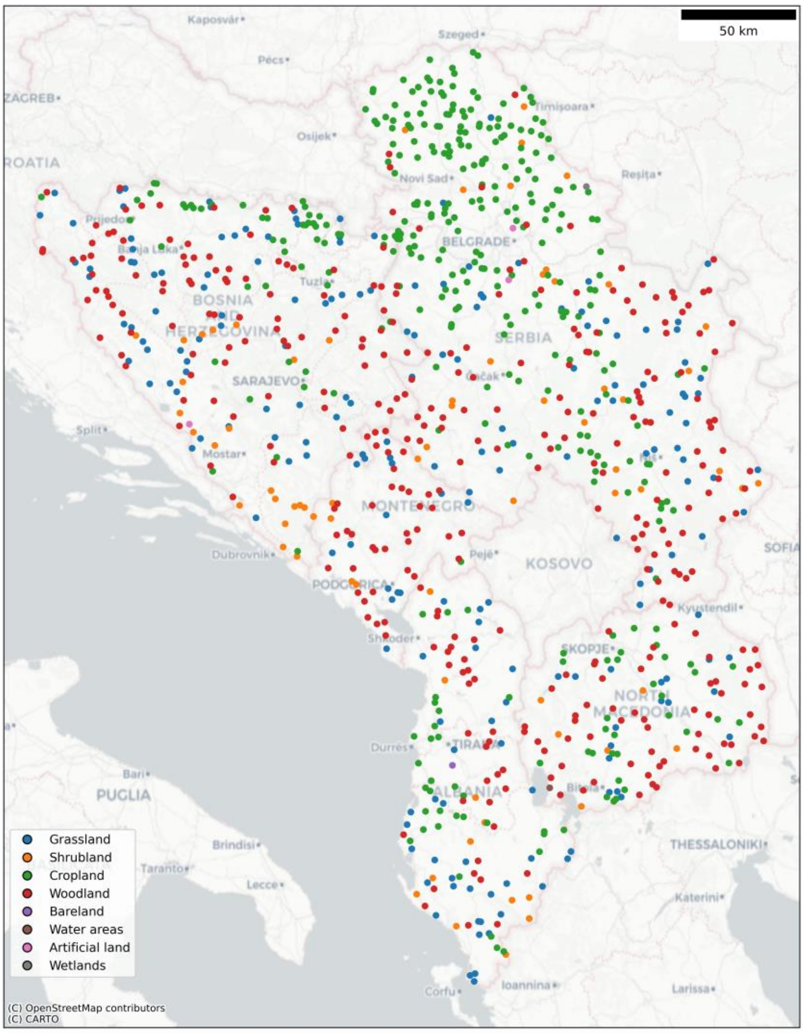
The LUCAS Topsoil dataset for the Western Balkans (LUCAS WB 2015) presents the laboratory analysis of the samples taken in the 2015 survey. After controlling the identification of samples, the dataset has 955 unique records with soil and agro-environmental data for the five countries. Table 3 and Figure 8 show the distribution of sampling points by country and by Land Cover (LC) class.

Table 3. Allocation of LUCAS WB 2015 sampling locations.

Country	**Points**	**Cropland B00**	**Woodland C00**	**Shrubland D00**	**Grassland E00**	**Other**
Albania	120	33	35	12	39	1
Bosnia and Herzegovina	243	56	96	22	68	1
North Macedonia	120	33	62	6	18	1
Montenegro	60	1	40	5	14	0
Serbia	412	214	111	27	57	3
TOTAL	**955**	**337**	**344**	**72**	**196**	**6**

Source: JRC analysis

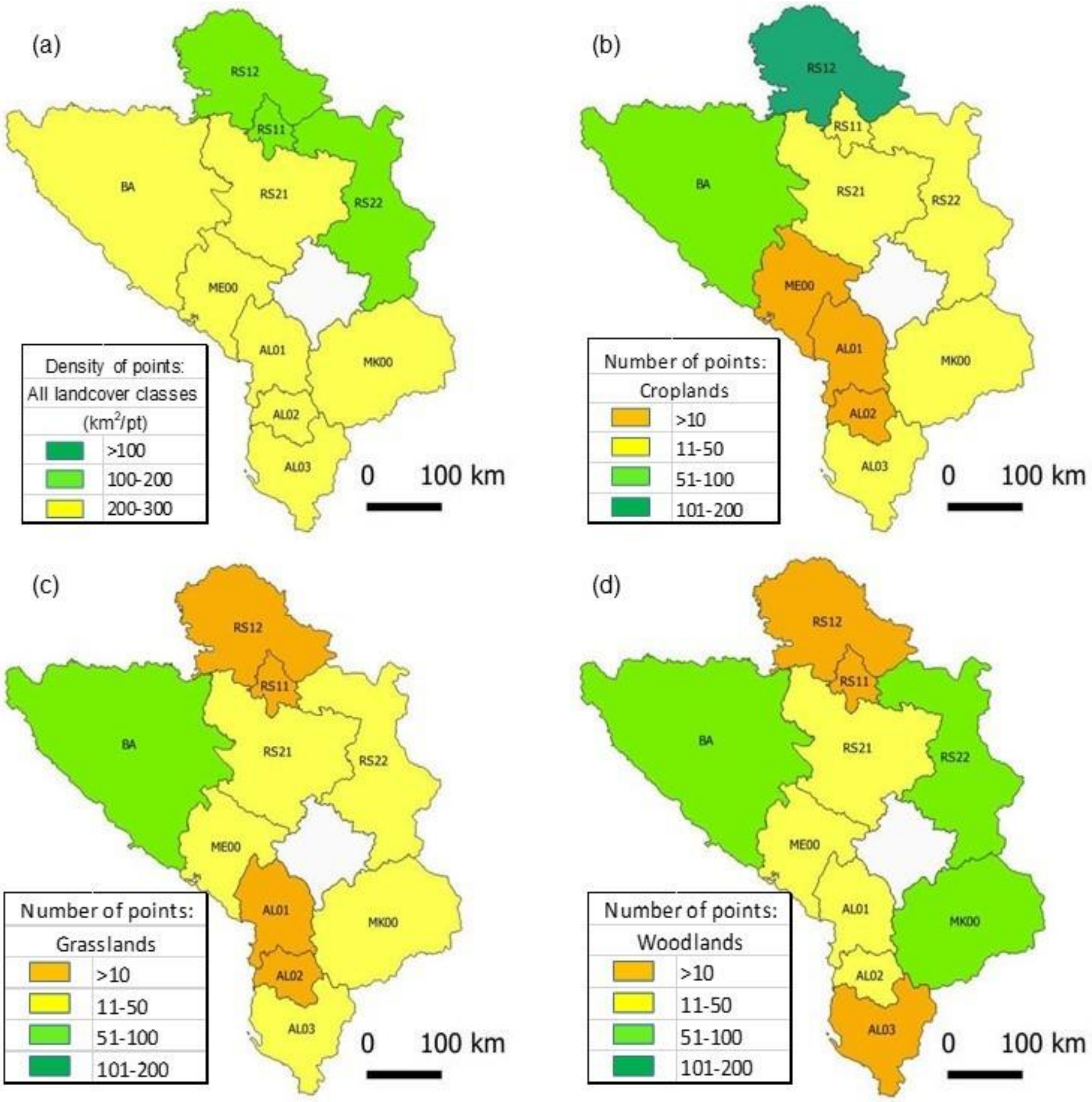
Figure 8. Distribution of sampling points in the Western Balkans.



Source: JRC analysis

Samples are identified with their Point ID, which serves to link the soil data with the field data. The field data consists of land cover, land use and environmental parameters associated with the individual points surveyed. Although the NUTS classification is exclusive to EU countries, Eurostat has established a similar coding system for non-EU countries, including candidate countries, potential candidates, and members of the European Free Trade Association, in cooperation with these countries. The description of LUCAS WB 2015 data was conducted based on statistical regions (SR) level 2 corresponding to the EU NUTS 2 level: Montenegro (ME), North Macedonia (MK), Albania (AL), and Serbia (RS) and for the entire country for Bosnia and Herzegovina (BA), categorised by land cover classes, is shown in Figure 9.

Figure 9. Sampling density in SR level 2 and country (for Bosnia and Herzegovina) a) for all land cover classes and number of points according to land cover classes b) croplands, c) grasslands and d) woodlands



Source: JRC analysis

The dataset is made available in a variety of formats (e.g. CSV, Excel and SHAPE) to facilitate accessibility and usability for a wide range of users, including researchers, policymakers, and practitioners. Data will be available through the European Soil Data Centre (ESDAC) using the following URL: https://esdac.jrc.ec.europa.eu/resource-type/datasets. The fields of the LUCAS WB 2015 Topsoil dataset are presented in Tables 4 and 5. The code explanation can be found at the Eurostat Technical reference document C3 Classification (Land cover & Land use)(Eurostat, 2022). As outlined in Table 4, soil data are reported in 12 fields (columns). A limited number of supplementary data have been extracted from the LUCAS Microdata to provide land cover and land use context to users of the soil data (Table 5)

An additional supplementary dataset and report (Arias-Navarro *et al.*, 2024b) containing ancillary environmental information for the soil sampling locations (e.g. climate, topographic setting, soil regions, NATURA 2000 sites, etc.) is also available to download from ESDAC.

Table 4. Soil fields in the LUCAS WB 2015 Topsoil dataset.

Field	**Description**
Point_ID	LUCAS Point Unique identifier
Coarse	% of coarse fragments (>2mm)
Clay	% of clay particles
Sand	% of sand particles
Silt	% of silt particles
pH_$CaCl_2$	pH – measured in calcium chloride
pH_H_2O	pH – measured in water
EC	Electrical conductivity (miliSiemens per meter – mS m^{-1})
OC	Organic carbon content (g kg^{-1})
$CaCO_3$	Calcium carbonate content (g kg^{-1})
P	Available phosphorus (g kg^{-1})
N	Total nitrogen (g kg^{-1})
K	Extractable potassium (g kg^{-1})
CEC	Cation exchange capacity (Millequivalents per 100 grams of soil cmol(+)/kg)

Source: JRC analysis

Table 5. Non-soil fields in the LUCAS WB 2015 Topsoil dataset.

Field	DESCRIPTION
Country name	
Country code	
Statistical Regions (SR) level 2 /country name	
Statistical Regions (SR) level 2/country code	
Climatic zones name	
Sample Ident	
Soil label	
Date	(ss/mm/yyyy)
TH_LAT	Theoretical Latitude
TH_LONG	Theoretical Longitude
Elevation	m
Can you see any sign of ploughing in the plot?	Yes, No, N.R (Not relevant)
Percentage of residual crops on the surface:	%
Percentage of stones on the surface:	%
LC1_0 name	Primary land cover name
LC1_0 (code)	Primary land cover code
LC1	Land Cover 1 - See C3 document[1]
LC1_SPEC	Land Cover 1 Species - See C3 document

[1] https://ec.europa.eu/eurostat/documents/205002/6786255/LUCAS2015_C3-Classification_20160729.pdf

LC1_PERC	Land Cover 1 - Percentage
LC2	Land Cover 2 - See C3 document
LC2_SPEC	Land Cover 2 Species - See C3 document
LC2_ PERC	Land Cover 2 - Percentage
LU1_0 name	Primary land use name
LU1_0 (code)	Primary land use code
LU1	Land Use 1 - See C3 document
LU1_TYPE	Land Use 1 Species - See C3 document
LU1_PERC	Land Use 1 - Percentage
LU2	Land Use 2 - See C3 document
LU2_TYPE	Land Use 2 Species - See C3 document
LU2_PERC	Land Use 2 - Percentage

Source: JRC analysis

5. Spatial representation of soil properties in the Western Balkans

Soil property data is presented on four maps: one for the entire dataset and three separate maps for cropland, grassland, and woodland points. Maps for bareland, shrubland, and wetland are not included due to the limited number of data points. The mapping of soil properties follows the same value ranges and criteria as the LUCAS 2009 and 2015 Topsoil Survey reports (Tóth *et al.*, 2013; Jones *et al.*, 2020), based on pedological and agrochemical considerations. An attempt was made to create maps at the SR level 2, but this was challenging due to the limited number of SR level 2 units available, with only three units in Albania, one in Montenegro, one in North Macedonia, and no definition at all in Bosnia and Herzegovina.

A minimum density of 250 km² per sample is considered a reasonable preliminary indicator for the confidence level of the LUCAS 2015 Soil survey to measure chemical soil properties of EU soils (Jones *et al.*, 2020). We assume that this threshold is also applicable to the Western Balkans. According to this criterion, the sampling density is sufficient in over 50% of SR level 2 regions, considering both the entire dataset and the different land cover (LC) classes separately (Table 6, Figure 9). However, the percentage of regions meeting this threshold varies significantly across different land cover classes: it is below 20% for cropland, around 90% for shrubland, and 0% for grassland and woodland.

Table 6. Summary statistics of sampling density in Statistical Regions (SR) level 2 and for the entire country for Bosnia and Herzegovina

	Sampling density (km² per sample) **Mean of SR level 2*/country**	**Sampling density (km² per sample)** **Median of SR level 2* /country**	**% of SR level 2 /country* with density <250 km² per sample**
Whole dataset	210	213.6	90
Cropland B00	2007.9	771.6	20
Grassland E00	2160.1	1117.4	0
Shrubland D00	212.2	213.6	90
Woodland C00	928	590	0

* The analysis by Statistical Regions (SR) level 2, corresponds to the EU's NUTS 2 classification

Source: JRC analysis

Sampling density was for all landcover classes mostly in the category 200-300 km² per sample, followed by the category 100-200 km² per sample (Table 7).

Table 7. Sampling density in SR level 2 and Bosnia and Herzegovina for the complete dataset; number of points in each Statistical Region/country for cropland, grassland, woodland and shrubland.

