Received: 15 January 2018 | Revised: 21 June 2019 | Accepted: 24 June 2019

DOI: 10.1111/ejss.12862

ORIGINAL ARTICLE

European Journal of Soil Science WILEY

Comparison of sampling with a spade and gouge auger for topsoil monitoring at the continental scale

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Abstract

The sampling method is a key aspect when designing a soil monitoring network. The determination of any physical and chemical property can be subject to uncertainties because of the sampling method. In this study, we compared the efficiency of sampling with a spade and a gouge auger for the physicochemical characterization of topsoil samples from 150 mineral soils under various land cover (LC) classes in Switzerland taken within the LUCAS 2015 Survey. The sampling methods differed in their scheme, accuracy of litter removal and control of sampling depth, which were more rigorous with the gouge auger than the spade method. Values of root mean square error of properties ranged between 1/2 and 1/30 of their mean values. Lin's concordance correlation coefficient showed that the spade and gouge auger methods produced similar results for all properties (LCCC $\geq$0.73), with a better relation for arable land than other LC classes. A poor relation was observed for potassium (LCCC = 0.35) in coniferous forest because of its shallow distribution in depth. We concluded that the simpler and cheaper spade method is an accurate method for topsoil sampling at the continental scale. From this study, it is clear that some improvements in the control of sampling depth and the accuracy of litter removal are needed, especially when monitoring forest soils and properties that change rapidly with depth. Spade sampling can help to expand the implementation of soil monitoring surveys at the continental scale at relatively low sampling cost.

Highlights

- Spade and gouge auger sampling methods were compared to monitor topsoil properties in the LUCAS Survey.
- The gouge auger is the method of choice for properties with patchy and shallow distribution.
- The spade method is efficient if sampling depth and litter removal are carefully controlled.
- Spade sampling can expand topsoil monitoring at continental scale at relatively low sampling cost.

KEYWORDS

arable land, grassland, land cover, LUCAS, organic carbon, soil properties, woodland

1 | INTRODUCTION

Soil monitoring is the systematic measurement of soil variables in a network of sampling units to detect temporal and spatial changes in soil conditions (Morvan et al., 2008). The early detection of such changes is a primary objective for scientific and policy organizations because it enables the design and implementation of policy measures to facilitate sustainable soil use and management in order that soils continue to deliver ecosystem services while preventing their degradation. The use of standardized and reliable sampling and analysis methods is essential to detect changes in soil variables. At the European scale, the Topsoil Survey of LUCAS (Land Use and Cover Area Frame Survey) is a good example of a harmonized soil monitoring network with ca. 27,000 locations throughout Europe in 2015. Samples have been taken according to the LUCAS soil sampling method at all locations and have been analysed with standard methods in a central laboratory (Eurostat, 2017).

The reliability of a soil analysis depends on the quality of the sample analysed. A soil sample must be representative of the sampling unit, composed of a proper number of subsamples, taken at a well-defined depth, and carefully handled and prepared for the specific analyses to be carried out. All these aspects have to be considered when designing the scheme for the sampling units, when choosing the equipment to collect samples and when preparing samples. Sampling units can be landscapes, fields or point locations (Spencer, Ogle, Breidt, Goebel, & Paustian, 2011) and the number of subsamples taken at each unit depends on the variation in soil conditions and the area to be represented. The equipment used to collect samples determines the type of sample and the depth sampled. For example, a spade is a convenient tool to collect disturbed topsoil samples, whereas a gouge auger is appropriate to take relatively undisturbed soil samples with better depth control. During sampling, accurate removal (or not) of vegetation residues from the sample can affect the content of nutrients such as organic carbon (OC), nitrogen (N) and phosphorus (P) in the soil samples.

The aim of this study was to assess the efficiency of the two sampling methods for topsoil characterization at the continental scale. We compared LUCAS sampling with a spade, a simple method developed by the European Commission, and sampling with a gouge auger, a more meticulous method often used in soil monitoring at the national scale, for example in the Swiss Soil Monitoring Network (NABO). Differences between the two sampling methods are the sampling scheme at the locations, the equipment used to collect soil and the procedure to form composite samples. We used the locations of the LUCAS 2015 Topsoil Survey in Switzerland to compare the sampling methods. Our purpose was to check whether the two sampling methods produced similar results for various physical and chemical properties in different land-cover (LC) classes.

2 | MATERIALS AND METHODS

2.1 | LUCAS Topsoil Survey

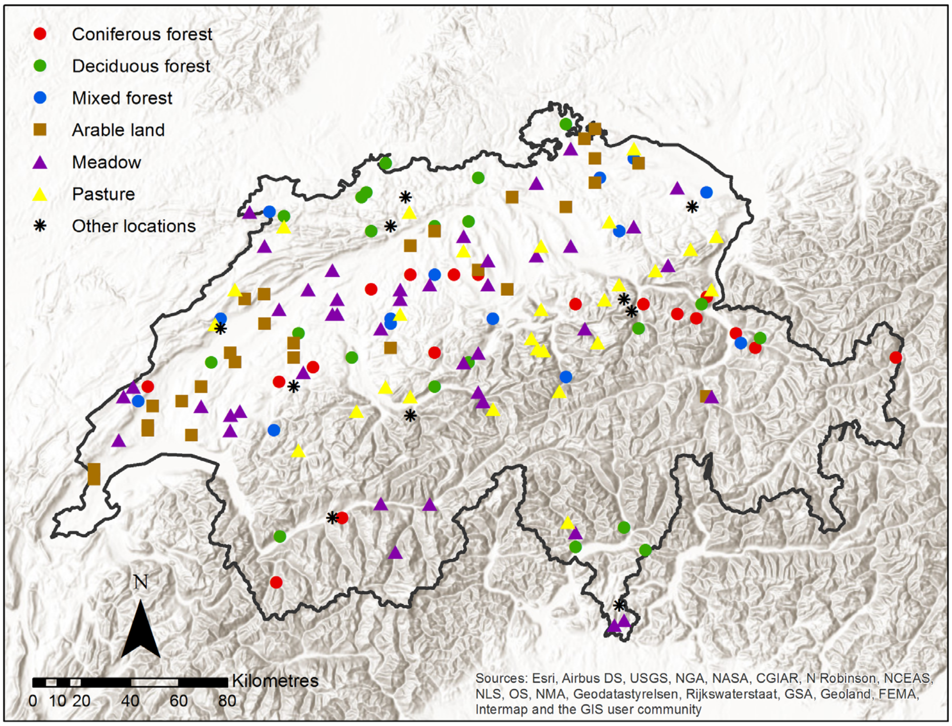
The LUCAS Topsoil Survey in 2015 consisted of 27,069 georeferenced locations in 34 European countries. The first LUCAS Topsoil Survey was carried out in 2009, covering 25 member states of the European Union (EU-25) with 19,967 locations. In 2012, the survey was extended to Romania and Bulgaria with 2,014 locations. In 2015, the survey was repeated in the same countries and extended to Albania, Bosnia and Herzegovina, Macedonia, Montenegro, Serbia and Switzerland. Furthermore, new locations between 1,000 and 1,500 m a.s.l., which were out of the scope of surveys in 2009 and 2012, were included in 2015 in all the countries. The locations of the LUCAS Topsoil Survey are based on the line intersections of a 2 × 2 km grid covering Europe, which is used for monitoring temporal changes in land use and LC in the EU (Tóth, Jones, & Montanarella, 2013).

Comparison of the LUCAS spade and gouge auger methods for topsoil sampling was carried out at the LUCAS locations of Switzerland. Here, the LUCAS topsoil survey has 160 locations distributed in woodland, arable and grassland LC classes (Figure 1). Topsoil samples (0–20 cm) were taken by the two sampling methods at each location in 2015. The samples were sent to a central laboratory for their characterization. Altogether, 320 samples were taken at the 160 locations of Switzerland: 160 samples by spade and 160 by gouge auger.

