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Changes in the physico-chemical properties of topsoil in a landslide-affected area (western part of the Transylvanian Basin, Romania)

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Landslides determine increases and decreases in specific soil compounds which is affecting soil fertility. The recovery of soil fertility is a long process and may be used as an indicator of the landslide age and can contribute to the management plan of the affected area. In order to add to data about soil properties affected by landslides, the current study focuses on a young and shallow landslide from the western part of the Transylvanian Depression. Soil samples were analysed from a physico-chemical point of view (pH, organic matter – OM, total organic carbon – TOC, major cations, and iron content) in two places, at between 0 and 60 cm depth (inside and outside the landslide). The results obtained showed lower values of pH inside the landslide, low values of TOC and rock fragments in both places studied (inside and outside the landslide) and no differences in soil texture between disturbed and undisturbed soil. The ammonium, magnesium and calcium content was higher outside the landslide, the sodium level was slightly higher outside the landslide, while the potassium concentration was higher inside the landslide. This study offers new data regarding recovery of soil fertility and highlights the importance of gaining knowledge on soil properties of relevance to future measures to increase the fertility of agricultural soils.

Key words: soil properties, soil fertility, landslide susceptibility, vegetal composition, Transylvanian Basin, Romania.

INTRODUCTION

Landslides, generated by natural factors or anthropogenic activities, affect human society in many ways, leading to socio-economic losses (Bajgier-Kowalska and Ziętera, 2002; Poprawa and Rączkowski, 2003; Petley, 2012; Corominas et al., 2014) as well as to environmental disasters and damage. Consequently, studies of landslides have been carried out worldwide, and global landslide maps of hazard and susceptibility have been drawn (Nadim et al., 2006; Hong and Adler, 2007; Hong et al., 2007; Komak, 2012; Bronowski et al., 2016; Mrozek et al., 2016). On the other hand, landslides contribute significantly to biophysical biodiversity (Geertsema and Pojar, 2007) mostly in aquatic ecosystems (Butler, 2001; Montgomery et al., 2003), in stream and riparian areas (Hartman et al., 1996; May and Gresswell, 2003; Montgomery et al., 2003), and in mountainous environments (Alexandrowicz and Margielewski, 2010; Alexandrowicz et al., 2003) causing changes in the diversity of sites, soils and habitats. A high diversity of landforms, relief, and edaphic and hydrogeological conditions creates unique biotopes that are controlled by mass movements (Alexandrowicz and Margielewski, 2010). Landslides can redistribute soils with different textures, and will change the soil where the site conditions have been radically altered. Spatial and temporal changes in plant community structure can be observed across the landscape, with considerable influence on diversity (Geertsema and Pojar, 2007).

Changes in soil properties appear due to mass movement of earth and this process is an important one in relation to agri-

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cultural areas, in particular as regards recovery of soil fertility. Changes in soil properties due to landslides have been reported for organic carbon, nitrogen, phosphorus, major cations and texture, with increased fertility over time (Manjusha, 1990; Reddy and Singh, 1993; Zarin and Johnson, 1995). Recovery of soil fertility is a lengthy process. Lundgren (1978), for example, reported low amounts of clay and organic carbon in soils within a landslide as compared to undisturbed soils, seven years following the landslide. Based on Pandey and Singh (1984), nutrient concentrations in forest soils recovered over a period of 40 years. Zarin and Johnson (1995) showed an incomplete recovery of organic carbon, calcium, potassium and magnesium, in the upper part of the soil profile, over a period of >55 years. Some other studies did not find any spatial or temporal differences in soil properties affected by landslides when compared to undisturbed soils. The high spatial heterogeneity of the parent material can be an important barrier for registering some significant patterns (Cheng et al., 2016).

The changes in soil properties are influenced by landslide type and a knowledge of this is essential to understanding how biological properties, as well as soil fertility, are affected (Cheng et al., 2016).