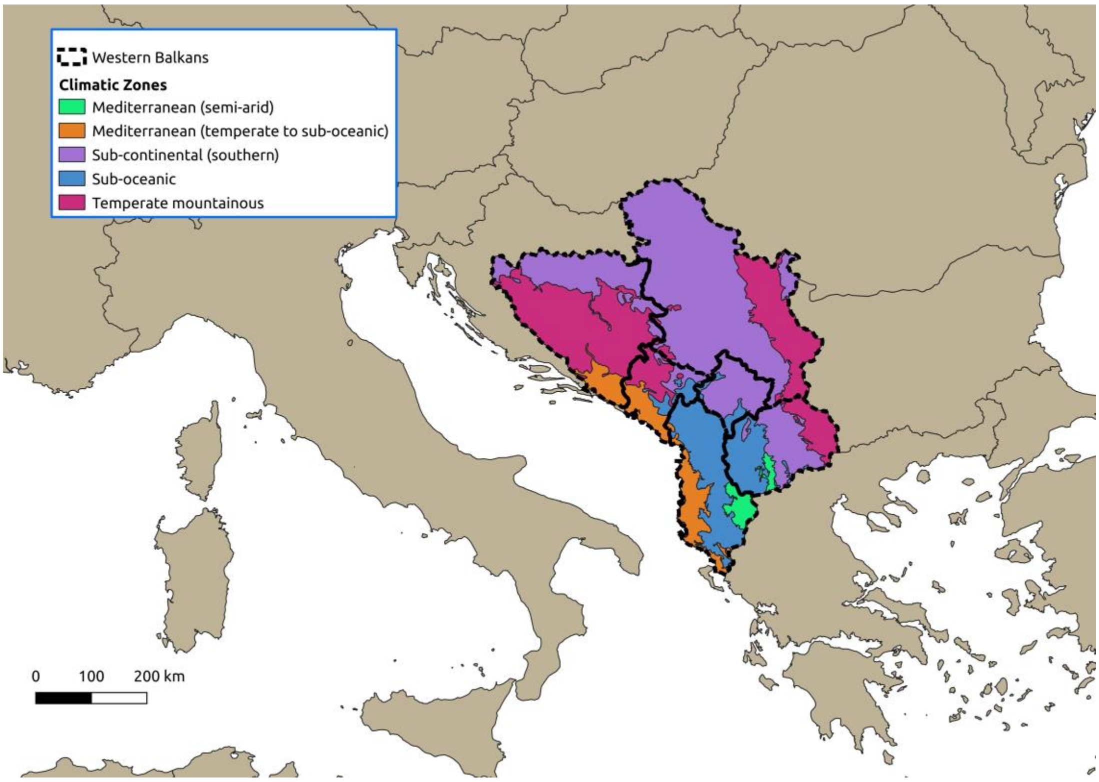
		Density of points	Number of points				Total number of points
SR level 2 / country name	SR level 2 / country code	All landcover classes (km^2/pt)	Cropland B00	Grassland E00	Woodland C00	Shrubland D00	
Veri	AL01	292.7	9	10	16	2	37
Qender	AL02	220.5	7	2	10	2	21
Jug	AL03	212.9	17	27	9	8	61
Bosnia and Herzegovina	BA	210.7	56	68	96	22	242
Montenegro	ME00	230.2	1	14	40	5	60
North Macedonia	MK00	214.3	33	18	62	6	119
Belgrade Region	RS11	134.8	13	2	5	2	22
Vojvodina Region	RS12	152.2	127	2	6	6	141
Region of Šumadija and Western Serbia	RS21	234.5	45	23	37	8	113
Region of Southern and Eastern Serbia	RS22	197.4	29	30	63	11	133

Source: JRC analysis

As in LUCAS 2015 for the EU, climate characterisation in the Western Balkans dataset was based on the work done by Tóth *et al.* (2013). This study built upon earlier research by Hartwich et al. (2005), who identified 35 Climatic Areas of Europe and grouped them into eight distinct climatic zones (Figure 10). These zones represent regions with specific climate conditions.

Dominant climatic zones of the Western Balkans are Sub continental (southern), Sub-oceanic, Temperate mountains, Mediterranean (semi-arid) and Mediterranean (temperate to sub-oceanic). Within these climatic zones, pedological assessments were conducted in a spatially explicit manner, taking into account the varying climate conditions. In the Western Balkans, the climate varies significantly, ranging from a typical Mediterranean climate along the coasts (characterised by dry, hot summers and wet, mild winters) to continental climate conditions in the uplands and higher mountain ranges. Both point data and aggregated data are described following the climatic zones for soil quality assessment illustrated in Figure 10.

Figure 10. Climatic zones of the Western Balkans based on Toth et al (2013)



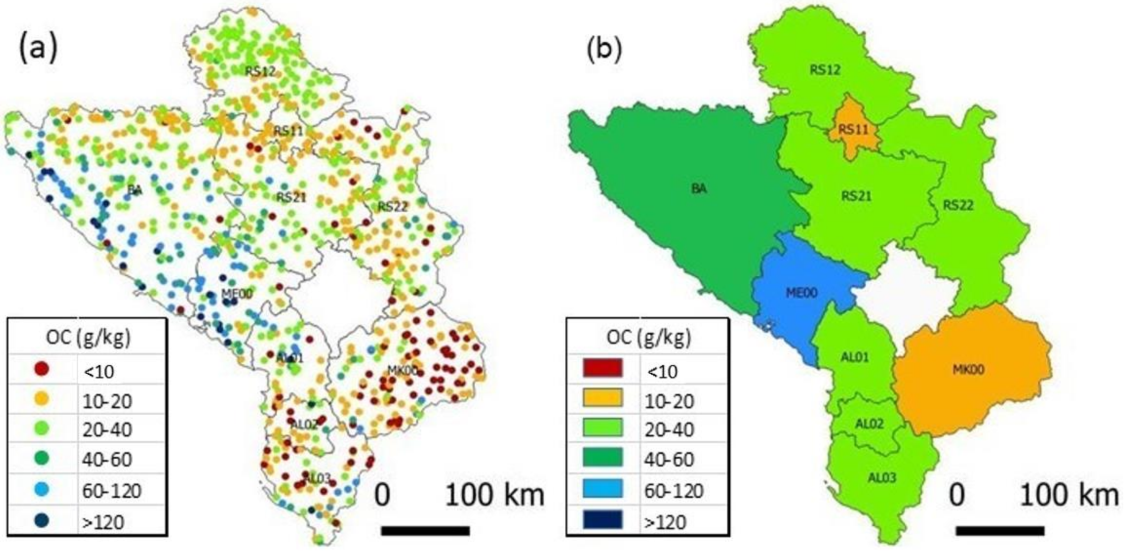
Source: JRC analysis

Regarding the soil type classification according to the World Reference Base for Soil Resources WRB 2022 (IUSS Working Group WRB, 2022) methodology, the large number of samples occurred in the combination Cambisols/Leptosols (17.7% of the total number of samples), followed by Phaeozems/Chernozems (16%), Phaeozems (9.5%), Vertisols (8.8%) while other soil types have a limited number. These categories of soil significantly demonstrate the distribution of major soil types that are dominated by Cambisols spread throughout the region followed by the fertile Phaeozems and Chernozems of the Pannonian Plain in Serbia with less extension in Bosnia and Herzegovina typically in the Republic of Srpska.

5.1. Organic carbon

Spatial variability of soil organic carbon (SOC) content depends on the climate and the share of land cover (i.e. vegetation type) across the Western Balkans (Figure 11).

Figure 11. Organic carbon content (all points) in all land cover classes (a) and at SR level 2 /country level



Source: JRC analysis

Organic carbon in **woodlands** was highest in the Mediterranean (temperate to sub-oceanic) zone with (mean values = 86.3 g kg^{-1}, median = 71.1 g kg^{-1}, followed by temperate mountains zone, sub-oceanic and finally Mediterranean semi-arid zone (Table 8, Figure 12). The higher content of the SOC in woodlands of the temperate regions is closely related also to the mineralization rates of soil organic matter (SOM). In semi-arid and arid regions lower content of SOC are due to lower biomass production (vegetation) as well as lower mineralization rates.

Previous studies have estimated that the whole Mediterranean region, in almost 75% of its territory has less than 1% of SOC (Zdruli *et al.*, 2004).

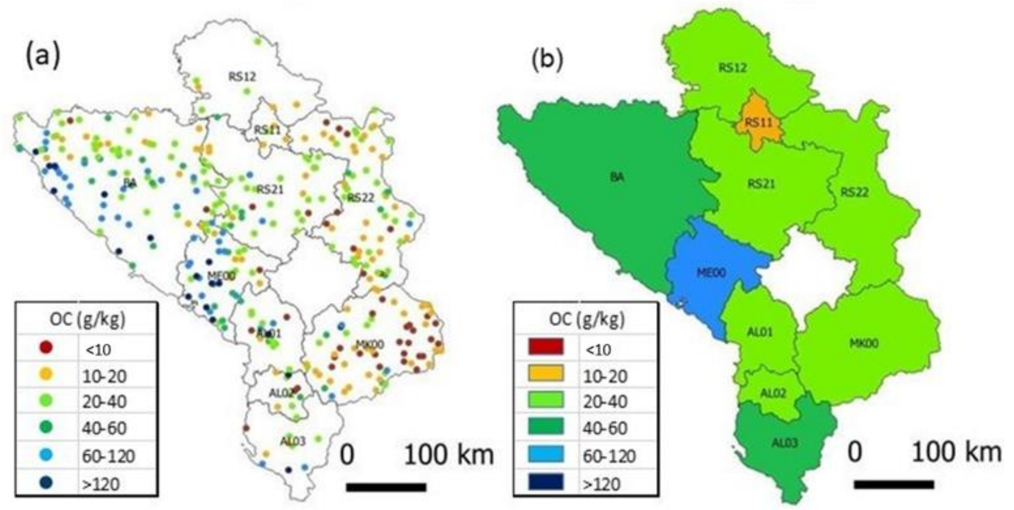
Table 8. Summary of soil organic carbon (SOC) content in woodland points

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest SOC content (g kg^{-1}) *	SR level 2 /country with lowest SOC content (g kg^{-1}) *
Mediterranean (semi-arid)	2	16.3				
Mediterranean (temperate to sub-oceanic)	17	86.3	71.1	56.7	ME00	ME00
					mean values = 97.5	mean values = 97.5
					median = 87	median = 87
Sub-continental (southern)	134	25.4	22.1	19.1	ME00	RS11
					mean values = 35.1	mean values = 17.4
					median = 30.4	median = 16.1
Sub-oceanic	54	36.5	24.4	33	AL03	ME00
					mean values = 50.1	mean values = 30.7
					median = 24.8	median = 22.6
Temperate mountainous	137	45.7	31.4	42.1	ME00	MK00
					mean values = 77.1	mean values = 9.7
					median = 65.6	median = 10.1

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Figure 12. Organic carbon content in woodlands (a) point data and at SR level 2 /country level



Source: JRC analysis

Organic carbon content in **grassland** points followed a similar trend to the woodland points. The mean values SOC content of grassland points in the Western Balkans was 29.5 g kg^{-1} and the highest SOC contents were observed in the Temperate mountains followed by Sub-oceanic zones, Mediterranean temperate to sub-oceanic and finally Mediterranean semi-arid zone (Table 9, Figure 13). It is obvious that grasslands host more SOC, and especially those in the Temperate mountains where the rainfall is high and temperature low such as in Bosnia and Herzegovina, Albania and Montenegro.

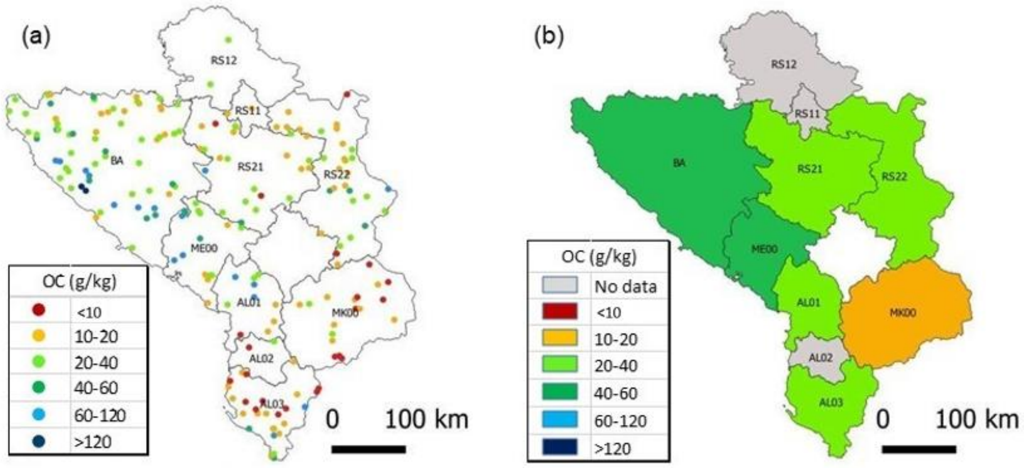
Table 9. Summary of soil organic carbon (SOC) content in grassland points.

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest SOC content (g kg^{-1}) *	SR level 2 /country with lowest SOC content (g kg^{-1}) *
Mediterranean (semi-arid)	9	17.1	12.9	17.9	AL03 mean values = 21.6 median = 12.9	MK00 mean values = 11.5 median = 10.1
Mediterranean (temperate to sub-oceanic)	21	25.8	14.2	281	ME00 mean values = 58.6 median = 58	AL03 mean values = 19 median = 12.9
Sub-continental (southern)	71	22.1	19.8	11.3	ME00 mean values = 27.4 median = 29.1	MK00 mean values = 11.3 median = 11.2
Sub-oceanic	25	29.6	20	24.1	AL01 mean values = 39.6 median = 22.4	MK00 mean values = 18.2 median = 17.4
Temperate mountainous	70	39.9	31.55	30.3	ME00 mean values = 53.2 median = 45.9	MK00 mean values = 7.8 median = 6.4

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Figure 13. Organic carbon content in grassland (a) point data and at SR level 2 /country level



Source: JRC analysis

The same trend is observed for OC content in **cropland** points with almost perfect match between Sub-continental (southern) zone (median = 19 g kg^{-1}) with sub-oceanic (median = 19.3 g kg^{-1}) and Temperate mountainous (median = 19.2 g kg^{-1}) (Table 10, Figure 14).

The dry and warm climate in the semi-arid Mediterranean zone limits agricultural production, particularly for crops like cereals, vineyards, olive groves, and fruit trees. This climate also hinders SOC accumulation. Most soils in this region, apart from Phaeozems and Chernozems, generally have low agricultural potential (e.g., Calcisol, Leptosol, Arenosol), making effective soil management practices crucial for sustaining agricultural production. In contrast, the southern sub-continental zone features soils with higher agricultural potential, such as Luvisols and Chernozems, and the climate is more favorable for farming. However, intensive agricultural practices in this zone accelerate the mineralization of SOM, leading to reduced OC accumulation.