2.2 | LUCAS spade method

A composite sample of approximately 500 g was prepared from five subsamples taken with a spade at each georeferenced location, following the LUCAS sampling instructions (Eurostat, 2015). The first subsample was taken at the georeferenced location and the other four were taken at a distance of 2 m following the cardinal directions (North, East, South and West) (Figure 2a). Before collecting the first subsample, vegetation residues, grass and litter were removed from the soil surface by raking with the spade. A V-shaped hole was dug to a depth of 20 cm using the spade and a slice of soil (approximately 3-cm thick) was taken parallel to one of the sides of the hole with the spade. The sides of the slice were trimmed with a knife so that we obtained a 3-cm-wide subsample on the spade (Figure 2c). The subsample was placed in a bucket. The

FIGURE 1 Locations of the LUCAS Topsoil Survey in Switzerland. The survey has 150 locations in mineral soils under various land cover classes (coniferous, deciduous and mixed forests, arable land, meadow and pasture) that were used for this study. Another 10 locations, including organic-rich soils, vineyards, an orchard and a garden, were not considered for the statistical analysis



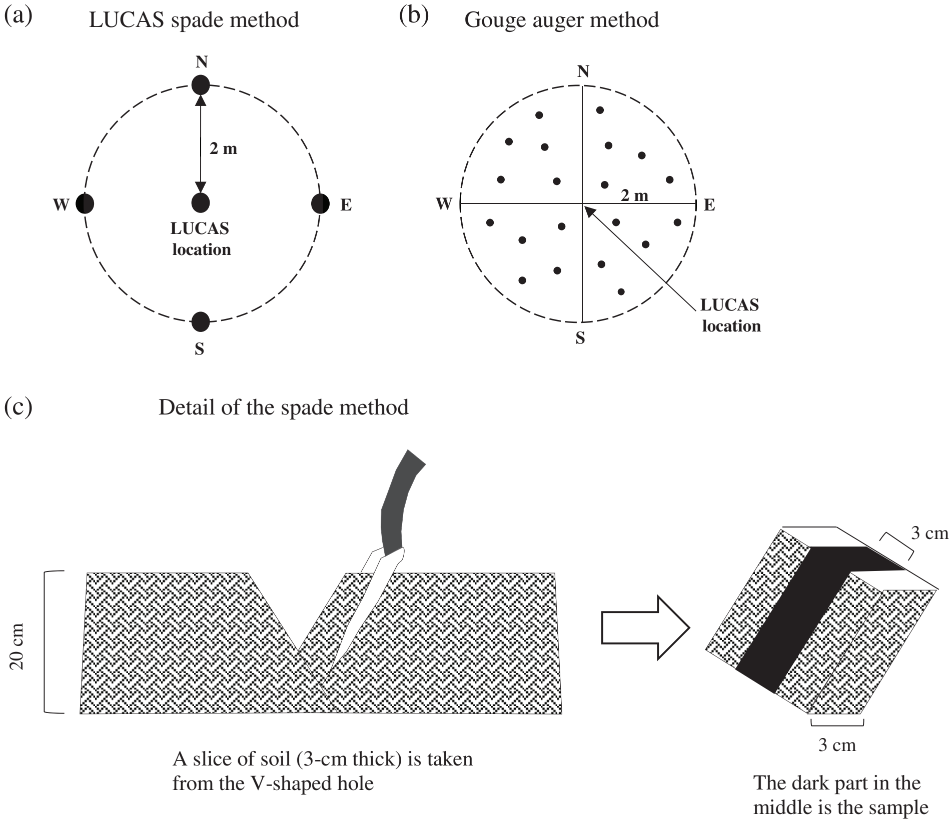


FIGURE 2 The sampling schemes of the LUCAS spade and gouge auger methods at each location. In the spade method, five subsamples were taken: one at the central LUCAS location and the other four at the cardinal directions (North, East, South and West). For the gouge auger method, the circle was divided into four quadrants (N–E, E–S, S–W and W–N) and five soil cores were taken in each quadrant

procedure was repeated for each subsample. Finally, the five subsamples in the bucket were mixed with a trowel and any vegetation residues and stones were removed. The protocol allowed us to leave some fine roots and undefined brownish organic material from the upper part (3 cm) of the soil when it was difficult to remove them completely. Approximately 500 g of the mixed soil were taken with the trowel from the bucket and placed in a plastic bag as the composite sample. The sample was air-dried before sending to the laboratory for analysis.

2.3 | Gouge auger method

A composite sample of approximately 500 g was taken from topsoil at each location as follows. The composite sample consisted of 20 soil cores taken with a gouge auger (internal diameter 2.5 cm) following a stratified random sampling approach. We had a circle of 4 m diameter around the georeferenced location that connected the four cardinal directions where subsamples were taken by the LUCAS sampling method. The circle was divided into four quadrants (N–E, E–S, S–W and W–N) (Figure 2b). Five soil cores were taken in each quadrant to a depth of 20 cm and placed in a bucket. Based on the analytical results of a sampling trial in Switzerland, 20 to 30 samples per plot are sufficient to provide a representative average for most of the soil properties (Federer, Schmitt, & Sticher, 1989). Before taking the soil cores, vegetation residues, grass and litter were removed from the soil surface. If a location was in woodland, special care was taken to completely remove the litter layer by hand. The 20 soil cores in the bucket were mixed with a trowel and remaining vegetation residues and stones were carefully removed. The composite sample of approximately 500 g was then transferred to a plastic bag. The sample was then air-dried before being sent to the laboratory for analysis.

In summary, the main differences between the two sampling methods are the instrument used for the sampling (spade or gouge auger), the number and spatial arrangement of subsamples taken (five with the LUCAS spade method and 20 with the gouge auger over the same sampling area) and the accuracy of removal of the litter layer, especially in woodland (the litter could be removed more rigorously with the gouge auger than the spade). In addition, surveyors noted that the sampling depth (20 cm) was uniform for the gouge auger, but it varied between 15 and 20 cm for the spade method. These differences make the gouge auger seem the more efficient method for topsoil characterization, although it can be more laborious and time-consuming, especially in woodland, than the spade method.

2.4 | Characterization of topsoil samples

All samples were analysed by the ISO standard methods for clay, silt and sand (ISO, 2009), OC (ISO, 1995a), calcium carbonate ($CaCO_3$; ISO, 1995b), N (ISO, 1995c), P (ISO, 1994a), pH in H_2O and in $CaCl_2$ (ISO, 2005), and electrical conductivity (EC; ISO, 1994b). Potassium (K) was analysed following the USDA-NRCS (2004) method by atomic absorption spectroscopy after extraction with ammonium acetate (NH_4OAc). All analyses were performed in the same laboratory.

2.5 | Statistical analysis of data

Statistical analysis was performed using the R statistical computing program (R × 64 3.0.3). For the description of the dataset, the Kruskal-Wallis test was used when comparing data between the two sampling methods and among the LC classes ($p < .05$). This test was chosen because data did not always meet normality. Data of the various LC classes were checked for normality using Q–Q plots. The post hoc analysis was performed with the Dunn test ($p < .05$).

The efficiency of the spade and gouge auger methods for topsoil characterization was assessed with the following methodology. The Bland and Altman diagram was used to detect potential outliers caused by errors of measurement in the paired data of soil properties analysed in samples taken by spade and gouge auger from the same location. The Bland and Altman method is a graphical way of comparing two measurements of the same variable. The diagram displays the difference between a pair of measurements plotted on the vertical 1:1 axis against the mean of the pair on the horizontal axis. Where the differences have a near-normal distribution, approximately 95% of the differences in the data is expected to lie between the limits of agreement; that is, the mean of the observed differences plus or minus two times the standard deviation (Bland & Altman, 1986). Where the distribution of differences is not near normal, the median, 2.5 and 97.5 percentiles are used as the limits of agreement (Bland & Altman, 1999). From these limits we decided whether the agreement between pairs of measurements was acceptable.

Lin's concordance correlation coefficient (LCCC) was used to compare the results of physical and chemical analyses between topsoil samples taken by the spade and gouge auger methods. The LCCC measures the fit of the data along a one-to-one line passing through the origin (Lin, 1989). If samples taken by the two sampling methods produce similar results for the soil properties analysed, the relation between them should fall on the line. We treated the gouge auger method as the reference method and assumed that soil properties were measured accurately in samples taken with this method. The root mean square error (RMSE) was also used to evaluate the average magnitude of the difference between the results of soil properties analysed for the two sampling methods.