The main objective of this study was to evaluate the modification of physicochemical properties of soil affected by landslides at the Călata locality, Romania. Thus, the current study focuses on the landslide effects on soil chemical content and on the recovery of some important elements, such as total organic carbon (TOC), the main cations (Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}) and soil texture. Secondly, the magnetic susceptibility and physical parameters of the soil (plasticity, bulk density and rock fragment) were analysed in order to understand the changes in soil properties induced by the landslide and to offer practical data for sustainable management of the area. In order to complete these objectives the landslide susceptibility was analysed using the GIS method. Assessment of the susceptibility of terrain to landslides is helpful for indicating the most vulnerable slope sectors.

STUDY AREA

In Romania, the most susceptible sectors for landslide occurrence are represented by the Curvature Subcarpathians followed by the Transylvanian Depression, Moldavian Plateau, Moldavian Subcarpathians, Getic Piemont and Eastern Carpathians (Bălteanu et al., 2010).

In the southern part of the Transylvanian Depression, formed of mudrocks containing illite and montmorillonite with sandstone intercalations, some old and large landslides are emplaced on homoclinal structures. The central part of the Transylvanian Depression, formed by mud rocks of Miocene-Pliocene age, is affected by shallow landslides; and the marginal areas, which are affected by diapirism, are highly susceptible to landslides (Bălteanu et al., 2010). Evaluation of instability factors and their influence on landslide occurrence has also been made on the Transylvanian Plain (Roşian et al., 2016), a large agricultural area, one of the regions most susceptible to landslides. Another susceptible area is the Someşan Plateau, which is part of the Transylvanian Depression, most of which fits into the extreme and high susceptibility classes for landslide occurrence (Bilaşco et al., 2011).

The area studied is situated in the Huedin Depression, on the north side of Călata Valley (Fig. 1). The Huedin Depression is located in the western part of the Transylvanian Depression at the foot of the Vlădeasa Mountains (part of the Apuseni Mountains) that form the western border of the depression. The village of Călata lies within the Călăţele locality (Cluj County). Based on Law 575/2001 regarding the plan of development of national territory (Section V – natural hazard risk zones) the town of Huedin is within a natural risk zone, the susceptibility level to landslides being medium.

The Transylvanian Basin contains a post-Cenomanian sedimentary succession (Upper Cretaceous to Neogene) divided in four tectonostratigraphic megasequences, associated successively with Late Cretaceous rifting, a Paleogene sag basin, a Early Miocene flexural basin and a Middle to Late Miocene backarc basin (Krézsek and Bally, 2006). In the study area, the Paleogene deposits represent the post-tectonic cover of the Carpathian units. During Paleocene-Early Eocene times, in the eastern and western part of the Transylvanian Basin, alluvial fan and fluvial systems deposited coarse to fine-grained reddish sediments with several lacustrine intercalations (Bucur et al., 2001; Codrea and Hosu, 2001). In Middle-Late Eocene the sedimentary succession was composed of evaporites, shallow-marine carbonates, outer shelf marls, shallow-marine sands and fine-grained fluvial deposits (Proust and Hosu, 1996). Beginning with the Early Oligocene, the carbonates were replaced by siliciclastics sediments (Filipescu, 2001).

Călata village is situated on bioclastic deposits with intercalation of calcarenites, dolomitic micrites and siliciclastic deposits. All these are part of the Vima Formation (Răileanu and Şaulea, 1956) being Priabonian in age. This is overlain by continental deposits of the Valea Nadăşului Formation (Popescu, 1978), this unit representing the second Paleogene continental sedimentary formation in Transylvania, comprising coastal plain and fluvial terrigenous deposits (Hosu, 1999). Within it is the Floreşti Member, a marine limestone deposit up to 3.5 m thickness (Rusu, 1995). The transition to the following deposits is made via green clays, thin white dolomicrites or brown limestones.

Geomorphologically, the Huedin Depression shows relief typical of intermontane depressions, being fragmented by the hydrographic network. In this process a fluvial relief comprising an alternation of valley corridors and interfluves was formed. One of these valley corridors is represented by the Călata Valley with slopes of 7–15° declivity and a difference between the top and the bottom of 80–130 m. These values indicate that the hydrographic network is not significantly deepened at the surface of the depression. Close to the Călata locality, the slope where the studied landslide occurred has a declivity of 7–12° and the difference between the top and the bottom of the slope is 84 m. The surface of the slope studied had not been homogeneous before the landslide took place, agricultural terraces being observed both in the field and on the satellite images. Thus, the slope stability was affected by the human intervention; the agricultural terraces being later abandoned, the land being currently used as pasture.