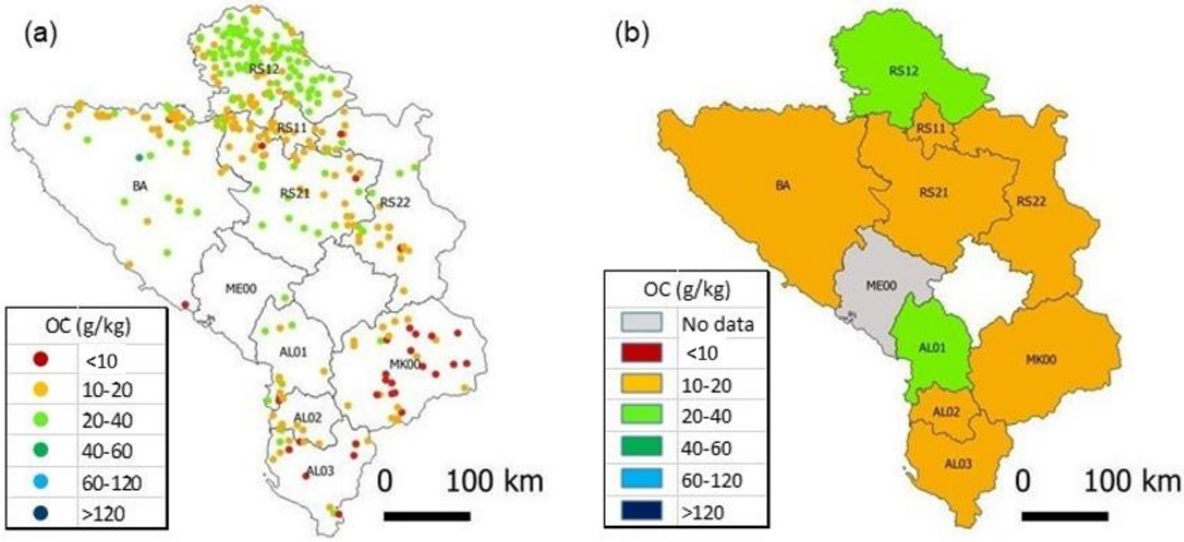
Table 10. Summary of soil organic carbon (SOC) content in cropland points.

<table>
<tr><th>Climatic zone</th><th>N points</th><th>Mean values
(g kg^{-1})</th><th>Median
(g kg^{-1})</th><th>Std dev
(g kg^{-1})</th><th>SR level 2 /country with highest SOC content
(g kg^{-1}) *</th><th>SR level 2 /country with lowest SOC content
(g kg^{-1}) *</th></tr>
<tr><td rowspan="3">Mediterranean (semi-arid)</td><td rowspan="3">14</td><td rowspan="3">12</td><td rowspan="3">10.8</td><td rowspan="3">7.9</td><td>AL03</td><td>MK00</td></tr>
<tr><td>mean values = 17.1</td><td>mean values = 10</td></tr>
<tr><td>median = 12.3</td><td>median = 10.8</td></tr>
<tr><td rowspan="3">Mediterranean (temperate to sub-oceanic)</td><td rowspan="3">25</td><td rowspan="3">14.9</td><td rowspan="3">12.4</td><td rowspan="3">7.2</td><td>AL01</td><td>AL02</td></tr>
<tr><td>mean values = 18.7</td><td>mean values = 13.2</td></tr>
<tr><td>median = 17.2</td><td>13.4</td></tr>
<tr><td rowspan="3">Sub-continental (southern)</td><td rowspan="3">272</td><td rowspan="3">20</td><td rowspan="3">19</td><td rowspan="3">7.3</td><td>BA</td><td>MK00</td></tr>
<tr><td>mean values = 19.1</td><td>mean values = 10</td></tr>
<tr><td>median = 17.6</td><td>median = 9.9</td></tr>
<tr><td rowspan="3">Sub-oceanic</td><td rowspan="3">12</td><td rowspan="3">19.3</td><td rowspan="3">19.2</td><td rowspan="3">8.5</td><td>AL01</td><td>MK00</td></tr>
<tr><td>mean values = 22</td><td>mean values = 15.8</td></tr>
<tr><td>median = 19.9</td><td>median = 13.4</td></tr>
<tr><td rowspan="3">Temperate mountainous</td><td rowspan="3">14</td><td rowspan="3">19.2</td><td rowspan="3">20.1</td><td rowspan="3">9.7</td><td>RS22</td><td>MK00</td></tr>
<tr><td>mean values = 23.5</td><td>mean values = 6</td></tr>
<tr><td>median = 23.2</td><td>median = 7.4</td></tr>
</table>

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Figure 14. Organic carbon content in cropland (a) point data and at SR level 2 /country level



Source: JRC analysis

The majority of bareland and shrubland points were located in Albania, Montenegro and North Macedonia. Most of the bareland points were under agricultural use, while shrubland points were in unused, abandoned areas or overgrazed lands. Here it is reported only the data for **shrublands** as those on barelands cover a very small and insignificant number. The highest amounts of SOC are in Mediterranean (temperate to sub-oceanic) (median = 61.5 g kg^{-1}) followed by Temperate mountainous (median = 39.9 g kg^{-1}) while the other climatic zones have same quantities, instead of Mediterranean (semi-arid) that with only one point was not possible to make statistical analysis (Table 11).

Table 11. Summary of soil organic carbon (SOC) content in shrubland points.

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest SOC content (g kg^{-1})*	SR level 2 /country with lowest SOC content (g kg^{-1})*
Mediterranean (semi-arid)	1	15.8				
Mediterranean (temperate to sub-oceanic)	17	73.6	61.5	42.9	ME00	AL03
					mean values = 110.5	mean values = 32.8
					median = 98.6	median = 34.6
Sub-continental (southern)	23	25.3	23.7	12.6	RS21	RS22
					mean values = 32.5	mean values = 16.2
					median = 27.8	median = 15.3
Sub-oceanic	11	36	23.7	23.8	AL03	MK00
					mean values = 42.6	mean values = 21.9
					median = 41.4	13.1
Temperate mountainous	20	48.2	39.9	29.9	BA	RS22
					mean values = 53.8	mean values = 24.2
					median = 53.6	median = 22.2

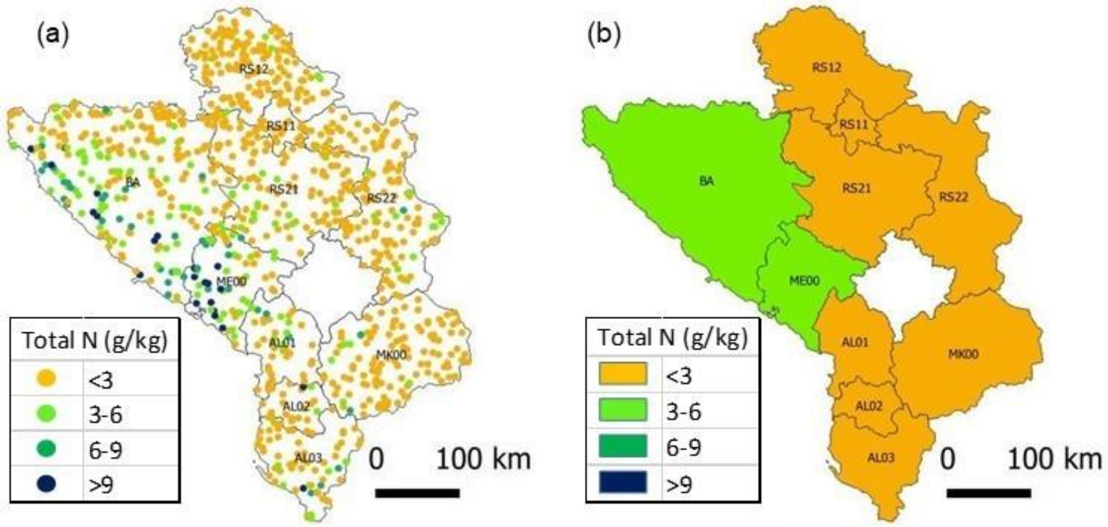
Source: JRC analysis

5.2. Nitrogen, phosphorus, and potassium

Nitrogen content

The spatial distribution of nitrogen (N) decreases from sub-oceanic zones to sub-continental and temperate mountainous areas, and finally to the Mediterranean climatic zone (Figure 15). Nitrogen content is lower in cropland, with mean and median values of 1.9 g kg^{-1}, compared to woodland, which has mean and median values of 3.1 and 2.9 g kg^{-1}, respectively, and grassland, with mean and median values of 2.6 and 2.1 g kg^{-1}, respectively. This lower N content in cropland is due to reduced storage of organic residues, which is affected by vegetation type and land management practices. Climate plays a key role in determining N stocks, as cooler and more humid conditions promote the accumulation of organic matter, leading to higher organic carbon (OC) and N levels in the topsoil. These findings align with results from the EU (Jones *et al.*, 2020).

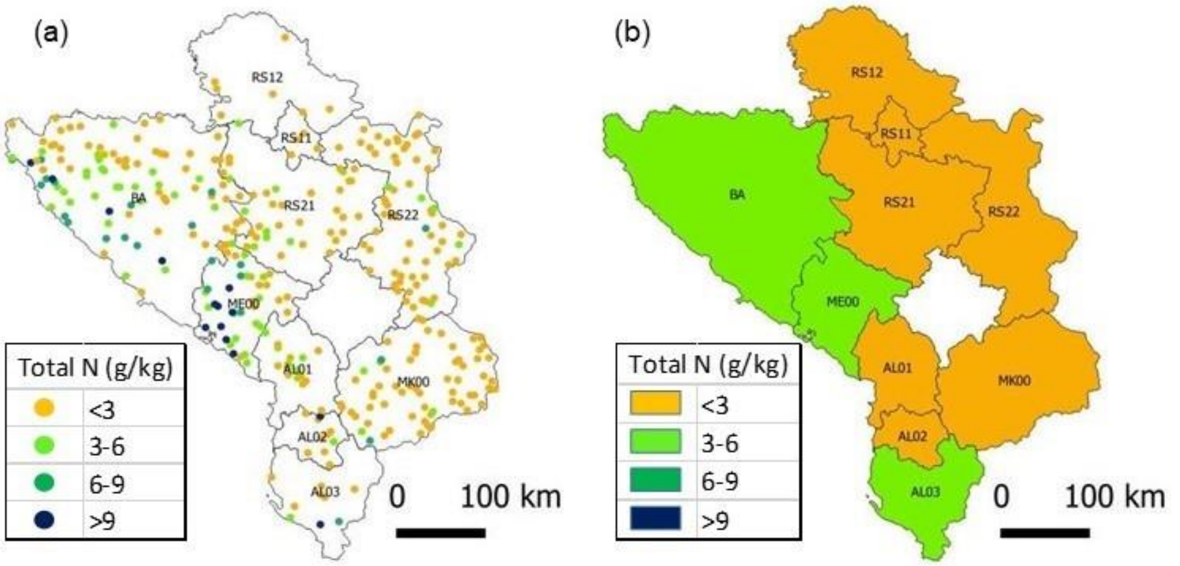
Figure 15. Nitrogen content (all points) presented (a) as point data and (b) average aggregated at SR level 2 /country level



Source: JRC analysis

The spatial distribution of N content in **woodlands** (Figure 16) is highly correlated with that OC (R^2=0.84), given that N is also a main component of soil organic matter (Celestina *et al.*, 2019). Table 12 shows that many OC-rich soils are also N-rich, at least in terms of absolute quantities. Given this relation, it is clear that LC and climate are the main drivers of the spatial distribution of N as it occurs with that of OC.

Figure 16. Nitrogen content in woodlands (a) point data and (b) average aggregated at SR level 2/country level



Source: JRC analysis

Similar to OC, N values are comparable among sub-oceanic (median = 2.1 g kg^{-1}), temperate mountain (median = 2.5 g kg^{-1}), and sub-continental southern zones (median = 2.0 g kg^{-1}). Surprisingly, the N content is significantly higher in the Mediterranean region, which ranges from temperate to sub-oceanic, with a median of 3.4 g kg^{-1} (Table 12). However, this higher value might not accurately represent the broader situation, as it is based on a very small sample size of only 17 data points. More comprehensive surveys are needed to confirm this observed trend.

Table 12. Summary of Nitrogen content in woodlands points.

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest N content (g kg^{-1}) *	SR level 2 /country with lowest N content (g kg^{-1}) *
Mediterranean (semi-arid)	2	1				
Mediterranean (temperate to sub-oceanic)	17	6.4	3.4	5.4	ME00 mean values = 8.1 6.8	ME00 mean values = 8.1 6.8
Sub-continental (southern)	134	2.2	2	1.2	ME00 mean values = 2.9 median = 2	MK00 mean values = 1.3 median = 1
Sub-oceanic	54	2.7	2.1	2.3	AL03 mean values = 4.8 median = 2.4	ME00 mean values = 2.4 median = 2.2
Temperate mountainous	137	3.4	2.5	2.9	ME00 mean values = 5.4 median = 5.2	MK00 mean values = 0.9 median = 0.8

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

The higher N content in temperate mountain **grasslands**, with a median of 3.2 g kg^{-1}, is likely due to favorable climatic conditions and the accumulation of organic materials, mainly leaves. In contrast, the Mediterranean semi-arid climatic zone has the lowest N levels, with a median of 1.2 g kg^{-1}, due to hotter and drier conditions and sparse vegetation. The other three climatic zones—Mediterranean (temperate to sub-oceanic) with a median of 1.9 g kg^{-1}, sub-continental southern with a median of 2.2 g kg^{-1}, and sub-oceanic with a median of 2.1 g kg^{-1}—show similar amounts of N (Table 13).

Table 13. Summary of Nitrogen content in grassland points.