Figure 3 shows examples of the Q–Q plot to check the normality of the data, the Bland and Altman diagram to identify potential outliers and the graphical representation of the LCCC for OC data in arable land.

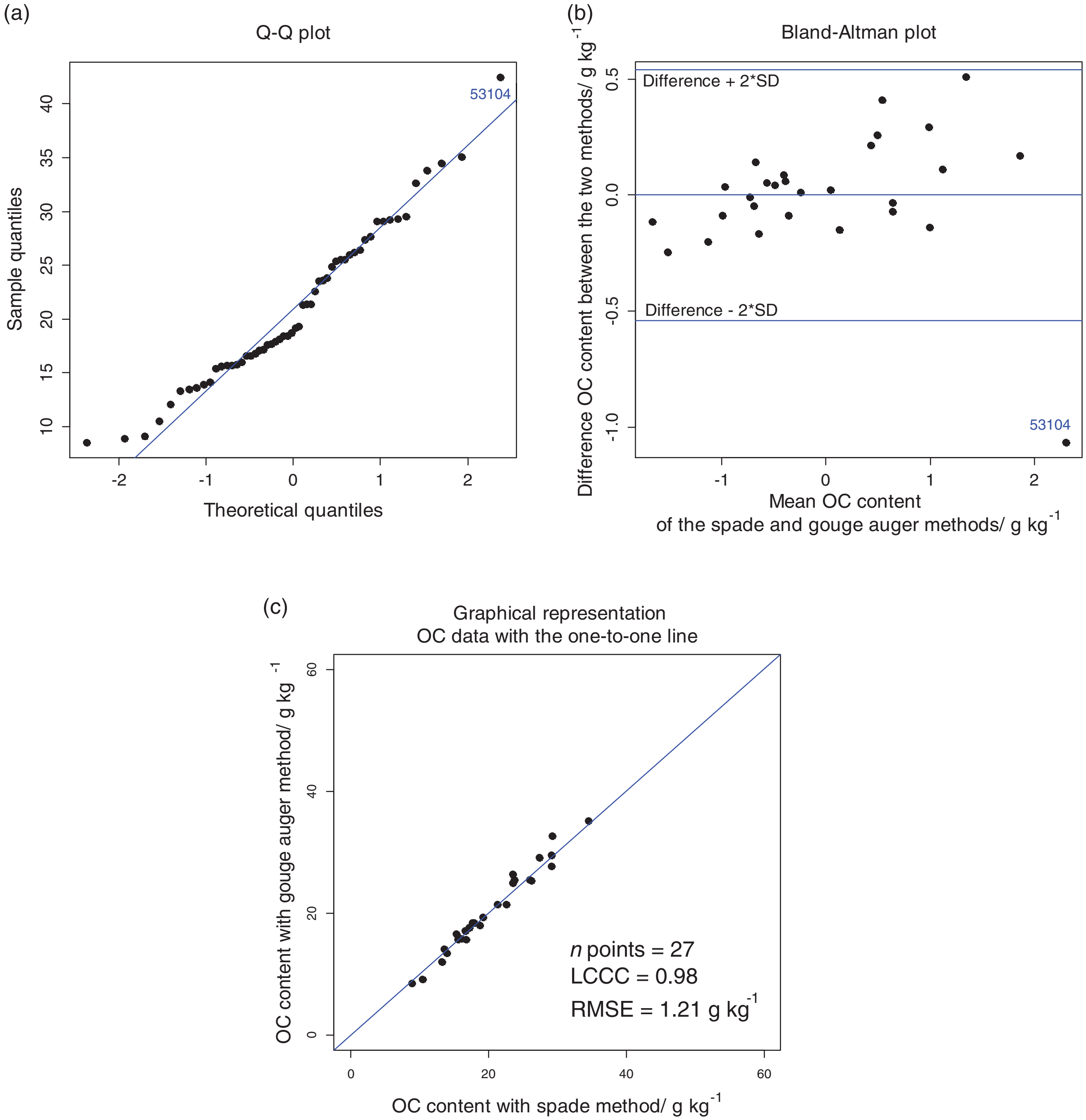


FIGURE 3 (a) The Q–Q plot, (b) the Bland and Altman diagram and (c) graphical representation of the data with the one-to-one line for OC (g kg^{-1}) in arable land. The Q–Q plot shows that the data follow a normal distribution. The Bland and Altman diagram shows that there is a potential outlier because of measurement errors. This outlier was removed to calculate Lin's concordance correlation coefficient (LCCC) and the root mean square error (RMSE)

3 | RESULTS AND DISCUSSION

3.1 | Data description

Topsoil samples were taken at 160 locations in Switzerland (Figure 1): 155 locations were on mineral soils and only five locations were on organic-rich soils (>200 g C kg^{-1} soil, de Brogniez et al., 2015). Organic-rich soils were omitted from the study because of the small number of observations for statistical analysis. The 155 locations on mineral soils covered the main LC classes in Switzerland: (a) arable land

(28 locations), (b) grassland including meadow (42 locations) and pasture (27 locations), and (c) woodland including coniferous forest (18 locations), deciduous forest (21 locations) and mixed forest (14 locations). We defined meadow as grassland that is allowed to grow unchecked to produce hay and therefore not regularly grazed by domestic livestock. In contrast, we considered grassland that is regularly grazed by domestic livestock (especially cattle and sheep) as pasture. Arable land included ploughed fields of cereals, root crops and fodder crops. The dataset also included two vineyards, a cherry orchard and a garden. They were not included in the arable land class because of their differences in vegetation type and tillage practices compared with the other locations in the class. Similarly, wetland was not included in the grassland class because of the differences in abiotic conditions of soil under wetland and the other grassland types. Abiotic conditions, vegetation type and tillage largely affect chemical properties analysed in this study. In total, 150 locations on mineral soils under woodland (coniferous, deciduous and mixed forests), meadow, pasture and arable land were considered for the statistical analysis.

Descriptive statistics of physical and chemical properties in topsoil for the LUCAS spade and gouge auger methods are given in Table 1. As shown in this table, the range of values, mean, median and standard deviation of properties were similar for both sampling methods. This suggests that the sampling method might not be a substantial source of variation in the analysis of the physical and chemical properties of topsoil samples. Mean and median values were similar to each other for most of the properties, which means that data were evenly divided around the mean. An exception was the $CaCO_3$ content. The median of $CaCO_3$ was 0 g kg^{-1} for the spade method and 1.0 g kg^{-1} for the gouge auger, whereas the mean content was 54.6 ± 128.2 g kg^{-1} for the spade method and 50.9 ± 121.1 g kg^{-1} for the gouge auger. This indicates that most of the topsoil samples had little $CaCO_3$ because of decalcification or crystalline parent rock, as shown by the positive skew of the $CaCO_3$ data distribution. Overall, the descriptive statistics showed that there was a wide range of textural classes and chemical conditions among the topsoil samples.

To compare the physical and chemical properties by LC class, we calculated measures of centrality and deviation for topsoil samples taken by the two methods but unseparated (Table 2). We decided to do so because all properties, except K in coniferous forest, had a similar range of values for samples taken with the spade and the gouge auger methods (p-value > .05, Tables S1 and S2). Potassium data were different between the two sampling methods only in coniferous forest (p-value = .01, Table S1), which suggested that the sampling method influenced laboratory analysis of K in this LC class. Descriptive statistics for K content are shown individually for the spade and the gouge auger methods in Table S2.