As regards landslides, in the entire Huedin Depression, 33.7% of landslides fall within medium susceptibility areas and all the rest (66.3%) in high and very high susceptibility areas (Fig. 2).

The hilly areas have inclinations of 7–15°, the landslide studied being situated on a slope with 7–12° inclination. The soil profiles are thin, the main component being clay with blocks of parent material, represented by the marine limestones of the Floreşti Member.

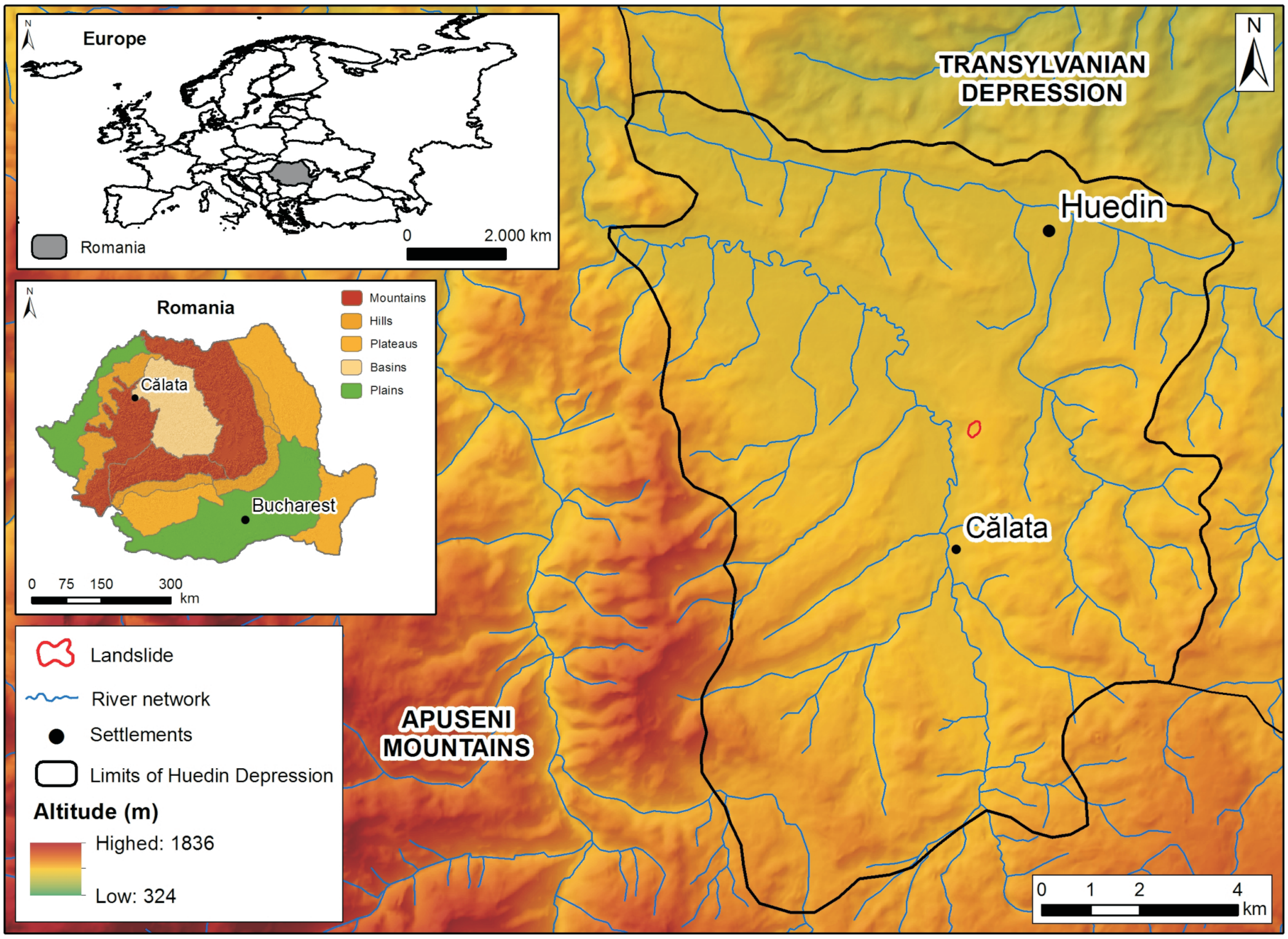

Fig. 1. Location of study site in the Călata Depression, western part of Transylvanian Depression

MATERIALS AND METHODS

SAMPLING SITES

Three sample points were chosen for this study. The first one (profile 1) is located on the landslide scarp, being ~140 cm in depth. Seven samples were investigated from this profile in order to evaluate the following soil physical parameters: humidity, plasticity limits, plasticity index, bulk density, grain-size, porosity, pore index, absorption capacity, and magnetic susceptibility (MS). The second location (profile 2 – 60 cm in depth) is situated inside the landslide body. Six samples were collected, every 10 cm, in order to investigate the physico-chemical parameters [magnetic susceptibility, total organic carbon (TOC), organic matter (OM), pH, total dissolved solids (TDS), electrical conductivity (EC), major cations, iron content, and rock fragments] from the upper part of the soil. The third location (profile 3) was placed outside the landslide body and it is 60 cm deep. In all six samples the parameters noted were analysed.

SOIL ANALYSIS