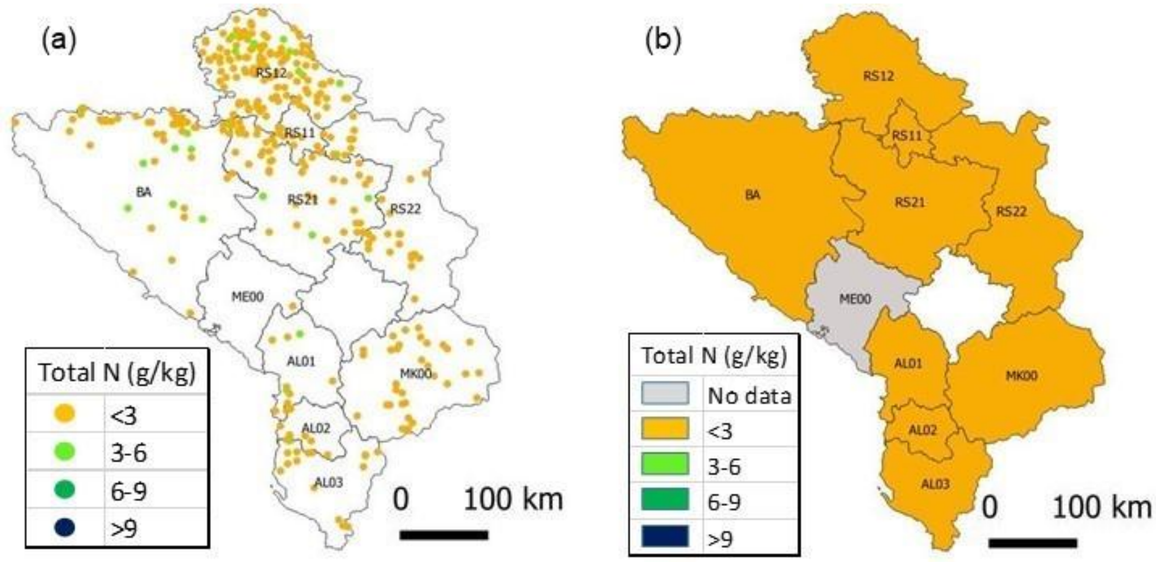
Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest N content (g kg^{-1})*	SR level 2/country with lowest N content (g kg^{-1}) *
Mediterranean (semi-arid)	9	1.9	1.2	1.6	AL03	MK00
					mean values = 2.3	mean values = 1.4
					median = 1.2	median = 1.4
Mediterranean (temperate to sub-oceanic)	21	2.4	1.9	2.1	ME00	AL03
					mean values = 4.6	mean values = 2
					median = 3.9	median = 1.6
Sub-continental (southern)	71	2.4	2.2	1	ME00	MK00
					mean values = 2.7	mean values = 1.2
					median = 2.6	median = 1.2
Sub-oceanic	25	2.8	2.1	1.8	ME00	MK00
					mean values = 3.3	mean values = 2.2
					median = 3.7	median = 2
Temperate mountainous	70	3.8	3.2	2.6	ME00	MK00
					mean values = 5.1	mean values = 0.8
					median = 4.5	median = 0.8

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

The N content in **croplands** is particularly low in the Mediterranean semi-arid zone, with a median of 1.4 g kg^{-1}) (Figure 17, Table 14). This low N content is due to the same reasons observed in grasslands. In Mediterranean regions, warm and/or dry conditions speed up the decomposition of organic matter, leading to lower N levels. This trend is consistent with findings from EU countries included in the 2015 LUCAS survey (Jones *et al.*, 2020), and similar patterns are observed in the Western Balkans. Intensively cultivated croplands in the Mediterranean semi-arid zone have the lowest N content. In contrast, the highest N content is found in temperate mountainous areas, with a median of 2.2 g kg^{-1}. However, there are relatively few data points from these mountain areas, and they contain limited cropland, making the conclusions based on these points relatively insignificant from an agricultural perspective.

Figure 17. Nitrogen content in croplands (a) point data and (b) average aggregated at SR level 2/country level



Source: JRC analysis

Table 14. Summary of Nitrogen content in croplands points.

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest N content (g kg^{-1}) *	SR level 2 /country with lowest N content (g kg^{-1}) *
Mediterranean (semi-arid)	14	1.4	1.4	0.8	AL03	MK00
					mean values = 2	mean values = 1.2
					median = 1.7	median = 1.2
Mediterranean (temperate to sub-oceanic)	25	1.8	1.7	0.7	AL01	AL02
					mean values = 2.3	mean values = 1.6
					median = 2.2	median = 1.6
Sub-continental (southern)	272	2.1	2.1	0.6	RS12	MK00
					mean values = 2.3	mean values = 1.2
					median = 2.4	median = 1.2
Sub-oceanic	12	2.1	2.1	0.6	AL01	MK00
					mean values = 2.3	mean values = 1.8
					median = 2.2	median = 2.1
Temperate mountainous	14	2.1	2.2	1	RS22	MK00
					mean values = 2.5	mean values = 0.7
					median = 2.6	median = 0.9

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

On the other side it is very significant that Sub-continental (southern) and Sub-oceanic have the same amount of N (median = 2.1 g kg^{-1}) indicating similar climate conditions and management practices, but the most relevant fact is related to Sub-continental (southern) zone that includes the fertile Pannonian plain with a significant number of points (272) where the N content is at the same level (median = 2.1 g kg^{-1}) as Sub-continental (southern) and Sub-oceanic. Nevertheless, it should be mentioned that these values are slightly below the EU countries included in 2015 LUCAS survey that are evaluated to have a little less than 3.0 g kg^{-1} N content. The reason for the lower values in the Western Balkans compared to EU countries could be attributed to the factors of soil formation, as there are distinct differences in the formation factors and current soil properties between the fertile soils of Germany, France, Belgium, and Northern Italy in the Po River valley and those of the Western Balkans. Specifically, the differences in soil formation factors, such as climate, topography, and parent material, have resulted in variations in soil characteristics, including fertility, texture, and organic matter content, which may contribute to the observed discrepancies.

Photo 1 Forage crops cultivated in the fertile loess derived soils of the Pannonian plain in Serbia.

Source: D. Vidojevic

In **shrublands**, only 72 out of a total of 955 points were sampled, so these results should be interpreted with caution. The highest N content is reported in the Mediterranean region (ranging from temperate to sub-oceanic), with a median of 6 g kg^{-1}, followed by the temperate mountains, which have a median of 3.1 g kg^{-1} (Table 15).

Table 15. Summary of Nitrogen content in shrublands points.

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest N content (g kg^{-1})*	SR level 2 /country with lowest N content (g kg^{-1})*
Mediterranean (semi-arid)	1	2.1				
Mediterranean (temperate to sub-oceanic)	17	6.5	6	3.9	ME00 mean values = 9.8 median = 9.9	AL03 mean values = 2.4 median = 2.4
Sub-continental (southern)	23	2.5	2.5	1.1	RS21 mean values = 3.1 2.8	RS22 mean values = 1.8 median = 10.6
Sub-oceanic	11	3.3	2	2.3	AL03 mean values = 3.6 median = 3	MK00 mean values = 2.7 median = 1.5
Temperate mountainous	20	4	3.1	2.3	BA mean values = 4 median = 3.7	RS22 mean values = 2.4 median = 2.3

* SR level 2 /country with three or more points were only considered

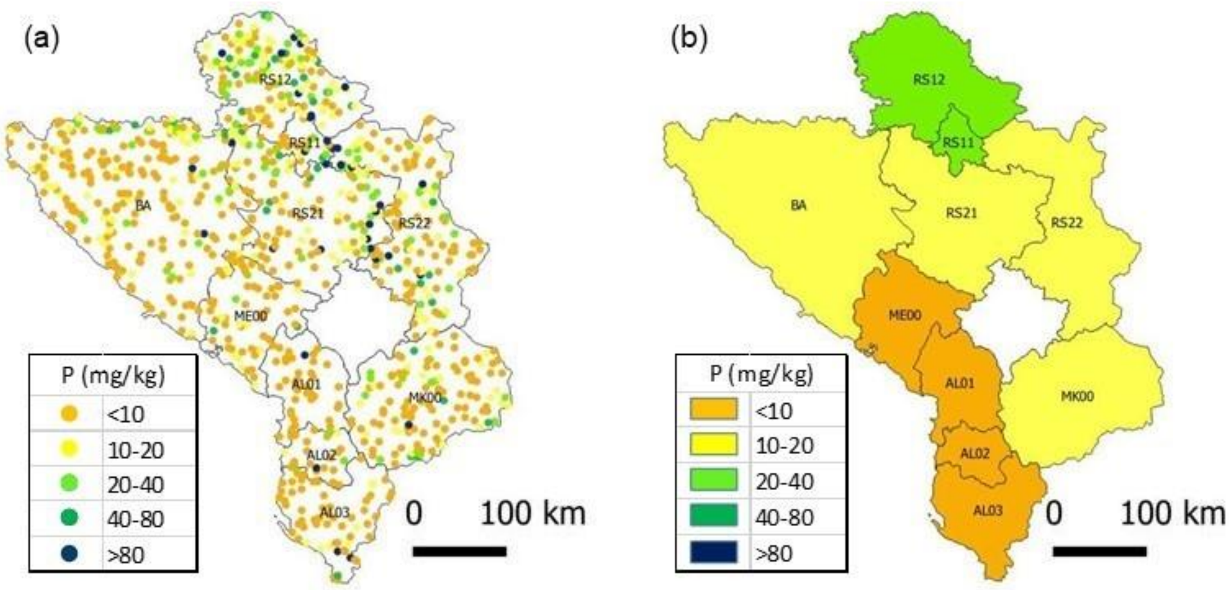
Source: JRC analysis

Phosphorus content measured as P-Olsen

Phosphorous (P) content is notably higher in the Sub-continental southern zone, followed by the Temperate Mountain zone, and is least prevalent in the Mediterranean climatic zone (Figure 18). In the Sub-continental (southern) zone, croplands exhibit a median P concentration of 14.6 mg kg^{-1}, based on 272 sampling points. This suggests that P levels in these croplands are adequate compared to other land uses within the region. However, when compared to EU standards, P levels in the Western Balkans are significantly lower. This discrepancy may be attributed to the relatively low fertiliser application rates in the Western Balkans. Notably, the region uses approximately two times less fertilizer (N, P, K) for its agricultural production than the EU, with an average of 73.9 kg per hectare of arable land in 2018, compared to 157.2 kg per hectare in the EU (Brankov & Matkovski, 2022). This difference in fertiliser application rates, combined with inherent natural conditions, may contribute to the lower P levels observed in the Western Balkans.

The spatial distribution of P is clearly influenced by land cover, with cropland soils showing higher P content compared to grassland and woodland soils (Figures 18 - 21). Specifically, woodland soils have a median P concentration of 4.2 mg kg^{-1} from 344 sampling points, while shrublands have a median of 6.2 mg kg^{-1} from 72 points. In contrast, the higher P levels in cropland soils indicate the influence of fertilisation practices (Tables 16 -19). This is particularly evident in highly productive soils under intensive cultivation, such as the Chernozems found in Serbia and the Republic of Srpska, as well as in the low-lying areas of Albania, Bosnia, Montenegro, and North Macedonia.

Figure 18. Phosphorous content (all points) presented (a) as point data and (b) average aggregated at SR level 2 /country level



Source: JRC analysis

Table 16. Summary of phosphorus content in woodland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1})	SR level 2 /country with highest P content (mg kg^{-1})*	SR level 2 /country with lowest P content (mg kg^{-1})*
Mediterranean (semi-arid)	2	4.2				
Mediterranean (temperate to sub-oceanic)	17	5	4.8	5.2	ME00 mean values = 6.4 median = 7.6	ME00 mean values = 6.4 median = 7.6
Sub-continental (southern)	134	9.3	6	16.6	RS11 mean values = 27.9 median = 28.1	MK00 mean values = 4.3 median = 0
Sub-oceanic	54	5.4	0	8.9	MK00 mean values = 8.1 median = 6.1	ME00 mean values = 1.1 median = 0
Temperate mountainous	137	7.6	6	7.8	RS22 mean values = 9.5 median = 6.2	MK00 mean values = 5.9 median = 0

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 17. Summary of phosphorus content in shrubland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1})	SR level 2 /country with highest P content (mg kg^{-1}) *	SR level 2 /country with lowest P content (mg kg^{-1})*
Mediterranean (semi-arid)	1	6.2				
Mediterranean (temperate to sub-oceanic)	17	3.2	4.2	3.3	AL03 mean values = 5.3 5.2	BA mean values = 2.3 median = 0
Sub-continental (southern)	23	26.7	10.8	33.5	RS12 mean values = 43 median = 31.4	RS21 mean values = 9.8 median = 6.7
Sub-oceanic	11	5.5	4.5	5.1	AL03 mean values = 8.4 median = 10.4	MK00 mean values = 3.4 median = 0
Temperate mountainous	20	4.9	5.4	4.2	BA mean values = 5.1 median = 5.6	RS22 mean values = 4.5 median = 4.8

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 18. Summary of phosphorus content in cropland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1})	SR level 2 /country with highest P content (mg kg^{-1})*	SR level 2 /country with lowest P content (mg kg^{-1})*
Mediterranean (semi-arid)	14	15.2	12	15.8	MK00 mean values = 17.1 12	AL03 mean values = 10.5 median = 12.2
Mediterranean (temperate to sub-oceanic)	25	10.1	6	18.2	AL02 mean values = 14.9 median = 3.35	AL01 mean values = 5.6 median = 7
Sub-continental (southern)	272	22.7	14.6	24.6	RS22 mean values = 39.8 median = 21.9	MK00 mean values = 15.6 median = 8.3
Sub-oceanic	12	14.8	5.1	21.1	AL01 mean values = 14.6 median = 4.1	MK00 mean values = 11.7 median = 6.7

Temperate mountainous	14	27.8	14.9	37.4	BA mean values = 42.3 median = 31.9	MK00 mean values = 10.2 median = 10.3