The statistical analysis (Tables S3 and S4) showed that texture was coarsest in the topsoil of coniferous forest (sand 346.1 ± 11.3 g kg^{-1} and clay 163.3 ± 6.1 g kg^{-1}, Table 2) and deciduous forest (sand 308.1 ± 16.9 g kg^{-1} and clay 193.3 ± 9.7 g kg^{-1}, Table 2), and finest in the topsoil of arable land (sand 259.1 ± 9.8 g kg^{-1} and clay 247.1 ± 5.2 g kg^{-1}, Table 2). Mean OC content was greater in the topsoil of woodland classes (coniferous forest 59.9 ± 34.2 g kg^{-1}, deciduous forest 56.1 ± 32.3 g kg^{-1} and mixed forest 48.4 ± 32.6 g kg^{-1}) and pasture (50.0

TABLE 1 Descriptive statistics of physical and chemical properties in topsoil (0–20 cm) samples taken with the LUCAS spade and the gouge auger methods in 150 locations on mineral soils

	Spade method (n samples = 150)					Gouge auger method (n samples = 150)				
	Range values	Mean	Median	SD	Skew	Range values	Mean	Median	SD	Skew
Clay/g kg^{-1}	40.0–400.0	200.0	200.0	7.1	0.0	40.0–420.0	205.3	210.0	7.2	0.1
Silt/g kg^{-1}	270.0–730.0	519.5	530.0	8.4	−0.2	250.0–700.0	521.9	530.0	8.0	−0.5
Sand/g kg^{-1}	60.0–690.0	280.1	255.0	12.6	0.5	60.0–710.0	273.3	245.0	11.7	0.7
OC/g kg^{-1}	8.9–151.5	43.9	37.4	27.6	1.5	5.6–147.2	41.9	33.5	26.7	1.7
$CaCO_3$/g kg^{-1}	0.0–775.0	54.6	0.0	128.2	3.3	0.0–800.0	50.9	1.0	121.1	3.6
N/g kg^{-1}	0.5–10.1	4.0	3.5	1.8	0.8	0.4–10.9	4.0	3.5	1.9	1.1
P/mg kg^{-1}	0.0–167.8	29.3	23.2	25.4	1.8	0.0–172.7	30.9	23.5	26.4	1.8
K/mg kg^{-1}	45.5–496.4	150.4	122.2	90.3	1.7	39.1–529.8	131.7	99.0	90.2	2.0
pH−H_2O	3.6–8.1	6.2	6.4	1.2	−0.3	3.6–8.0	6.1	6.3	1.1	−0.3
pH−$CaCl_2$	3.0–7.6	5.9	6.1	1.3	−0.3	3.1–7.6	5.9	6.1	1.2	−0.4
EC/mS m^{-1}	4.8–90.8	33.6	29.8	19.1	0.9	4.3–113.0	34.1	30.0	21.2	1.0

OC: organic carbon; EC: electrical conductivity; K: potassium; N: nitrogen; P: phosphorus; SD: standard deviation; Skew: coefficient of skewness.

TABLE 2 Descriptive statistics of physical and chemical properties in the topsoil (0–20 cm) of mineral soils by land cover class

	Coniferous forest (*n* samples = 36)					Deciduous forest (*n* samples = 42)					Mixed forest (*n* samples = 28)				
	Range values	Mean	Median	SD	Skew	Range values	Mean	Median	SD	Skew	Range values	Mean	Median	SD	Skew
Clay/g kg^{-1}	80.0–290.0	163.3	155.0	6.1	0.5	40.0–370.0	193.3	200.0	9.7	0.2	60.0–340.0	200.0	205.0	6.4	−0.3
Silt/g kg^{-1}	360.0–600.0	490.6	520.0	7.5	−0.3	250.0–660.0	499.3	535.0	9.9	−0.8	330.0–620.0	523.6	540.0	6.7	−1.2
Sand/g kg^{-1}	180.0–560.0	346.1	340.0	11.3	0.2	90.0–710.0	308.1	305.0	16.9	0.6	80.0–510.0	276.8	270.0	9.2	0.4
OC/g kg^{-1}	18.7–151.5	59.9	50.2	34.2	1.1	18.0–150.1	56.1	50.3	32.3	1.4	5.6–128.5	48.4	35.7	32.6	0.9
$CaCO_3$/g kg^{-1}	0.0–468.0	47.2	0.0	113.7	2.5	0.0–800.0	165.7	45.5	241.1	1.4	0.0–383.0	68.7	3.5	112.8	1.6
N/g kg^{-1}	1.4–7.4	4.1	3.7	1.9	0.5	1.9–10.1	4.4	3.7	2.0	0.3	0.5–7.2	3.7	3.2	1.9	0.5
P/mg kg^{-1}	0.0–56.5	19.9	16.9	14.7	0.7	0.0–56.4	17.7	13.1	14.7	0.9	0.0–44.3	9.8	7.0	11.0	1.6
pH−H_2O	3.6–7.9	5.5	5.1	1.5	0.3	4.0–7.7	6.5	7.1	1.2	−0.8	4.6–8.1	6.4	6.4	1.1	−0.2
pH−$CaCl_2$	3.0–7.5	5.1	4.5	1.5	0.3	3.7–7.4	6.1	6.9	1.3	−0.7	4.1–7.4	6.1	6.2	1.1	−0.3
EC/mS m^{-1}	6.2–90.8	22.5	14.1	21.7	2.0	6.6–58.1	31.6	30.1	14.9	0.2	4.3–73.5	32.1	28.9	19.5	0.4
	Arable land (*n* samples = 56)					**Meadow (*n* samples = 84)**					**Pasture (*n* samples = 54)**				
	Range values	**Mean**	**Median**	**SD**	**Skew**	**Range values**	**Mean**	**Median**	**SD**	**Skew**	**Range values**	**Mean**	**Median**	**SD**	**Skew**
Clay/g kg^{-1}	150.0–340.0	247.1	240.0	5.2	0.2	60.0–420.0	188.9	190.0	6.6	0.6	70.0–330.0	212.8	210.0	6.3	−0.4
Silt/g kg^{-1}	320.0–700.0	493.2	480.0	8.1	0.3	340.0–730.0	535.0	530.0	7.7	0.2	420.0–690.0	562.4	560.0	6.4	0.0
Sand/g kg^{-1}	110.0–460.0	259.1	240.0	9.8	0.6	60.0–530.0	276.7	285.0	11.4	0.1	90.0–520.0	224.3	195.0	10.5	0.9
OC/g kg^{-1}	8.5–42.5	21.1	18.9	7.3	0.5	13.0–102.8	37.4	29.7	18.9	1.6	22.9–105.6	50.0	43.7	21.8	0.2
$CaCO_3$/g kg^{-1}	0.0–190.0	18.8	1.0	45.1	2.8	0.0–410.0	36.3	0.0	78.4	2.9	0.0–210.0	21.3	0.0	52.9	2.5
N/g kg^{-1}	1.1–4.1	2.5	2.5	0.7	0.4	1.7–8.2	4.3	3.8	1.6	0.9	2.8–8.8	5.1	4.7	1.7	1.0
P/mg kg^{-1}	15.6–112.9	48.7	45.4	23.3	0.9	6.6–109.3	36.8	29.3	24.2	0.8	0.0–172.7	27.4	19.7	32.7	3.2
pH−H_2O	4.8–8.1	6.7	6.8	0.9	−0.6	4.2–7.7	6.2	6.1	1.0	−0.1	4.3–7.7	5.7	5.4	1.0	0.3
pH−$CaCl_2$	4.5–7.6	6.4	6.5	0.9	−0.7	3.9–7.6	5.9	5.9	1.1	−0.1	3.9–7.4	5.4	5.1	1.0	0.3
EC/mS m^{-1}	12.3–55.1	25.6	22.4	10.4	0.9	4.9–113.0	39.0	36.7	20.4	0.7	4.8–108.9	44.7	38.2	22.7	0.7

Note: Measures of centrality and dispersion were calculated for the samples taken with the spade and the gouge auger method together.

OC: organic carbon; EC: electrical conductivity; K: potassium; N: nitrogen; P: phosphorus; SD: standard deviation; Skew: coefficient of skewness.