Soil physical parameters were investigated based on national and international protocols, as follows: humidity (SR ISO 11465:1998); grain-size (STAS 1913/5-85 and SR EN 14688-2:2005); bulk density (ISO 17892-2:2014), free swell index (IS-2720-Part-40-1970), and plasticity limits (STAS 1913/4-86).

In order to evaluate variation in ferromagnetic minerals, the magnetic susceptibility of the soil samples was measured with a Bartington MS3 system with MS2E surface scanning sensor. The MS values are expressed in SI units and were multiplied by 10,000. The MS2 system operates by generating a low frequency, low intensity, AC magnetic field around the sensor. When sample material is placed near the sensor, the resulting change in this field is sensed by the system and converted to magnetic susceptibility readings for both positive and negative values, to a resolution of 2 x 10^{-6} SI units. The measurement period was 5 seconds at 2 kHz operating frequency.

Physico-chemical parameters (pH, total dissolved solids, and electrical conductivity) were analysed in an aquatic soil solution at 1:4 soil:distilled water ratio, using a WTW Multi350i multiparameter device. The major cations (Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}) were analysed in an aquatic soil solution (1:4 soil:distilled water ratio), filtered through nylon membrane sterile syringe filters (0.45 μm pore size). In order to protect the ion chromatograph column, the aquatic soil solutions were then diluted with ultrapure water (resistivity of 18.2 MΩ cm) to an electrical conductivity of ≈100 μS/cm. The cation analyses were performed by ion-chromatography method using a Dionex 1500 IC system equipped with a CS12A column (4 x 250 mm), IonPac CG12A precolumn (4 x 50 mm), self-regenerating suppressor (CSRS ultra II, 4 mm) and a conductivity detector. The eluent