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

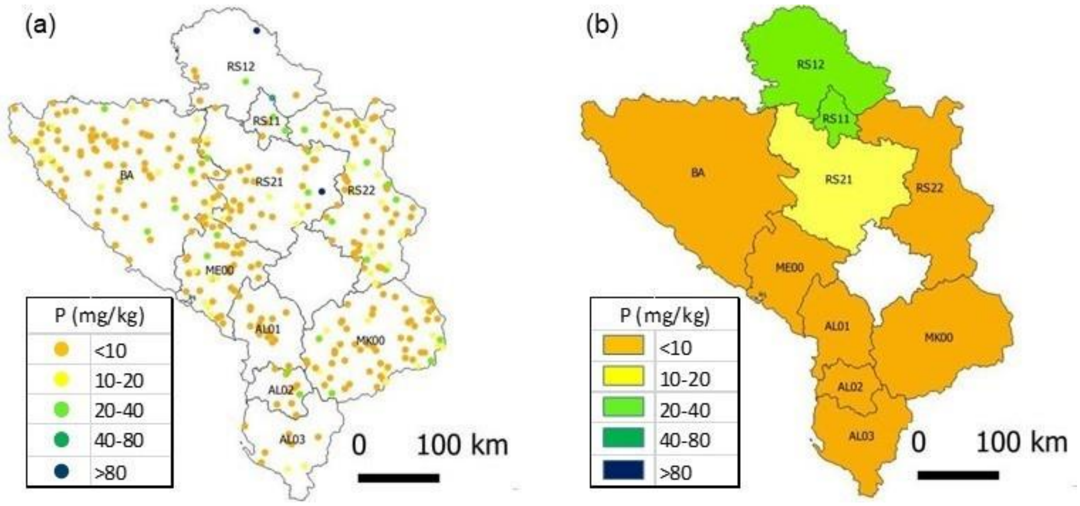
Table 19. Summary of phosphorus content in grassland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1})	SR level 2 /country with highest P content (mg kg^{-1})*	SR level 2 /country with lowest P content (mg kg^{-1})*
Mediterranean (semi-arid)	9	33.1	6.4	80.1	MK00 mean values = 71.1 median = 19.4	AL03 mean values = 2.7 median = 0
Mediterranean (temperate to sub-oceanic)	21	7.7	4.4	13.1	ME00 mean values = 16.2 median = 9.7	AL03 mean values = 6.2 median = 0
Sub-continental (southern)	71	13.1	8.4	17.7	RS21 mean values = 17.3 median = 10	ME00 mean values = 4.9 median = 2
Sub-oceanic	25	8.1	0	15.9	MK00 mean values = 16.2 median = 17.5	AL01 mean values = 1.8 median = 0
Temperate mountainous	70	8.8	7.4	11.6	RS22 mean values = 13.5 median = 8.4	MK00 mean values = 1.2 median = 0

* SR level 2 /country with three or more points were only considered

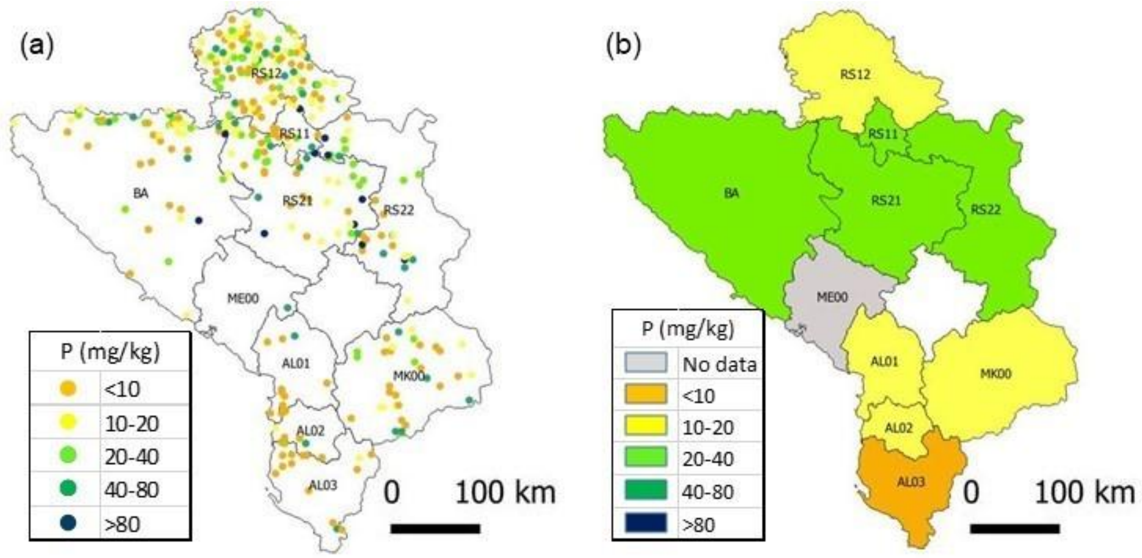
Source: JRC analysis

Figure 19. Phosphorous content in woodlands (a) point data and (b) average aggregated at SR level 2 /country level



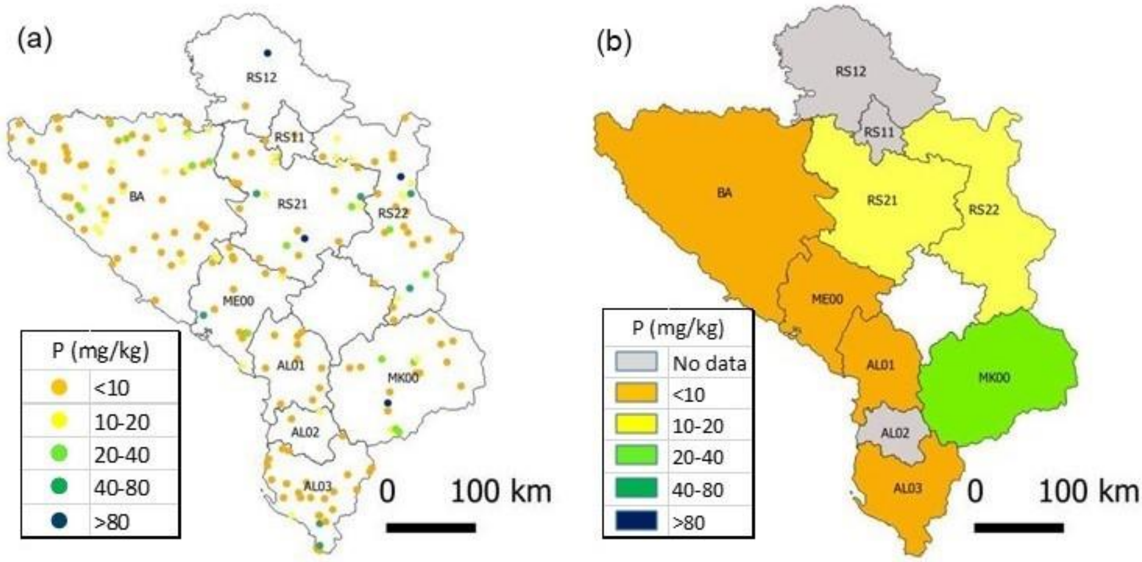
Source: JRC analysis

Figure 20. Phosphorous content in croplands (a) point data and (b) average aggregated at SR level 2 /country level



Source: JRC analysis

Figure 21. Phosphorous content in grasslands (a) point data and (b) average aggregated at SR level 2 /country level



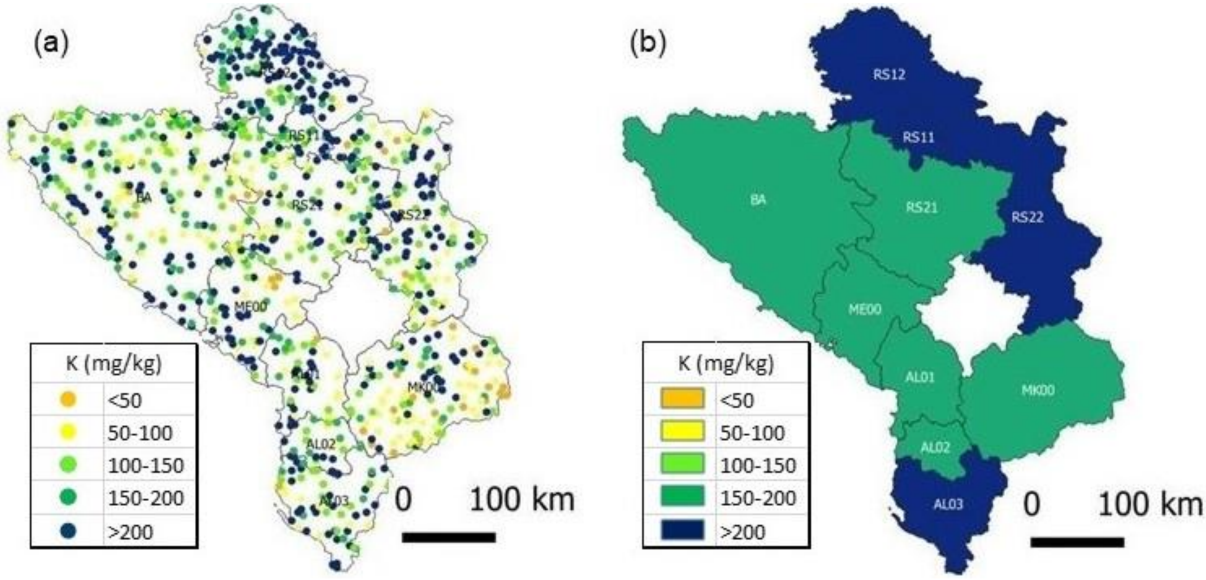
Source: JRC analysis

Overall, while the Western Balkans experience specific land cover-induced variability in P levels, EU regions exhibit a broader range of potassium variability influenced by diverse soil textures and environmental conditions. These disparities highlight differing regional soil management practices and natural conditions that impact nutrient distribution.

Potassium content

The spatial variability of potassium (K), presented in Figure 22, is primarily influenced by texture and mineralogy, as well as fertiliser application.

Figure 22. Potassium content (all points) presented (a) as point data and (b) average aggregated at SR level 2/country level



Source: JRC analysis

Soils with a higher clay content have an enhanced ability to retain K, reducing the likelihood of leaching. These factors play a critical role in determining the distribution of K across different land classes. The lowest potassium level of 114.6 mg kg^{-1} was observed in **croplands** within the Sub-oceanic climatic zone, while the highest level of 225.9 mg kg^{-1} was found in the **woodlands** and **shrublands** of the Mediterranean (temperate to sub-oceanic) zone (Tables 20 – 23). Interestingly, this pattern differs from the typical findings within the EU, where K content is generally higher in cropland and grassland areas compared to woodland sites (Jones *et al.*, 2020). This discrepancy could be attributed to several factors, such as differences in soil composition or the natural mineral content of the region's soils. Figures 23, 24, and 25 present the K content across different land uses, specifically woodlands, grasslands, and croplands.

Table 20. Summary of potassium in woodland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1}	SR level 2 /country with highest K content (mg kg^{-1}) *	SR level 2 /country with lowest K content (mg kg^{-1}) *
Mediterranean (semi-arid)	2	106.1				
Mediterranean (temperate to sub-oceanic)	17	199.2	225.9	84.8	ME00 mean values = 224.6 median = 231.4	ME00 mean values = 224.6 median = 231.4
Sub-continental (southern)	134	148.7	120.7	159.2	RS12 mean values = 256.2 median = 163.2	ME00 mean values = 74.6 median = 57.2
Sub-oceanic	54	171.8	140.7	116.6	AL03 mean values = 323.5 median = 293	ME00 mean values = 120.3 median = 85.7
Temperate mountainous	137	147.6	127.2	88.2	RS21 mean values = 215.6 median = 180.8	MK00 mean values = 91.2 median = 61.2

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 21. Summary of potassium in shrublands points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (g kg^{-1})	Std dev (mg kg^{-1})	SR level 2 /country with highest K content (mg kg^{-1}) *	SR level 2 /country with lowest K content (mg kg^{-1}) *
Mediterranean (semi-arid)	2	106.1				
Mediterranean (temperate to sub-oceanic)	17	199.2	225.9	84.8	ME00 mean values = 224.6 median = 231.4	ME00 mean values = 224.6 median = 231.4
Sub-continental (southern)	134	148.7	120.7	159.2	RS12 mean values = 256.2 median = 163.2	ME00 mean values = 74.6 median = 57.2
Sub-oceanic	54	171.8	140.7	116.6	AL03 mean values = 323.5 median = 293	ME00 mean values = 120.3 median = 85.7
Temperate mountainous	137	147.6	127.2	88.2	RS21 mean values = 215.6 median = 180.8	MK00 mean values = 91.2 median = 61.2

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 22. Summary of potassium in grassland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1})	SR level 2 /country with highest K content (mg kg^{-1}) *	SR level 2 /country with lowest K content (mg kg^{-1}) *
Mediterranean (semi-arid)	9	150.9	115.1	81.8	AL03 mean values = 172.3 median = 160.6	MK00 124.1 median = 81.8
Mediterranean (temperate to sub-oceanic)	21	220.6	162.6	169.2	AL03 mean values = 249.3 median = 194.6	ME00 mean values = 154.2 median = 124.6
Sub-continental (southern)	71	247.8	156.1	430.9	RS22 mean values = 539.3 median = 150.3	ME00 mean values = 146.4 median = 159.6
Sub-oceanic	25	179.9	145.7	125.1	AL01 mean values = 205.2 median = 145.7	MK00 mean values = 140.8 median = 135.2
Temperate mountainous	70	226.5	218	142	RS22 mean values = 273.7 median = 237	ME00 mean values = 152.3 median = 137.1

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

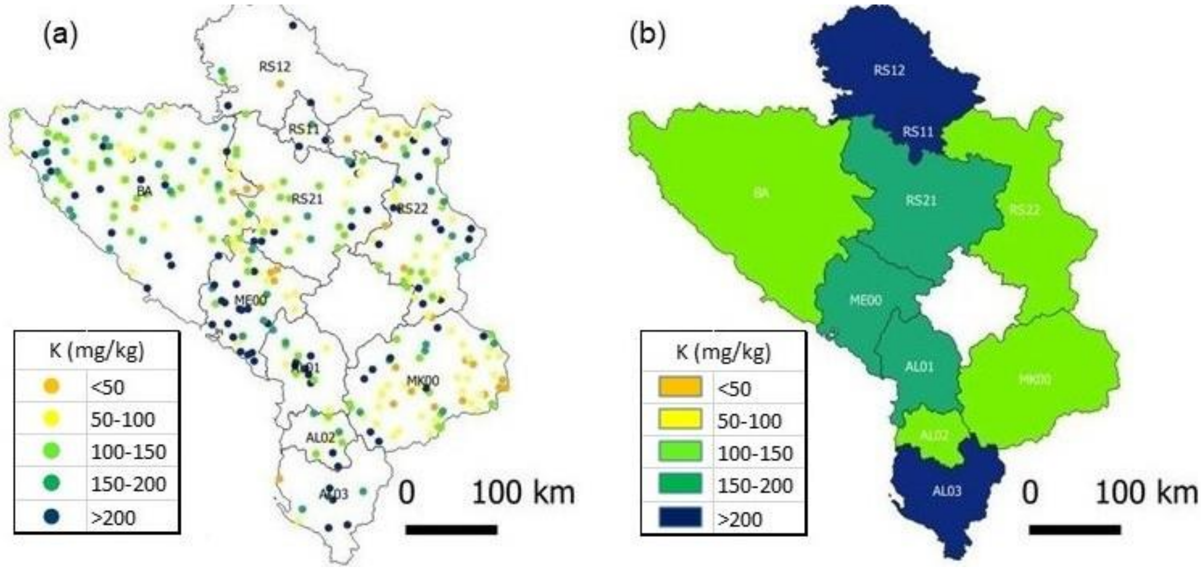
Table 23. Summary of potassium in cropland points.