± 21.8 g kg^{-1}) than in meadow (37.4 ± 18.9 g kg^{-1}) and arable land (21.1 ± 7.3 g kg^{-1}) (Table 2). Similarly, mean N content was greater in the topsoil of pasture (5.1 ± 1.7 g kg^{-1}), woodland classes (deciduous forest 4.4 ± 2.0 g kg^{-1}, coniferous forest 4.1 ± 1.9 g kg^{-1} and mixed forest 3.7 ± 1.9 g kg^{-1}) and meadow (4.3 ± 1.6 g kg^{-1}) than in arable land (2.5 ± 0.7 g kg^{-1}) (Table 2). Vegetation type and management practices are the main factors accounting for OC and N contents in topsoil in each LC class because they determine the supply of organic residues to soil and their degradation (Post & Kwon, 2000). The larger contents of OC and N in pasture than in meadow are partly linked to the incorporation of livestock excreta in pasture. As expected, topsoil in arable land had the smallest contents of OC and N because of management practices (Martens, Reedy, & Lewis, 2003). Mean P for both sampling methods was largest in the topsoil of arable land (P 48.7 ± 23.3 mg kg^{-1}), followed by meadow (P 36.8 ± 24.2 mg kg^{-1}) and pasture (P 27.4 ± 32.7 mg kg^{-1}) (Table 2). In the same way, mean K was also largest in the topsoil of arable land (184.7 ± 67.4 mg kg^{-1} in the spade method and 167.9 ± 82.9 mg kg^{-1} in the gouge auger method), followed by meadow (155.2 ± 100.8 mg kg^{-1} in the spade method and 130.2 ± 87.8 mg kg^{-1} in the gouge auger method) and pasture (165.3 ± 92.6 mg kg^{-1} in the spade method and 152.3 ± 105.9 mg kg^{-1} in the gouge auger method) (Table S2). The woodland classes had the smallest P and K contents, especially coniferous forest with a mean P content of 19.9 ± 14.7 mg kg^{-1} (Table 2) and K content of 81.8 ± 18.4 mg kg^{-1} in the spade method and 62.8 ± 18.2 mg kg^{-1} in the gouge auger method (Table S2). This results from the larger nutrient supply to meadow, pasture and notably arable land from fertilization.

Mean EC was greater in the topsoil of pasture and meadow (44.7 ± 22.7 mS m^{-1} and 39.0 ± 20.4 mS m^{-1}, respectively) and deciduous and mixed forests (31.6 ± 14.9 mS m^{-1} and 32.1 ± 19.5 mS m^{-1}, respectively) than in coniferous forest and arable land (22.5 ± 21.7 mS m^{-1} and 25.6 ± 10.4 mS m^{-1}, respectively) (Table 2 and Tables S3 and S4). Mean pH in H_2O and $CaCl_2$ was greater in arable land (6.7 ± 0.9 in H_2O and 6.4 ± 0.9 in $CaCl_2$), deciduous (6.5 ± 1.2 in H_2O and 6.1 ± 1.3 in $CaCl_2$) and mixed (6.4 ± 1.1 in H_2O and 6.1 ± 1.1 in $CaCl_2$) forests than in meadow (6.2 ± 1.0 in H_2O and 5.9 ± 1.1 in $CaCl_2$), coniferous forest (5.5 ± 1.5 in H_2O and 5.1 ± 1.5 in $CaCl_2$) and pasture (5.7 ± 1.0 in H_2O and 5.4 ± 1.0 in $CaCl_2$) (Table 2 and Tables S3 and S4). Electrical conductivity and pH depend on many factors linked to climate, soil and management. Edaphic factors affecting EC and pH include mineralogy and texture. In addition, EC and pH are also affected by land use, vegetation type, irrigation and fertilization.

3.2 | Effect of sampling method on the analysis of physical and chemical properties in topsoil samples taken in mineral soils

The LCCC showed a strong relation between the two sampling methods for all properties analysed. It ranged from 0.88 for EC to 0.98 for $CaCO_3$ content (Table 4a). The removal of outliers did not change the results of the statistical analysis. The LCCC ranged from 0.89 for EC to 0.98 for $CaCO_3$ content and pH in $CaCl_2$ (Table 3b). These data suggest that the laboratory analysis gave almost the same results

TABLE 3 Lin's concordance correlation coefficient and root mean square error for physical and chemical properties between topsoil samples taken with the LUCAS spade and gouge auger in mineral soils

(a) Comparison between the two sampling methods in the overall data set of 150 locations sampled			
Soil properties	***n* locations**	**LCCC**	**RMSE**
Clay/g kg^{-1}	150	0.96	18.87
Silt/g kg^{-1}	150	0.91	34.81
Sand/g kg^{-1}	150	0.94	40.99
OC/g kg^{-1}	150	0.92	10.98
$CaCO_3$/g kg^{-1}	150	0.98	25.37
N/g kg^{-1}	150	0.92	0.75
P/mg kg^{-1}	150	0.93	9.57
K/mg kg^{-1}	150	0.89	42.97
pH−H_2O	150	0.97	0.30
pH−$CaCl_2$	150	0.97	0.29
EC/mS m^{-1}	150	0.88	9.88
(b) Comparison between the two sampling methods after the removal of outliers based on Bland and Altman diagram. For each location removed, a pair of samples is discarded: one taken with the LUCAS spade and other taken with the gouge auger method			
Soil properties	***n* locations**	**LCCC**	**RMSE**
Clay/g kg^{-1}	150	0.96	18.87
Silt/g kg^{-1}	149	0.92	32.38
Sand/g kg^{-1}	149	0.95	37.40
OC/g kg^{-1}	146	0.96	7.46
$CaCO_3$/g kg^{-1}	149	0.98	21.97
N/g kg^{-1}	148	0.95	0.59
P/mg kg^{-1}	149	0.96	7.09
K/mg kg^{-1}	147	0.90	37.84
pH−H_2O	148	0.97	0.26
pH−$CaCl_2$	148	0.98	0.24
EC/mS m^{-1}	149	0.89	9.39

EC: electrical conductivity; K: potassium; LCCC: Lin's concordance correlation coefficient; N: nitrogen; OC: organic carbon; P: phosphorus; RMSE: root mean square error.

TABLE 4 Lin's concordance correlation coefficient root mean square error for physical and chemical properties between topsoil samples taken with the LUCAS spade and gouge auger in mineral soils by land cover class (a) for the overall dataset and (b) after removal of outliers

(a) Comparison between the two sampling methods in the overall dataset of locations sampled: coniferous forest (18 locations), deciduous forest (21 locations), mixed forest (14 locations), arable land (28 locations), meadow (42 locations) and pasture (27 locations)

	Coniferous forest			Deciduous forest			Mixed forest		
	n locations	LCCC	RMSE	*n* locations	LCCC	RMSE	*n* locations	LCCC	RMSE
Clay/g kg^{-1}	18	0.91	24.94	21	0.97	22.68	14	0.96	16.90
Silt/g kg^{-1}	18	0.79	48.99	21	0.89	45.62	14	0.88	32.29
Sand/g kg^{-1}	18	0.84	63.68	21	0.96	48.60	14	0.92	35.56
OC/g kg^{-1}	18	0.79	21.99	21	0.97	8.17	14	0.92	12.76
$CaCO_3$/g kg^{-1}	18	0.98	21.74	21	0.99	38.92	14	0.91	47.85
N/g kg^{-1}	18	0.73	1.25	21	0.97	0.48	14	0.96	0.55
P/mg kg^{-1}	18	0.89	6.75	21	0.87	7.27	14	0.95	3.39
K/mg kg^{-1}	18	0.35	25.49	21	0.91	33.41	14	0.96	32.16
pH−H_2O	18	0.98	0.29	21	0.98	0.23	14	0.97	0.27
pH−$CaCl_2$	18	0.99	0.24	21	0.99	0.20	14	0.98	0.22
EC/mS m^{-1}	18	0.98	3.90	21	0.76	10.22	14	0.90	8.64

	Arable land			Meadow			Pasture		
	n locations	LCCC	RMSE	*n* locations	LCCC	RMSE	*n* locations	LCCC	RMSE
Clay/g kg^{-1}	28	0.97	11.65	42	0.96	18.58	27	0.96	18.34
Silt/g kg^{-1}	28	0.96	21.87	42	0.91	32.95	27	0.90	28.09
Sand/g kg^{-1}	28	0.97	23.98	42	0.93	41.23	27	0.96	30.00
OC/g kg^{-1}	28	0.96	2.03	42	0.95	5.92	27	0.84	12.32
$CaCO_3$/g kg^{-1}	28	0.94	15.32	42	0.99	8.21	27	0.90	23.40
N/g kg^{-1}	28	0.83	0.43	42	0.94	0.63	27	0.83	0.97
P/mg kg^{-1}	28	0.95	6.58	42	0.94	8.05	27	0.86	16.90
K/mg kg^{-1}	28	0.87	38.10	42	0.86	50.19	27	0.84	54.75
pH−H_2O	28	0.96	0.26	42	0.93	0.36	27	0.95	0.31
pH−$CaCl_2$	28	0.96	0.25	42	0.94	0.35	27	0.95	0.32
EC/mS m^{-1}	28	0.91	4.28	42	0.82	12.08	27	0.83	12.92