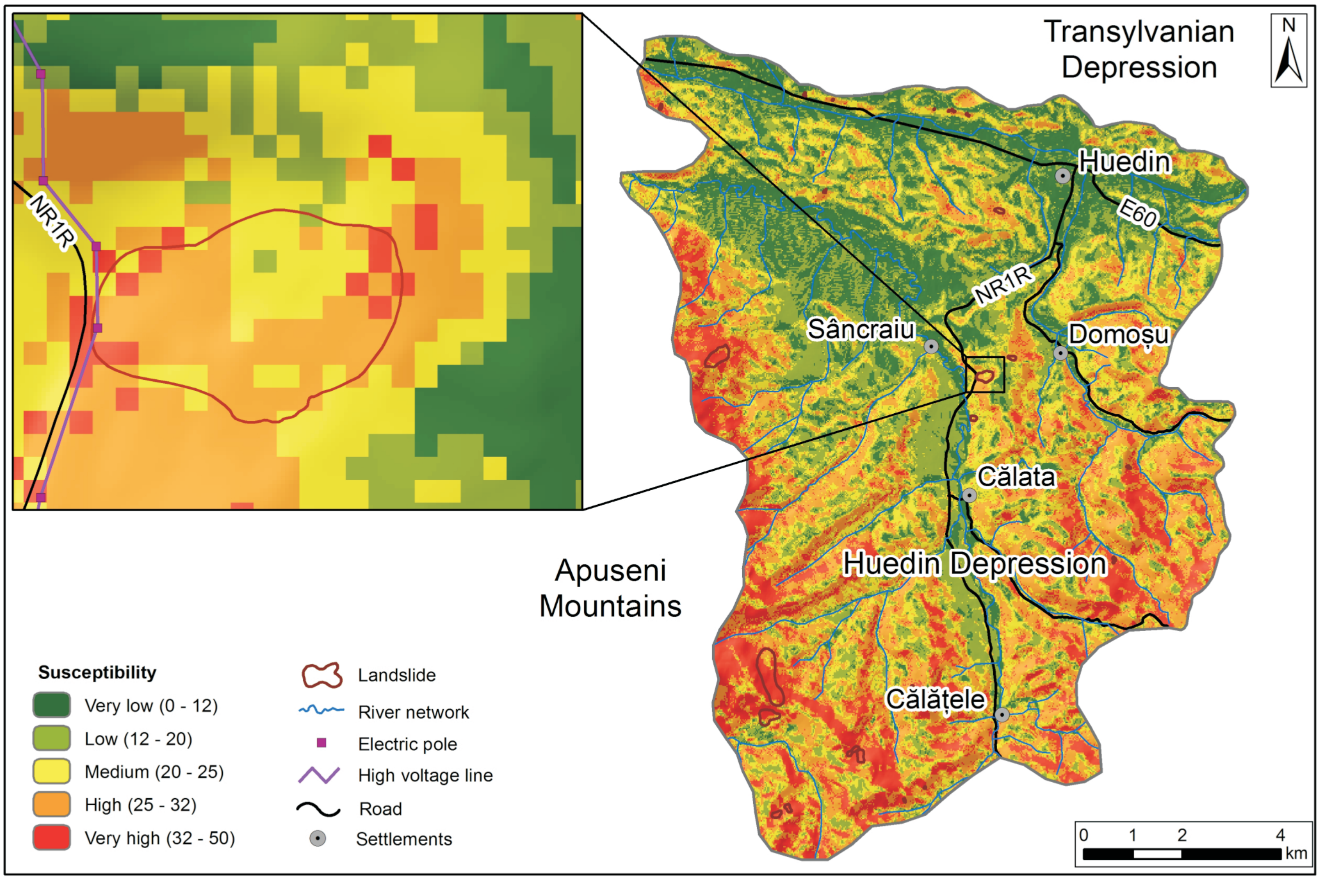

Fig. 2. Landslide susceptibility map of the Călata area

used was an aquatic solution of metasulphonic acid (20 mM), at a flow rate of 1ml/min. Iron content was measured by an atomic absorption spectrometer system (AAS-F ZEEnit 700, Analytic Jena), equipped with air-acetylene flame and a hollow – cathode lamp. Prior to AAS analysis, the soil samples were mineralized with aqua regia.

The total organic carbon and organic matter was determined through Walkley and Black's (1934) method.

Percentages of rock fragments, determined based on the methodology described by van Eynde et al. (2017), were obtained based on grain-size determination, using the sift method. Only the fragments between 3 and 20 mm were taken into consideration. Rock fragments are particles 2 mm or larger in diameter and include all sizes that have horizontal dimensions less than the size of a pedon (Miller and Guthrie, 1984).

Mineralogical content was identified through X-ray diffraction using a Bruker D8 Advance device. Identification of the mineral phases was performed with *Diffrac. Eva 2.1* using the PDF2 (2012) database.