Climatic zone	N points	Mean values (mg kg^{-1})	Median (mg kg^{-1})	Std dev (mg kg^{-1})	SR level 2/country with highest K content (mg kg^{-1}) *	SR level 2 /country with lowest K content (mg kg^{-1}) *
Mediterranean (semi-arid)	14	154.3	128.2	89.2	AL03 mean values = 242.2 median = 204	MK00 mean values = 119.1 median = 121.7
Mediterranean (temperate to sub-oceanic)	25	215.2	200.7	102.4	AL01 mean values = 274.1 median = 278.4	AL03 mean values = 200.2 median = 132.2
Sub-continental (southern)	272	243.4	209.6	135.6	MK00 mean values = 314.3 median = 302.6	BA mean values = 163.7 median = 156.7
Sub-oceanic	12	134.1	114.6	75.3	AL01 mean values = 152.5 median = 123.5	MK00 mean values = 105.7 median = 72.7
Temperate mountainous	14	215.5	184.1	127.3	RS22 mean values = 331.4 median = 315.4	MK00 mean values = 145.1 median = 67.8

* SR level 2 /country with three or more points were only considered

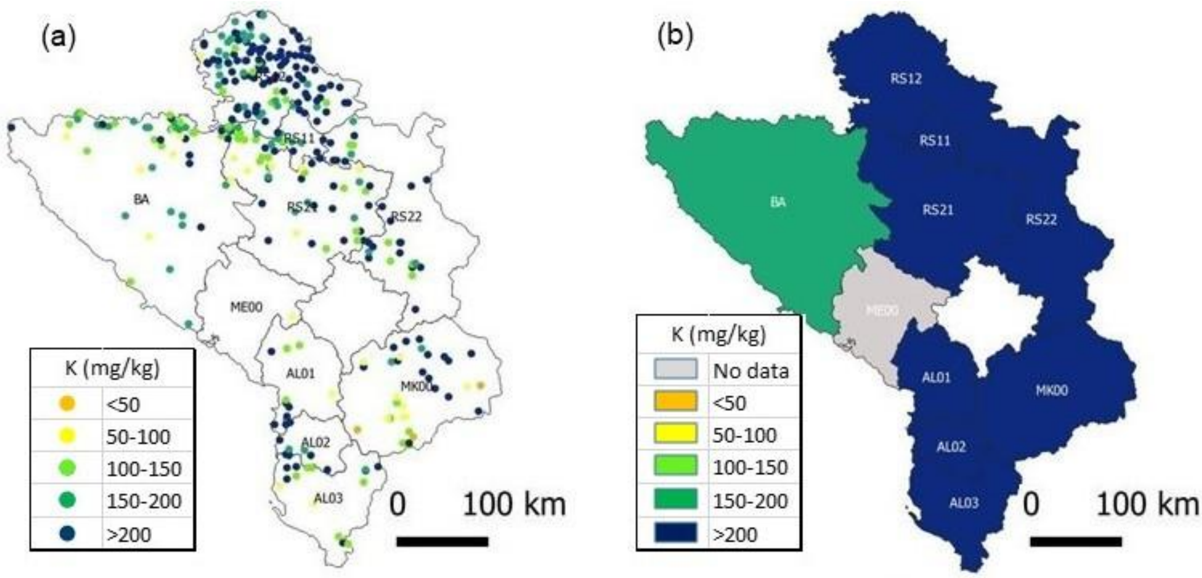
Source: JRC analysis

Figure 23. Potassium content in woodlands (a) point data and (b) average aggregated at SR level 2/country level



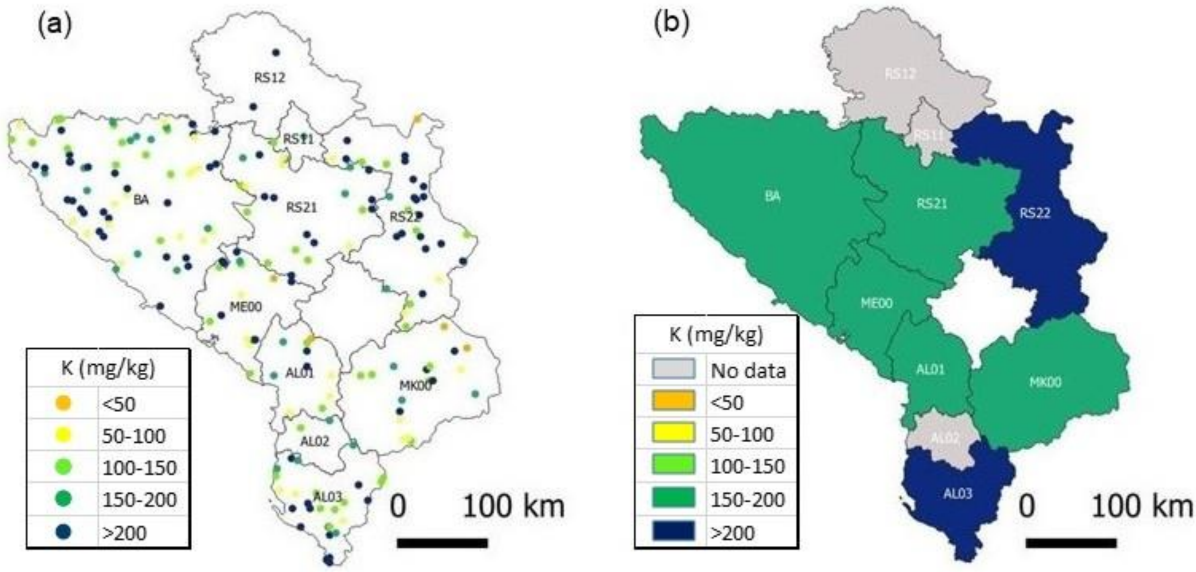
Source: JRC analysis

Figure 24. Potassium content in croplands (a) point data and (b) average aggregated at SR level 2/country level



Source: JRC analysis

Figure 25. Potassium content in grasslands (a) point data and (b) average aggregated at SR level 2/country level



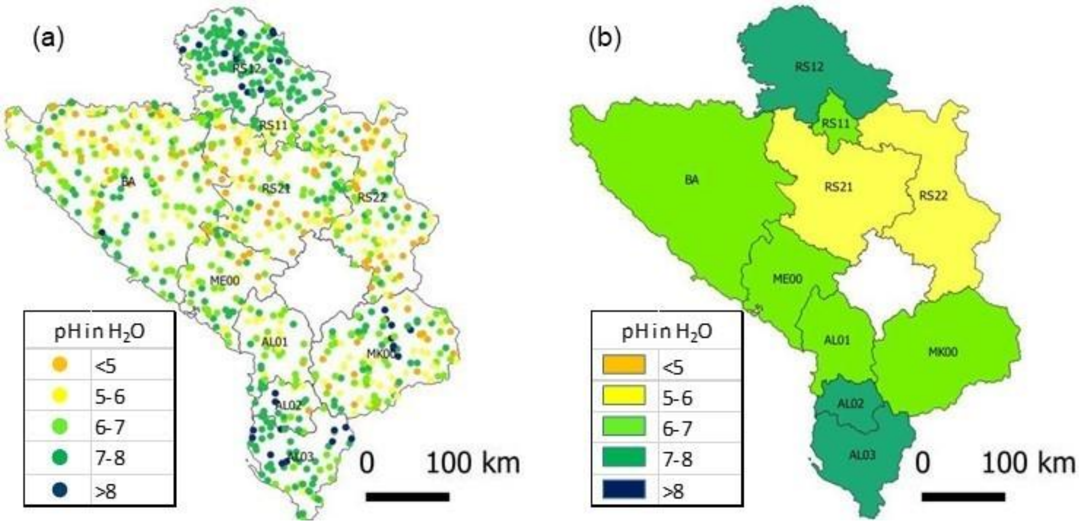
Source: JRC analysis

5.3. pH and carbonates

pH (measured in water and calcium chloride)

The spatial distribution of soil pH, whether measured in water (pH in H_2O) or calcium chloride (pH in $CaCl_2$), is primarily influenced by the underlying rock type (lithology) and climate. Additionally, agricultural soil management practices, such as liming and irrigation, play significant roles in altering soil pH levels. In regions affected by ultrabasic rocks, such as certain areas in Albania, Montenegro, and North Macedonia, topsoil tends to be acidic. However, these areas are relatively small compared to the rest of the region. Conversely, flatlands formed from calcareous parent materials typically exhibit more alkaline pH levels. In Albania and similar environments in other countries, pH is also high in saline and sodic soils, such as Solonchaks and Solonetz (Figure 26).

Figure 26. pH in H_2O (all points) presented (a) as point data and (b) average aggregated at SR level 2 /country level



Source: JRC analysis

For **croplands**, the average pH in water is 7.4, ranging from 6.5 to 7.8. In terms of pH in $CaCl_2$, croplands have an average value of 6.78, with the lowest recorded at 6.2 in the Temperate mountain areas characterized by ultrabasic rocks, and the highest at 7.4 in the Mediterranean (temperate to sub-oceanic) zones.

Woodlands exhibit the lowest pH values, especially when measured in CaCl2, with levels as low as 5.2 in the Sub-continental (southern) climatic zone. **Grasslands** have pH values similar to those of croplands, though they are slightly lower. The average median pH value for grasslands in water is 6.7, and in $CaCl_2$, it is 6.4 (Tables 24 - 29).

Table 24. Summary of pH in H_2O in woodland points

Climatic zone	N points	Mean values	Median	Std dev	SR level 2 /country with highest pH in H_2O content *	SR level 2 /country with lowest pH in H_2O content *
Mediterranean (semi-arid)	2	7.2				
Mediterranean (temperate to sub-oceanic)	17	6.7	6.9	0.7	ME00 mean values = 6.5 median = 6.4	ME00 mean values = 6.5 median = 6.4
Sub-continental (southern)	134	5.7	5.6	1	RS12 mean values = 6.8 median = 7	BA mean values = 5.4 median = 5.3
Sub-oceanic	54	6.2	6.1	0.9	AL03 mean values = 7.4 median = 7.3	ME00 mean values = 5.8 median = 6
Temperate mountainous	137	5.9	6	1	ME00 mean values = 6.1 median = 6.4	RS21 mean values = 5 median = 5.1

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 25. Summary of pH in $CaCl_2$ in woodland points

Climatic zone	N points	Mean values	Median	Std dev	SR level 2 /country with highest pH in $CaCl_2$ content *	SR level 2 /country with lowest pH in $CaCl_2$ content *
Mediterranean (semi-arid)	2	6.7				
Mediterranean (temperate to sub-oceanic)	17	6.5	6.6	0.8	ME00 mean values = 6.2 median = 6.2	ME00 mean values = 6.2 median = 6.2
Sub-continental (southern)	134	5.4	5.2	1	RS12 mean values = 6.5 median = 6.8	BA mean values = 5 median = 4.9
Sub-oceanic	54	5.8	5.8	1	AL03 mean values = 7.1 median = 7.1	ME00 mean values = 5.4 5.6
Temperate mountainous	137	5.5	5.7	1.1	BA mean values = 5.9 median = 6.1	RS21 mean values = 4.6 median = 4.6

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 26. Summary of pH in H_2O in cropland points

Climatic zone	N points	Mean values	Median	Std dev	SR level 2 /country with highest pH in H_2O content *	SR level 2 /country with lowest pH in H_2O content *
Mediterranean (semi-arid)	14	6.9	6.8	0.9	AL03 mean values = 7.8 median = 8	MK00 mean values = 6.5 median = 6.4
Mediterranean (temperate to sub-oceanic)	25	7.7	7.8	0.3	AL02 mean values = 7.7 median = 7.8	AL01 mean values = 7.6 median = 7.6
Sub-continental (southern)	272	7	7.6	1.1	RS12 mean values = 7.7 7.8	RS21 mean values = 5.9 median = 5.7
Sub-oceanic	12	6.5	6.5	0.9	MK00 mean values = 6.8 median = 6.8	AL01 mean values = 6 median = 5.9
Temperate mountainous	14	6.7	6.5	0.8	RS22 mean values = 6.9 median = 6.9	MK00 mean values = 6.6 median = 6.2

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 27. Summary of pH in $CaCl_2$ in cropland points

Climatic zone	N points	Mean values	Median	Std dev	SR level 2 /country with highest pH in $CaCl_2$ content *	SR level 2 /country with lowest pH in $CaCl_2$ content *
Mediterranean (semi-arid)	14	6.5	6.6	0.7	AL03 mean values = 7.3 median = 7.4	MK00 mean values = 6.2 median = 6.2
Mediterranean (temperate to sub-oceanic)	25	7.3	7.4	0.3	AL03 mean values = 7.3 median = 7.4	AL01 mean values = 7.2 median = 7.2
Sub-continental (southern)	272	6.7	7.3	1.1	RS12 mean values = 7.4 median = 7.5	RS21 mean values = 5.6 median = 5.4
Sub-oceanic	12	6.2	6.4	0.9	MK00 mean values = 6.5 median = 6.6	AL01 mean values = 5.7 median = 5.7
Temperate mountainous	14	6.4	6.2	0.9	RS22 mean values = 6.7 median = 6.8	MK00 mean values = 6.1 median = 5.8

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 28. Summary of pH in H_2O in grassland points