(b) Comparison between the two sampling methods after the removal of outliers based on Bland and Altman diagram in each land cover class. For each location removed, a pair of samples is discarded: one taken with the LUCAS spade and other taken with the gouge auger method

	Coniferous forest (total *n* locations = 18)			Deciduous forest (total *n* locations = 21)			Mixed forest (total *n* locations = 14)		
	n locations	LCCC	RMSE	*n* locations	LCCC	RMSE	*n* locations	LCCC	RMSE
Clay/g kg^{-1}	18	0.91	24.94	21	0.97	22.68	14	0.96	16.90
Silt/g kg^{-1}	18	0.79	48.99	20	0.92	39.75	14	0.88	32.29
Sand/g kg^{-1}	17	0.84	63.29	20	0.97	41.95	13	0.95	29.48
OC/g kg^{-1}	17	0.89	15.73	21	0.97	8.17	14	0.92	12.76
$CaCO_3$/g kg^{-1}	18	0.98	21.74	20	0.99	29.3	14	0.91	47.85
N/g kg^{-1}	17	0.94	0.55	21	0.97	0.48	14	0.96	0.55
P/mg kg^{-1}	17	0.86	6.60	20	0.89	6.88	14	0.95	3.40

(Continues)

TABLE 4 (Continued)

(b) Comparison between the two sampling methods after the removal of outliers based on Bland and Altman diagram in each land cover class. For each location removed, a pair of samples is discarded: one taken with the LUCAS spade and other taken with the gouge auger method

	Coniferous forest (total *n* locations = 18)			Deciduous forest (total *n* locations = 21)			Mixed forest (total *n* locations = 14)		
	n locations	LCCC	RMSE	*n* locations	LCCC	RMSE	*n* locations	LCCC	RMSE
K/mg kg^{-1}	17	0.37	25.80	21	0.91	33.41	13	0.95	32.05
pH−H_2O	17	0.98	0.25	20	0.98	0.22	14	0.97	0.27
pH−$CaCl_2$	18	0.99	0.24	20	0.99	0.19	14	0.98	0.22
EC/mS m^{-1}	17	0.99	3.60	20	0.83	8.48	13	0.93	7.34

	Arable land (total *n* locations = 28)			Meadow (total *n* locations = 42)			Pasture (total *n* locations = 27)		
	n locations	LCCC	RMSE	*n* locations	LCCC	RMSE	*n* locations	LCCC	RMSE
Clay/g kg^{-1}	27	0.98	9.03	41	0.97	16.3	26	0.97	14.54
Silt/g kg^{-1}	27	0.97	19.05	41	0.96	22.08	26	0.92	26.09
Sand/g kg^{-1}	28	0.97	23.98	41	0.97	25.80	26	0.97	27.31
OC/g kg^{-1}	27	0.98	1.21	41	0.97	4.81	26	0.93	8.06
$CaCO_3$/g kg^{-1}	27	0.99	6.78	41	0.99	6.60	26	0.96	14.12
N/g kg^{-1}	27	0.97	0.17	42	0.94	0.63	26	0.89	0.77
P/mg kg^{-1}	27	0.97	5.20	42	0.94	8.05	26	0.97	7.49
K/mg kg^{-1}	27	0.88	32.89	41	0.88	42.58	26	0.87	46.98
pH−H_2O	28	0.96	0.26	41	0.96	0.27	25	0.98	0.22
pH−$CaCl_2$	28	0.96	0.25	41	0.97	0.26	25	0.98	0.20
EC/mS m^{-1}	27	0.93	3.62	41	0.86	10.61	27	0.83	12.92

EC: electrical conductivity; K: potassium; LCCC: Lin's concordance correlation coefficient; N: nitrogen; OC: organic carbon; P: phosphorus; RMSE: root mean square error.

for samples taken with the spade and gouge auger methods. Values of RMSE that ranged between 1/2 and 1/25 of their mean values (Tables 2 and 3a,b) confirmed this and demonstrated that, in general, the LUCAS spade method can be good for topsoil sampling of mineral soils at the continental scale. However, when considering individual LC classes and properties with a patchy surface distribution or that change rapidly with depth, there were some differences in the laboratory data for the two sampling methods.

3.3 | Effect of sampling method on the analysis of physical and chemical properties in relation to land cover

The differences in LCCC and RMSE for properties analysed among individual LC classes indicated that the sampling method did affect the outcome to some degree (Table 4). Here, we have structured the discussion by groups of soil properties, based on the type (chemical or physical properties), their importance in soil surveys and differences observed for LCCC and RMSE among LC classes.

3.3.1 | Effect on the analysis of OC and N

In woodland classes, the smallest LCCC for OC and N contents between the sampling methods was for coniferous forest (0.79 and 0.73, respectively), followed by mixed forest (0.92 and 0.96, respectively) and deciduous forest (0.97 for both OC and N) (Table 4a). The RMSE for OC and N was greater in coniferous (21.99 and 1.25 g kg^{-1}, respectively) than in mixed (12.76 and 0.55 g kg^{-1}, respectively) and deciduous forests (8.17 and 0.48 g kg^{-1}, respectively) (Table 4a). The removal of the outliers confirmed this order. Organic carbon and N in coniferous forest had a smaller LCCC (0.89 and 0.86, respectively) with a larger RMSE (15.73 and 0.55 g kg^{-1}) compared to mixed and deciduous forests (Table 4b). These differences in LCCC and average magnitude of the difference for OC and N contents between samples taken by the two methods in woodland classes can be explained by the efficiency of removal of the litter layer before the mineral horizon was sampled. The litter layer in woodland is an important source of OC and N. If removal of the litter layer is not complete or is excessive (removing the first few centimetres of mineral topsoil also), OC and N would be measured inaccurately. This could be the case for the samples taken by spade, in which removal of the litter layer was less rigorous than by the gouge auger method. Samples taken in coniferous forest were particularly affected by this because it is often more difficult to separate their litter layer from the mineral topsoil than in deciduous forest. The needle litter in coniferous forest makes the boundary between organic and mineral layers diffuse and spatially heterogeneous compared with the broadleaf litter of deciduous forest. Thus, it is crucial to separate the litter layer from the mineral topsoil accurately in coniferous forest to determine OC and N contents correctly in the mineral topsoil.

For samples from grassland, the LCCC for OC and N contents was smaller in pasture (0.84 for OC and 0.83 for N) than in meadow (0.95 for OC and 0.94 for N) (Table 4a). The RMSE for OC and N contents was larger in pasture (12.32 and 0.97 g kg^{-1}, respectively) than in meadow (5.92 and 0.63 g kg^{-1}, respectively) (Table 4a). Similar results were observed after the removal of outliers. The LCCC was 0.93 for OC and 0.89 for N in pasture compared to 0.97 for OC and 0.94 for N in meadow (Table 4b). The RMSE for OC and N was 8.06 and 0.77 g kg^{-1}, respectively, in pasture compared to 4.81 and 0.63 g kg^{-1}, respectively, in meadow (Table 4b). The smaller LCCC and larger RMSE for OC and N in pasture than in meadow can be explained by the heterogeneous distribution of livestock excreta, source of OC and N, on the surface of pasture (White, Sheffield, Washburn, King, & Green, 2001). The spatial arrangement and number of subsamples from the LUCAS spade and gouge auger methods (Figure 2) have identified this spatial variability to different extents. Consequently, OC and N contents for the two sampling methods for each location varied more in pasture than in meadow.

In arable land, OC had a larger value of LCCC (0.96) together with a smaller value of RMSE (2.03 g kg^{-1}) compared to the other LC classes (pasture, meadow and the woodland classes) (Table 4a). Similarly, the LCCC of OC was largest (0.98) and the RMSE was smallest (1.21 g kg^{-1}) in arable land after the removal of outliers (Table 4b). These differences are linked to the control of sampling depth in the two methods and the vertical distribution of OC in the various LC classes. The gouge auger gives better control of sampling depth than the spade. In the woodland classes, meadow and pasture, where the vertical distribution of OC is shallower than in arable land, any variation in the sampling depth can be a source of error in the analysis of these properties. Lark, Rawlins, and Lark (2014) had already observed that the variance in sampling depth in uncultivated locations produced a variation in OC determination in the LUCAS topsoil survey carried out in 2009. In arable land, where vertical distribution of OC is often deeper because topsoil is ploughed to 15–30-cm depth (Jobbágy & Jackson, 2000; Meersmans, Weselmael, De Ridder, & Van Molle, 2009), this is not an issue.