We conducted a field survey within the area studied in relation to the plant community based on two drawn relevés with an area of 12 m^2 (4 x 3 m) placed inside and outside of the landslides studied. In each relevé the recording and identification of all species was performed.

RESULTS AND DISCUSSION

The landslide studied is a young and shallow one – affecting the soil and the upper part of substrate – the triggering moment being no older than 2010. It was triggered on a 7–12° inclination slope; at this angle, it is well-known that an area is susceptible to landslides (Roşian et al., 2018). The landslide's body is represented by small trenches, detaching one from another, along with grassy vegetation. Their movement produces some bare areas on its surface, which are affected by erosion through pluvio-denudation and torrential flow of rainwater. The landslide studied is 55,665 m^2 in area, and lies at 641 m altitude (with the scarp zone at 629 m altitude and the basal part at 602 m).

Based on the Dikau et al. (1996) classification, the landslide studied is a translational one. There is a main scarp in the upper part of the landslide (Fig. 3) followed by the main body which contains transverse cracks. After 2010, one of the transverse cracks evolved into a secondary scarp which favoured the movement of the soil mass towards the basal part of the slope where the infrastructure is located (the DN1R road and an electrical network).

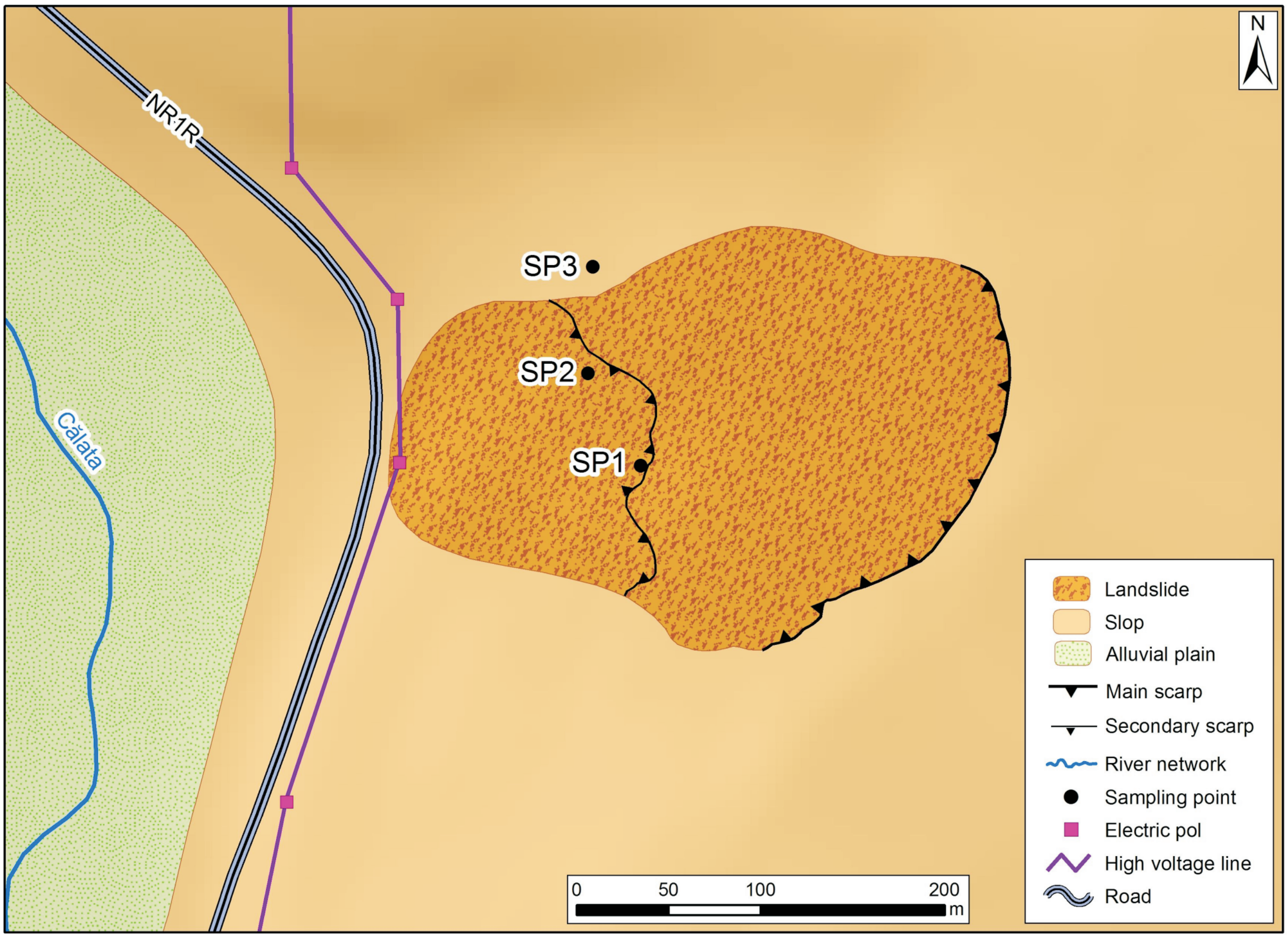

Fig. 3. Geomorphological sketch of the landslide studied

GENERAL CHARACTERIZATION OF THE SOIL

From the landslide scarp, a soil profile, 140 cm in thickness, was studied and consequently the following horizons are described: Horizon A (topsoil 0–40 cm) comprises low plasticity clays, brownish in colour, with calcareous/dolomitic sandstones in decimetric blocks of two types: reddish sandstones with macro-feldspars and grayish, fine calcareous/dolomitic sandstone. The bulk density of the clays reaches 2.05 g/cm^3 and the porosity and pore index register the lowest values; Horizon A/C (40–60 cm) is represented by dark clays with low plasticity and blocks of parent material; Horizon C (parent material 60–140 cm) is formed of dark clays and sandy clays with low plasticity. At this level, together with the blocks of parent material, some newly formed minerals (mostly dendritic in shape) have been observed. Mineralogical