Climatic zone	N points	Mean values	Median	Std dev	SR level 2 /country with highest pH in H_2O content *	SR level 2 /country with lowest pH in H_2O content*
Mediterranean (semi-arid)	9	6.9	6.9	0.7	AL03 mean values = 7.2 median = 7.4	MK00 mean values = 6.5 median = 6.6
Mediterranean (temperate to sub-oceanic)	21	7.6	7.8	0.7	AL03 mean values = 7.7 median = 7.8	ME00 mean values = 7.1 median = 7.2
Sub-continental (southern)	71	6.1	6	1	MK00 mean values = 7.7 median = 7.9	ME00 mean values = 5.5 median = 5.6
Sub-oceanic	25	6.7	6.9	0.9	ME00 mean values = 7.4 median = 7.4	MK00 mean values = 5.9 median = 6
Temperate mountainous	70	6.4	6.2	0.9	ME00 mean values = 6.7 median = 6.9	MK00 mean values = 6.1 median = 5.8

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 29. Summary of pH in $CaCl_2$ in grassland points

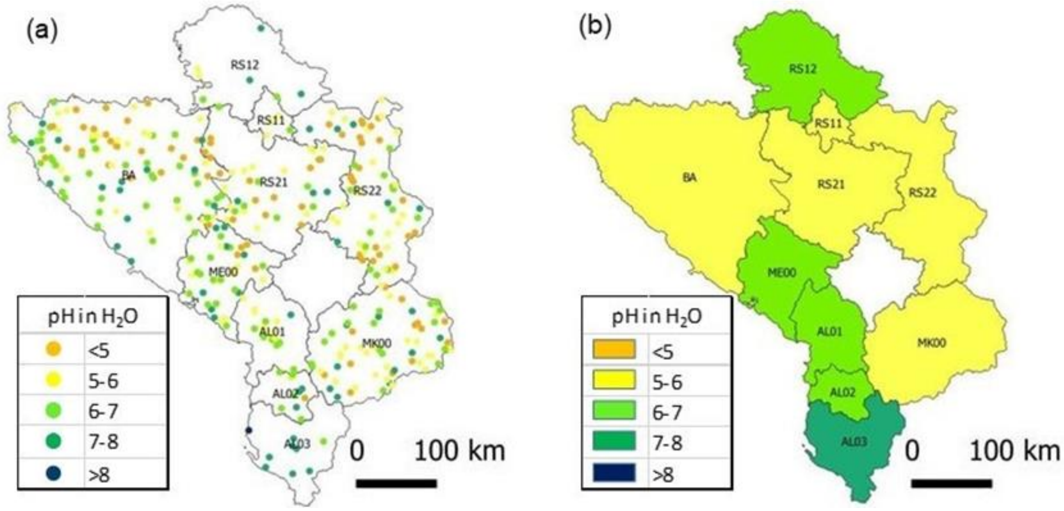
Climatic zone	N points	Mean values	Median	Std dev	SR level 2 /country with highest pH in $CaCl_2$ content *	SR level 2 /country with lowest pH in $CaCl_2$ content *
Mediterranean (semi-arid)	9	6.6	6.6	0.7	AL03 mean values = 6.8 median = 7	MK00 mean values = 6.3 median = 6.6
Mediterranean (temperate to sub-oceanic)	21	7.2	7.4	0.5	AL03 mean values = 7.3 median = 7.4	ME00 mean values = 6.8 median = 6.9
Sub-continental (southern)	71	5.8	5.8	1	MK00 mean values = 7.2 median = 7.5	ME00 mean values = 5.1 median = 5.1
Sub-oceanic	25	6.4	6.6	0.9	ME00 mean values = 7.1 median = 7.1	MK00 mean values = 5.6 median = 5.7
Temperate mountainous	70	6.1	6	0.9	ME00 mean values = 6.4 median = 6.6	MK00 mean values = 5.6 median = 5.3

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

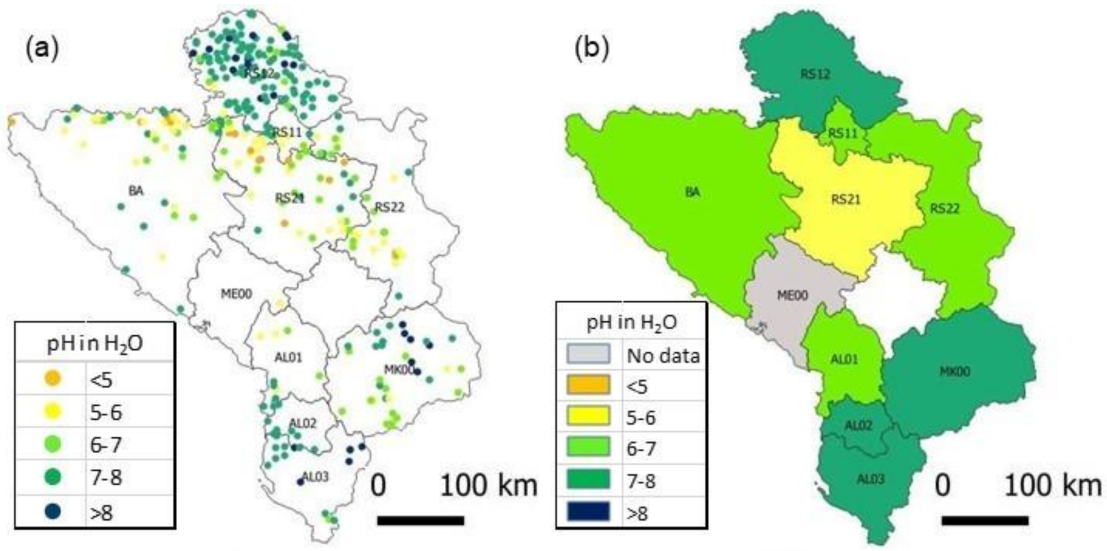
The comparison between soil pH levels in the Western Balkans and the EU (Jones *et al.*, 2020) highlights both similarities and differences shaped by geology, climate, and agricultural practices. In both regions, calcareous parent materials lead to more alkaline soils, while acidic environments are associated with ultrabasic rocks in the Western Balkans and podzols in the EU's boreal zone. However, while Western Balkan woodland areas generally have higher pH levels, the EU boreal and northern sub-continental zones display very acidic soils, revealing the influence of podzolization processes. Croplands across both regions generally exhibit neutral to alkaline pH due to soil management practices like liming and irrigation, although the EU shows a broader range of pH variation. In grasslands, the EU experiences a wide pH spectrum, reflecting its diverse grassland types across varying climates. Figures 27, 28, and 29 present the pH (in H_2O) values across different land uses.

Figure 27. pH H_2O in woodlands (a) point data and (b) average aggregated at SR level 2/country level.



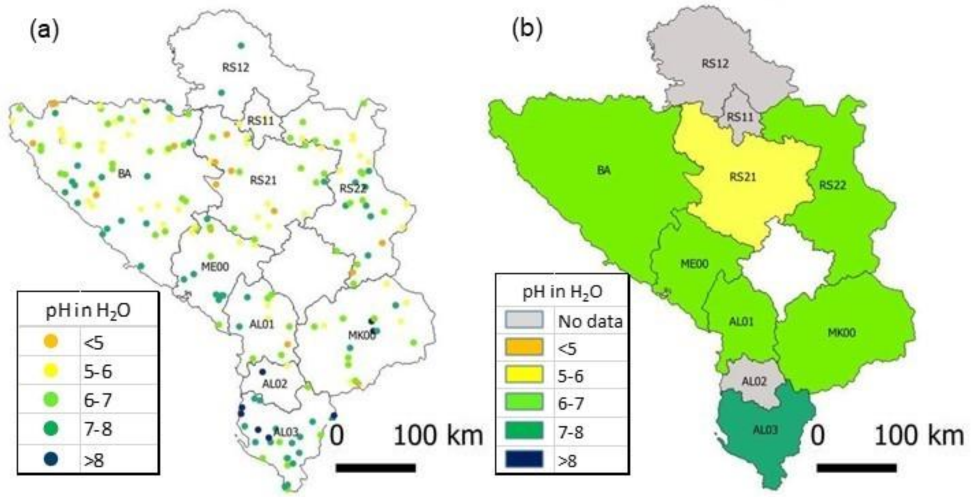
Source: JRC analysis

Figure 28. pH H_2O in croplands (a) point data and (b) average aggregated at SR level 2/country level.



Source: JRC analysis

Figure 29. pH H_2O in grassland (a) point data and (b) average aggregated at SR level 2/country level.



Source: JRC analysis

Carbonate content

In the Western Balkans, carbonate ($CaCO_3$) content is prevalent in soils classified as Calcisols, many of which feature a calcic or petrocalcic horizon, as seen in Albania (Photo 2) (Figure 30).

Photo 2. Calcisols with calcic horizons in Albania

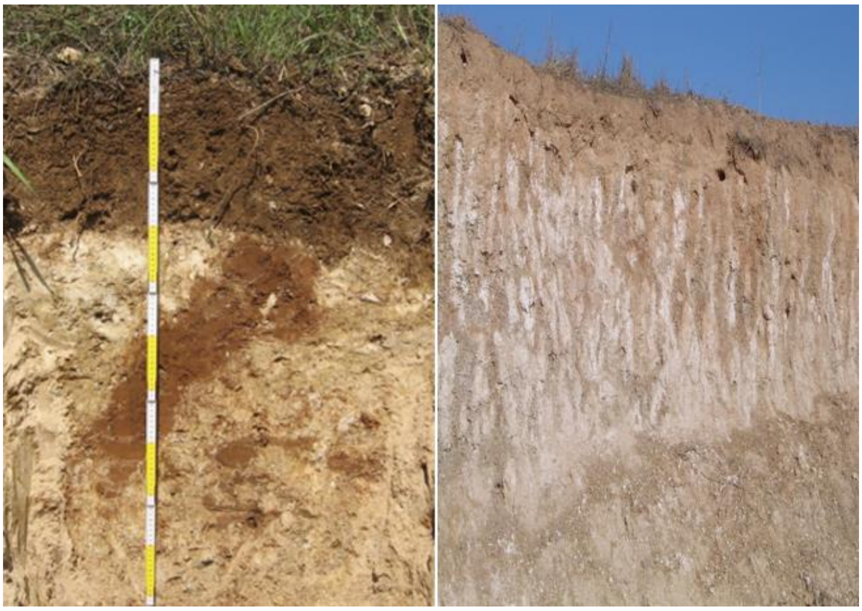


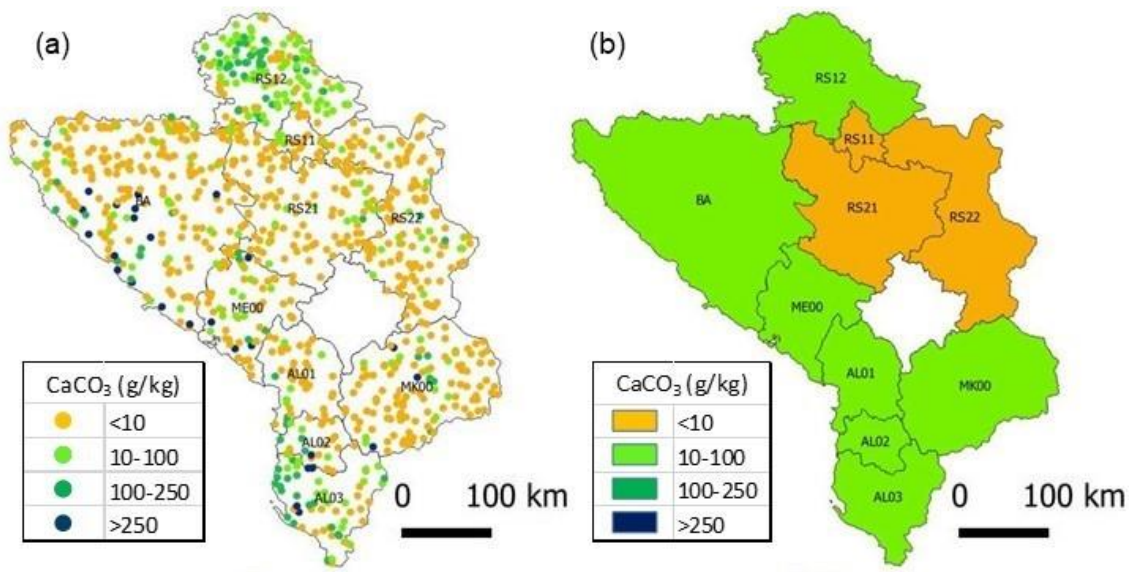
Photo credits: P. Zdruli

However, the distribution of these soils is generally limited compared to other soil types, which is evident from the lack of carbonate data, especially in Serbia. In **woodlands**, the mean $CaCO_3$ content is 49.4 g kg^{-1}, with a very low median value (Table 30). In **croplands**, the mean $CaCO_3$ content is 50.4 g kg^{-1}, with a median value of 23.5 g kg^{-1} (Table 31). Croplands with higher carbonate levels are mostly found in the Mediterranean (temperate to sub-oceanic) zone. **Grasslands** generally have higher carbonate levels than woodlands, with a mean value of

45.8 g kg^{-1} (Table 32). In contrast, the EU shows greater $CaCO_3$ presence, particularly in the Mediterranean zones, where cropland, grassland, and woodland areas often exceed 250 g kg^{-1} of $CaCO_3$. Sub-oceanic regions also demonstrate significant carbonate content (>100 g kg^{-1}). However, in the rest of the EU's climatic zones, $CaCO_3$ levels in all land cover classes are very low (<1 g kg^{-1}) (Jones *et al.*, 2020).

This comparison underscores that while both regions display $CaCO_3$ accumulation in Mediterranean areas, the EU has markedly higher $CaCO_3$ levels overall, influenced significantly by its diverse lithological and climatic conditions.