Regarding N in arable land, the RMSE was smallest (0.43 g kg^{-1}) but the LCCC (0.83) was not as large as in other LC classes (Table 4a). The largest value of LCCC for N (0.97) together with a small value of RMSE (0.48 g kg^{-1}) was observed in deciduous forest (Table 4a). This can be explained by the denser rooting at depth in deciduous forest than at depth in the other LC classes (Jackson et al., 1996), which results in a more homogeneous distribution of N in the topsoil. The less rigorous control of sampling depth with the spade had a little effect on the analysis of N due to its homogeneous vertical distribution in topsoil. After the removal of a pair of samples in arable land because of the large difference in N content between them, the LCCC of N was as large as in deciduous forest (0.97) and the RMSE was smallest (0.17 g kg^{-1}) in arable land (Table 4b). As explained for OC, this is linked to a more homogeneous distribution of N at depth due to the ploughing in arable land. Consequently, variations in the sampling depth with the spade affected little of the analysis of N.

In summary, analysis of OC and N in topsoil samples taken with the spade and gouge auger in arable land, meadow and deciduous forest produced very similar results with a small average magnitude of difference (Table 4). Therefore, the use of the simpler spade method is adequate for topsoil monitoring in these LC classes. However, awareness is necessary when monitoring OC and N in pasture and coniferous forest. The smallest LCCC and the largest RMSE for OC and N in these LC classes (Table 4) indicated that sampling with a gouge auger was more appropriate for monitoring purposes because it resolved the patchy distribution of N on the pasture surface and removal of needle-type litter in coniferous and mixed forest more accurately. One way to improve the accuracy of sampling depth with the spade would be to mark the spade with the depth at which the sample has to be taken. This would help the surveyor to control the sampling depth better.

3.3.2 | Effect on the analysis of P and K

The LCCC was smallest in pasture for P content (0.86) and in the coniferous forest for K content (0.35) (Table 4a). In accord with the LCCC, the RMSE was largest for P in pasture (16.90 mg kg^{-1}) and for K in meadow and pasture (50.19 and 54.75 mg kg^{-1}, respectively) (Table 4a). After the removal of a pair of samples in pasture because of the large difference in P content between them, the LCCC value increased to 0.97 and the RMSE decreased to 7.49 mg kg^{-1} (Table 4b). Even so, the RMSE for P in pasture was one of the largest compared to the other LC classes. For K, the LCCC of coniferous forest (0.37) was still the lowest after the removal of an outlier (Table 4b). The RMSE values for K were again largest in meadow and pasture (42.58 and 46.98 mg kg^{-1}, respectively) after the removal of outliers (Table 4b). These results indicated a considerable difference in K content between samples taken with the spade and the gouge auger in coniferous forest, pasture and meadow. The Kruskal-Wallis test actually showed significant differences in K data between the two sampling methods in coniferous forest (p-value = .01, Table S1). The results also suggested a considerable difference in P content between samples taken with the two methods in pasture. Phosphorus and K are strongly cycled by plants, which leads to a rapid upward transport of these two nutrients by plant roots within the soil profile (Jobbágy & Jackson, 2004). Thus, K and P have shallow vertical distributions (Jobbágy & Jackson, 2001). The shallow distribution of P and K is expected to be more evident in coniferous forest and grassland (such as meadow and pasture) than in the other LC classes because of their shallower rooting profiles (Jackson et al., 1996). The poorer control of sampling depth with the spade had more effect on the accuracy of the analyses of P and K in coniferous forest, meadow and pasture. Furthermore, the very small LCCC for K content in coniferous forest (Table 4a,b) showed that analysis of this nutrient in samples taken with the spade and the gouge auger did not produce the same results. The large effect of sampling method on the analysis of K in coniferous forest was not only because of the shallow distribution of this nutrient, but also because of the difficulties in removing needle-type litter, a key source of K, accurately in this LC class. The larger values of mean and median for K content in samples taken with the spade than with the gouge auger (Table S2) indicated that the litter layer was removed less carefully with the spade method in most of the locations. However, more attention was paid to the litter removal with the gouge auger method.

Overall, the spade method was an appropriate method for topsoil monitoring of P and K at the continental scale for arable land, deciduous and mixed forests, and to a smaller extent for meadow and pasture. Although the RMSE values for P and K were largest in meadow and pasture, their magnitude was acceptable in relation to the range of values in these LC classes (values of P and K were more than twice the value of RMSE). The spade method was also appropriate for P monitoring in coniferous forest. However, the very small LCCC for K in this LC class suggested that special attention should be given to topsoil sampling for monitoring this nutrient in coniferous forest. In this case, it is advisable to use the more accurate gouge auger method for sampling.

3.3.3 | Effect on the analysis of EC, pH and $CaCO_3$

The LCCC for EC between samples taken with the spade and auger was largest in coniferous forest (0.98) and smallest in pasture and deciduous forest (0.83 and 0.76, respectively) (Table 4a). In accord with the LCCC, RMSE was smallest in coniferous forest (3.90 mS m^{-1}) and largest in pasture (12.92 mS m^{-1}) (Table 4a). The removal of the outliers confirmed this order. The LCCC was largest in coniferous forest (0.99) and smallest in pasture and deciduous forests (0.83 in both LC classes) (Table 4b). The RMSE was smallest in coniferous forest (3.60 mS m^{-1}) and largest in pasture (12.92 mS m^{-1}) (Table 4b). Differences in EC between spade and auger samples were probably related to the spatial heterogeneity of EC in the topsoil (Corwin & Lesch, 2005). This suggests that topsoil sampling with the gouge auger for monitoring EC is more reliable because a larger number of subsamples were taken over the same area and the samples were more evenly spread than the spade samples. The LCCC and RMSE for pH in water and $CaCl_2$ RMSE were similar for all LC classes (Table 4a,b). They showed a strong relation and an acceptable average magnitude of difference between samples taken by the two methods. Thus, the spade method appears to be appropriate for pH monitoring at the continental scale. Calcium carbonate content also had similar LCCC values for all LC classes (Table 4a,b); however, the RMSE for $CaCO_3$ was smaller in arable land and meadow (15.32 and 8.21 g kg^{-1}, respectively) than in the other LC classes (Table 4a). After the removal of outliers, the RMSE of $CaCO_3$ was still the smallest in arable land (6.78 g kg^{-1}) and meadow (6.60 g kg^{-1}) (Table 4b). This is probably due to a homogeneous distribution of carbonates with depth because of natural causes or ploughing in arable land and meadow. Overall, the LCCC and the RMSE for EC, pH and $CaCO_3$ content for the two sampling methods were good and support the use of the simpler spade method for topsoil sampling when monitoring these properties in woodland, grassland and arable land.

3.3.4 | Effect on the analysis of clay, silt and sand

The clay, silt and sand contents in coniferous forest had the smallest LCCC (clay 0.91, silt 0.79 and sand 0.84) and the largest RMSE (clay 24.94 g kg^{-1}, silt 48.99 g kg^{-1} and sand 63.68 g kg^{-1}) between spade and auger samples (Table 4a). After the removal of an outlier, the RMSE of sand content slightly decreased to 63.29 g kg^{-1}. This was due to the difficulties of removing needle-type litter in coniferous forest as explained above. Some of the topsoil mineral layer might be removed with the litter in coniferous and mixed forests. This is more likely to happen with the spade than the auger method, in which litter removal is more rigorous. The smallest RMSE values for clay (11.65 g kg^{-1}), silt (21.87 g kg^{-1}) and sand (23.98 g kg^{-1}) contents for arable land (Table 4a) can be explained by the homogeneous texture of the ploughed depth (usually 15–30 cm) in this LC class. After the removal of outliers, the RMSE values were also smallest in arable land (9.03 g kg^{-1} for clay, 19.05 g kg^{-1} for silt and 23.98 for sand) compared to the other LC classes (Table 4b). In general, the relation and average magnitude of the differences for clay, silt and sand contents between the two sampling methods were good. Thus, the simpler spade method is a convenient approach for topsoil monitoring of texture at the continental scale regardless of the LC class.

4 | CONCLUSIONS

The effect of LUCAS spade and gouge auger samplings on the analysis of physical and chemical properties (texture, OC, $CaCO_3$, N, P, K, pH and EC) was studied in mineral topsoil under different LC classes in Switzerland. For all properties, large values of LCCC (0.83–0.99) together with small values of RMSE were observed in arable land compared with pasture, meadow and woodland classes. This indicated that the analysis gave more similar results for samples taken with the two methods in arable land, where the topsoil is homogenized as a result of the ploughing. Deciduous forest had the largest LCCC for OC and N (0.97 for both properties) with small RMSE values (8.17 g kg^{-1} for OC and 0.48 g kg^{-1} for N) among the woodland classes, because of the denser and deeper rooting of this forest type, which results in a homogeneous distribution of OC and N in topsoil. Coniferous forest had the smallest LCCC for OC, K and texture (the lowest LCCC was 0.35 for K) because of the presence of the needle-type litter layer and shallow distribution of properties at depth. Pasture had a small LCCC for N (0.83) because of its patchy distribution on the surface. The gouge auger was the method of choice (a) for coniferous forest because of the more accurate needle-type litter removal and (b) for pasture because of the larger number of subsamples and therefore better spatial coverage. This study has shown that some improvements should be made if the spade method is used in these LC classes. First, precise removal of the needle-type litter layer must be ensured. Second, it is crucial to take samples accurately down to the target depth because forest soils usually have a shallow distribution of OC, N, P and K. These aspects should be clearly specified in the instructions for the LUCAS spade sampling.

Although some improvements are required, the LUCAS spade method is efficient for topsoil monitoring of physical and chemical properties in most of the LC classes. The lowest LCCC was 0.73 for N (except K) in coniferous forest. Furthermore, the spade sampling is a cheap and simple method that facilitates the conducting of a topsoil survey at the continental scale at a relatively low sampling cost.

Data Availability Statement

The data that support the findings of this study are freely available in the European Soil Data Centre (ESDAC) at https://esdac.jrc.ec.europa.eu/, title LUCAS 2015 Topsoil data of Switzerland, upon registration.

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REFERENCES

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two pairs of clinical measurements. *The Lancet*, *327*, 307–310.

Bland, J. M., & Altman, D. G. (1999). Measuring agreement in method comparison studies. *Statistical Methods in Medical Research*, *8*, 135–160.

Corwin, D. L., & Lesch, S. M. (2005). Characterizing soil spatial variability with apparent soil electrical conductivity: Part II. Case study. *Computers and Electronics in Agriculture*, *46*, 135–152.

de Brogniez, D., Ballabio, C., Stevens, A., Jones, R. J. A., Montanarella, L., & van Wesemael, B. (2015). A map of the topsoil organic carbon content of Europe generated by a generalized additive model. *European Journal of Soil Science*, *66*, 121–134.

Eurostat (2015). *Technical reference document C1: Instructions for surveyors*. Retrieved from http://ec.europa.eu/eurostat/documents/205002/6786255/LUCAS2015-C1-Instructions-20150227.pdf

Eurostat (2017). *Land cover/use statistics (LUCAS)*. Retrieved from http://ec.europa.eu/eurostat/web/lucas

Federer, P., Schmitt, H. W., & Sticher, H. (1989). Wie repräsentativ sind Bodenanalysen? *Landwirtschaft Schweiz Band*, *2*, 363–367.

International Organization for Standardization (ISO). (1994a). *Soil quality — determination of phosphorus — spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution*. ISO 11263:1994. Geneva, Switzerland: International Standards Organization.

International Organization for Standardization (ISO). (1994b). *Soil quality — determination of the specific electrical conductivity*. ISO 11265:1994. Geneva, Switzerland: International Standards Organization.

International Organization for Standardization (ISO). (1995a). *Soil quality — determination of organic and total carbon after dry combustion (elementary analysis)*. ISO 10694:1995. Geneva, Switzerland: International Standards Organization.

International Organization for Standardization (ISO). (1995b). *Soil quality — determination of carbonate content — volumetric* *method*. ISO 10693:1995. Geneva, Switzerland: International Standards Organization.

International Organization for Standardization (ISO). (1995c). *Soil quality — determination of total nitrogen — modified Kjeldahl method*. ISO 11261:1995. Geneva, Switzerland: International Standards Organization.

International Organization for Standardization (ISO). (2005). *Soil quality — determination of pH*. ISO 10390:2005. Geneva, Switzerland: International Standards Organization.

International Organization for Standardization (ISO). (2009). *Particle size analysis — laser diffraction methods*, ISO 13320:2009. Geneva, Switzerland: International Standards Organization.

Jackson, R. B., Canadell, J., Ehleringer, J. R., Mooney, H. A., Sala, O. E., & Schulze, E. D. (1996). A global analysis of root distributions for terrestrial biomes. *Oecologia*, *108*, 389–411.

Jobbágy, E. G., & Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, *10*, 423–436.

Jobbágy, E. G., & Jackson, R. B. (2001). The distribution of soil nutrients with depth: Global patterns and the imprint of plants. *Biogeochemistry*, *53*, 51–77.

Jobbágy, E. G., & Jackson, R. B. (2004). The uplift of soil nutrients by plants: Biogeochemical consequences across scales. *Ecology*, *85*, 2380–2389.

Lark, R. M., Rawlins, B. G., & Lark, T. A. (2014). Implications of the field sampling procedure of the LUCAS topsoil survey for the uncertainty in soil organic carbon concentrations. *Geophysical Research Abstracts*, *16*, EGU2014–EGU2196.

Lin, L. I. (1989). A concordance correlation coefficient to evaluate reproducibility. *Biometrics*, *45*, 255–268.

Martens, D. A., Reedy, T. E., & Lewis, D. T. (2003). Soil organic carbon content and composition of 130-year crop, pasture and forest land-use managements. *Global Change Biology*, *10*, 65–78.

Meersmans, J., Weselmael, B.v., De Ridder, F., & Van Molle, M. (2009). Modelling the three-dimensional spatial distribution of soil organic carbon (SOC) at the regional scale (Flanders, Belgium). *Geoderma*, *152*, 43–52.

Morvan, X., Saby, N. P. A., Arrouays, D., Le Bas, C., Jones, R. J. A., Verheijen, F. G. A., … Kibblewhite, M. G. (2008). Soil monitoring in Europe: A review of existing systems and requirements for harmonisation. *Science of the Total Environment*, *391*, 1–12.

Post, W. M., & Kwon, K. C. (2000). Soil carbon sequestration and land-use change: Processes and potential. *Global Change Biology*, *6*, 317–328.

Spencer, S., Ogle, S. M., Breidt, F. J., Goebel, J. J., & Paustian, K. (2011). Designing a national soil carbon monitoring network to support climate change policy: A case example for US agricultural lands. *Greenhouse Gas Measurement and Management*, *1*, 167–178.

Tóth, G., Jones, A., & Montanarella L. (2013). *LUCAS topsoil survey: Methodology, data and results*. EUR–JRC Technical Reports; EUR 26102 EN. Luxembourg: Publications Office of the European Union. https://doi.org/10.2788/97922

United States Department of Agriculture - Natural Resources Conservation Service (USDA – NRCS). (2004). *Ion exchange and extractable cations: Potassium measured with atomic absorption spectrophotometer*. Soil Survey Laboratory Methods Manual Soil Survey Investigations Report 42. United States Department of Agriculture - Natural Resources Conservation Service, Washington, DC.

White, S. L., Sheffield, R. E., Washburn, S. P., King, L. D., & Green, J. T. (2001). Spatial and time distribution of dairy cattle excreta in an intensive pasture system. *Journal of Environmental Quality*, *30*, 2180–2187.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Fernández-Ugalde O, Jones A, Meuli RG. Comparison of sampling with a spade and gouge auger for topsoil monitoring at the continental scale. *Eur J Soil Sci*. 2019;1–14. https://doi.org/10.1111/ejss.12862