Figure 30. $CaCO_3$ content (all points) presented (a) as point data and (b) average aggregated at SR level 2 /country level



Source: JRC analysis

Table 30. Summary of $CaCO_3$ in woodland points

Climatic zone	**N points**	**Mean values (g kg^{-1})**	**Median (g kg^{-1})**	**Std dev (g kg^{-1})**	**SR level 2 /country with highest $CaCO_3$ content (g kg^{-1})***	**SR level 2/ country with lowest $CaCO_3$ content (g kg^{-1})***
Mediterranean (semi-arid)	2	122				
Mediterranean (temperate to sub-oceanic)	17	76.6	8	139.1	ME00 mean values = 41.1 median = 6	ME00 mean values = 41.1 median = 6
Sub-continental (southern)	134	12	0	61.7	RS12 mean values = 36.8 median = 27.5	RS11 mean values = 0.4 median = 0
Sub-oceanic	54	13.3	1	41.6	AL03 mean values = 52.6 56	ME00 mean values = 1.2 median = 1
Temperate mountainous	137	23.6	1	88.8	ME00 mean values = 43.8 median = 3.5	RS21 mean values = 0.8 median = 0.5

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 31. Summary of $CaCO_3$ in cropland points

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest $CaCO_3$ content (g kg^{-1})*	SR level 2 /country with lowest $CaCO_3$ content (g kg^{-1})*
Mediterranean (semi-arid)	14	10.8	0	23.6	AL03 mean values = 37.2 median = 41	MK00 mean values = 0.2 median = 0
Mediterranean (temperate to sub-oceanic)	25	157.3	109	178.4	AL02 mean values = 164.7 median = 115	AL01 mean values = 48 median = 24.5
Sub-continental (southern)	272	37.9	7	57.2	MK00 mean values = 66.2 median = 16	RS22 mean values = 0.7 median = 0
Sub-oceanic	12	13.1	1	28.8	MK00 mean values = 28.8 median = 0	AL01 mean values = 0.8 median = 1
Temperate mountainous	14	34.1	0.5	112.1	BA mean values = 63.6 median = 0	MK00 mean values = 1 median = 0

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 32. Summary of $CaCO_3$ in grassland points

Climatic zone	N points	Mean values (g kg^{-1})	Median (g kg^{-1})	Std dev (g kg^{-1})	SR level 2 /country with highest $CaCO_3$ content (g kg^{-1})*	SR level 2 /country with lowest $CaCO_3$ content (g kg^{-1})*
Mediterranean (semi-arid)	9	17.4	1	39.4	AL03 mean values = 30.2 median = 2	MK00 mean values = 1.5 0.5
Mediterranean (temperate to sub-oceanic)	21	127.1	128	119.5	ME00 mean values = 207.8 median = 183.5	AL03 mean values = 107.7 median = 131.5
Sub-continental (southern)	71	11.3	1	36.7	MK00 mean values = 86.4 median = 183.5	RS21 mean values = 0.9 median = 0
Sub-oceanic	25	25.7	2	51.2	ME00 mean values = 50.3 median = 37	MK00 mean values = 0 median = 0
Temperate mountainous	70	47.8	1	122.1	BA mean values = 70.8 median = 1.5	MK00 mean values = 2 median = 0

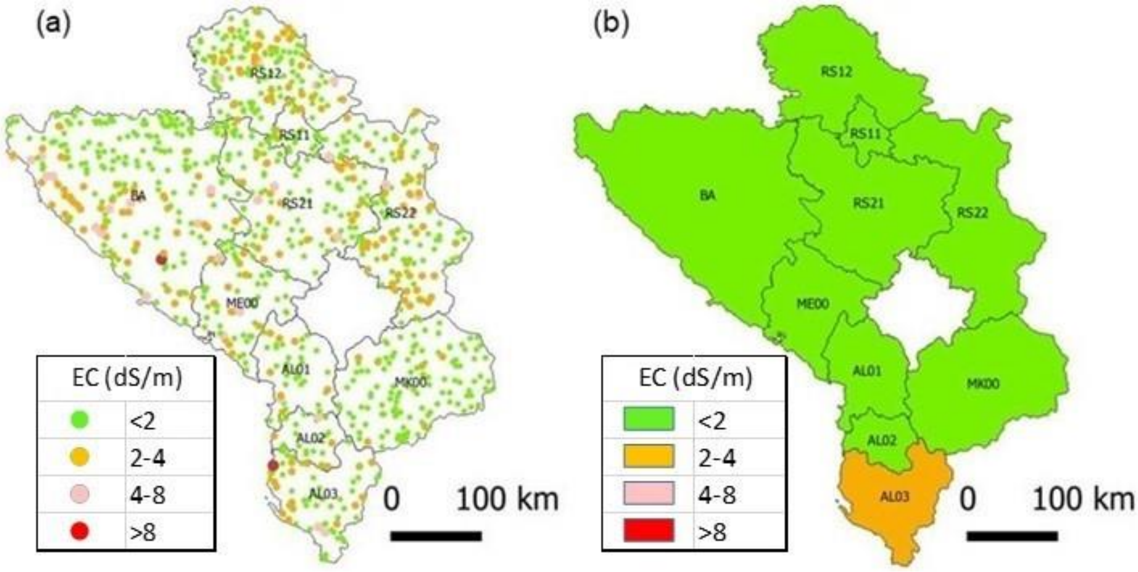
* SR level 2 /country with three or more points were only considered

Source: JRC analysis

5.4. Electrical conductivity

Electrical conductivity (EC) is indirectly used to assess the presence of soluble salts in soil (Friedman, 2005). Factors influencing EC include soil texture and parent material, climate, and soil management practices, particularly the use of poor-quality irrigation water and fertilisation methods. Most of the points across the EU showed low EC, which indicates that they were not saline and that their salt contents were at a minimum (Figure 29). However, Figure 31 shows some salinity hotspots, specifically in Albania where salinity affects approximately 15,000 hectares along the Adriatic coast. Other countries have only limited areas impacted by salinity, so no statistical analyses have been carried out for electrical conductivity.

Figure 31. Electrical conductivity content (all points) presented (a) as point data and (b) average aggregated at SR level 2/country level



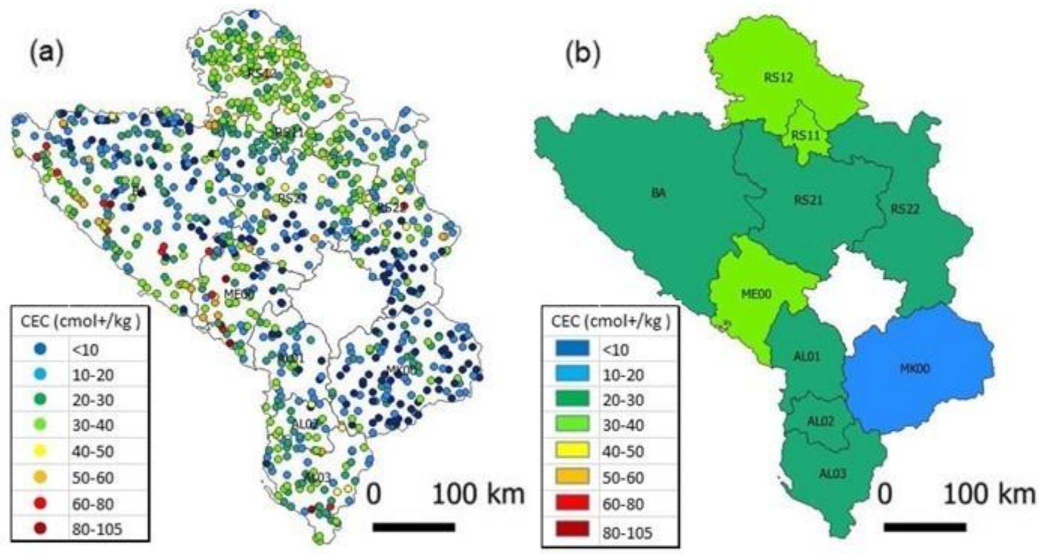
Source: JRC analysis

5.5. Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) is a soil indicator directly related to soil reactivity and soil nutrient retention capacity. It measures the potential negative charges in the soil that are able to adsorb nutrient cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}). CEC reflects a soil's ability to retain and exchange cations, making it a key factor in assessing the soil's potential fertility. Soils with high CEC can hold more cations and have a greater capacity for exchange than those with low CEC. This property significantly influences soil structure stability, nutrient availability, soil pH, and the soil's response to fertilisers and other amendments. CEC is also a valuable indicator of soil fertility because it indicates the soil's capacity to supply calcium, magnesium, and potassium, important nutrients for plants but also some potentially toxic metals such as cadmium, lead, nickel, copper, and zinc.

Data from the LUCAS WB 2015 survey show that the highest CEC values are found in **grasslands** in the Temperate mountainous climatic zone, with mean values of 28.1 cmol(+)/kg. Following this are **woodlands** in the Mediterranean (temperate to sub-oceanic) climatic zone, with mean values of 38.9 cmol(+)/kg, and **croplands** in the Sub-continental (southern) climatic zone, with mean values of 29 cmol(+)/kg. Generally, CEC values above 10 cmol(+)/kg are considered sufficient for biomass production, indicating that the CEC values in the Western Balkans are generally favorable. Clay soils may exhibit even higher CEC values (Figure 32, Tables 33, 34, and 35).

Figure 32. Cation Exchange Capacity (all points) presented (a) as point data and (b) average aggregated at SR level 2/country level



Source: JRC analysis

Table 33. Summary of Cation exchange capacity in woodland points

Climatic zone	N points	Mean values (cmol+ kg^{-1})	Median (cmol+ kg^{-1})	Std dev (cmol+ kg^{-1})	SR level 2 /country with highest CEC content (cmol+ kg^{-1})*	SR level 2 /country with lowest CEC content (cmol+ kg^{-1}) *
Mediterranean (semi-arid)	2	15.2				
Mediterranean (temperate to sub-oceanic)	17	38.9	30.9	23	ME00 mean values = 45.6 median = 38.8	ME00 mean values = 45.6 median = 38.8
Sub-continental (southern)	134	18.3	15.2	11.9	RS11 mean values = 29.5 29.9	MK00 mean values = 12.4 median = 8.6
Sub-oceanic	54	22.6	19.6	17.3	AL03 mean values = 52.6 median = 37.7	MK00 mean values = 15.7 median = 9.5
Temperate mountainous	137	23.2	20.1	17.4	ME00 mean values = 33 median = 33.6	MK00 mean values = 7.9 median = 6.4

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 34. Summary of Cation exchange capacity in cropland points

Climatic zone	N points	Mean values (cmol+ $kg^{-1)}$	Median (cmol+ $kg^{-1)}$	Std dev (cmol+ $kg^{-1)}$	SR level 2 /country with highest CEC content (cmol+ $kg^{-1)}$ (1)	SR level 2 /country with lowest CEC content (cmol+ $kg^{-1)}$(1)
Mediterranean (semi-arid)	14	16.7	15.2	13	AL03 mean values = 31.2 median = 25.6	MK00 mean values = 13.7 11.8
Mediterranean (temperate to sub-oceanic)	25	28	26.4	9.2	AL01 mean values = 34.8 median = 35.2	AL02 mean values = 26.2 median = 27.3
Sub-continental (southern)	272	29	30.2	11.1	RS11 mean values = 33.8 median = 34.5	BA mean values = 19.3 16.5
Sub-oceanic	12	16	13.8	7	AL01 mean values = 15.7 median = 17.9	MK00 mean values = 13.4 median = 12.4
Temperate mountainous	14	20	17.8	13.1	RS22 mean values = 37.5 35.8	MK00 mean values = 6.6 median = 3.6

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

Table 35. Summary of Cation Exchange capacity in grassland points

Climatic zone	N points	Mean values (cmol+ kg$^{-1)}$	Median (cmol+ kg$^{-1)}$	Std dev (cmol+ kg$^{-1)}$	SR level 2 /country with highest CEC content (cmol+ kg$^{-1)}$ (1)	SR level 2 /country with lowest CEC content (cmol+ kg$^{-1)}$ (1)
Mediterranean (semi-arid)	9	21.6	18.6	11.5	AL03 mean values = 27.8 25.5	MK00 mean values = 13.8 median = 11.5
Mediterranean (temperate to sub-oceanic)	21	25.7	27.9	10.6	ME00 mean values = 28.1 median = 24	AL03 mean values = 24.9 median = 25.2
Sub-continental (southern)	71	22.3	19.4	12.6	RS22 mean values = 25 median = 28.2	ME00 mean values = 10.4 median = 10.4
Sub-oceanic	25	21.2	19.7	10	AL03 mean values = 28.4 27.3	MK00 mean values = 11.2 median = 12.8
Temperate mountainous	70	28.1	26.4	15.1	BA mean values = 29.5 median = 25.8	MK00 mean values = 19.8 median = 16.5

* SR level 2 /country with three or more points were only considered

Source: JRC analysis

6. Conclusions

Regular monitoring offers valuable insights into the condition of soils and the various pressures they face. The LUCAS Soil module, part of the Land Use/Cover Area frame statistical Survey, fulfills the European Commission's requirements by gathering data that describe soil conditions and health in relation to land use practices. This was the first survey conducted in 2015 in the Western Balkans, forming the foundation for this report.

The LUCAS WB 2015 Soil dataset comprises 955 unique records with soil and agro-environmental data from five countries: Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia. Analysis of topsoil properties from this dataset revealed several key outcomes:

— **Organic carbon, N**, and **P levels** was decreasing from cooler, temperate mountainous regions to warmer areas. Overall, woodland and grassland contained more SOC and N than cropland, while P levels were higher in cropland compared to woodland and grassland.

— **Potassium content** was lower in colder regions and higher in the warmer Mediterranean areas, possibly due to leaching, though there is no definitive scientific explanation. Generally, K levels were higher in cropland and grassland than in woodland, likely due to fertilisation practices.

— **Topsoil pH**, measured in both H_2O and $CaCl_2$, tended to be acidic in mountain regions, especially in soils formed from ultrabasic rocks, and more alkaline in the Mediterranean zone, particularly along the Albanian coast and surrounding hills where higher **carbonate content** was observed. Cropland had higher pH values compared to grassland and woodland.

— **Electrical conductivity** (EC) measurements were taken for all soils to provide a preliminary assessment of salinity levels in the Western Balkans. The results generally indicated low salinity, with most countries exhibiting low EC values. However, it is possible that areas with salinity issues may have been under-represented in the sampling, highlighting the need for further surveys to confirm these findings.

This study highlights the status of soil information in the Western Balkans region, showing that soils are under pressure. The present state of soil degradation in Western Balkans could be seamlessly incorporated into the EU soil degradation dashboard, as both soil databases are harmonized.

The region urgently needs updated soil data and new surveys supported by reliable laboratory analyses. These needs are increasingly critical as the region progresses towards EU membership and must align its soil legislation with EU standards.

It is strongly recommended that this region continue participating in future LUCAS surveys with a dedicated funding mechanism, ensuring compatibility with those conducted in EU countries. Such surveys should align with the Soil Monitoring and Resilience Law to facilitate continuous soil health monitoring.

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