analysis of them indicated the presence of quartz, calcite and dolomite, formed through the weathering of mudstones and bioclastic limestones. These two types of rocks were analysed in thin section and showed the following characteristics: the mudstone is almost entirely made of carbonate mud with sparse, very small grains of quartz and flakes of mica. The bioclastic limestone consists of various microfossil fragments set in a matrix of microcrystalline calcite. Intraclasts are represented by quartz grains, thin flakes of mica and very rare feldspar grains.

Generally, the clays investigated have low plasticity with a liquid limit between 21.72 and 32.93%. Based on the plasticity diagram, all the samples analysed fall into the low plasticity class. The position of Atteberg limits can be related to the mineralogy of the clayey soils (Casagrande, 1948; Holtz and Kovacs, 1981; Ohlmacher, 2000). Thus, the liquid limit and plasticity index for each sample analysed was plotted on the plasticity diagram. The plasticity diagram included the montmorillonite, illite, kaolinite and chlorite fields and showed that all the samples came from areas situated outside the main mineralogical fields. Underwood (1967) demonstrated that soils with clay fractions composed of illite and montmorillonite have a higher absorption capacity, and are more susceptible to produce landslides, than those composed of kaolinite and chlorite.

The colloidal activity of clays, calculated as a ratio between the plasticity index and the clay content (Skempton, 1948) is low, with a minimum value of 0.09 and a maximum value of 0.54. Based on this parameter, the clays investigated fall into the inactive clays category (Skempton, 1953). The colloidal activity values can be correlated with the mineralogical content (Moos, 1938) indicating that values <0.33 suggest the presence of quartz, calcite and muscovite. The colloidal activity of these minerals is low due to the simple crystalline structure. Moreover, colloidal activity with values <0.75 indicates that the clays have the following characteristics: the clayey fraction contains mainly kaolinite or low percentages of clay minerals; were deposited in the freshwater; were deposited in brackish waters but subsequently percolated by freshwaters. Thus, based on the index obtained of colloidal activity as well as the results obtained from the plasticity diagram, the analysed soil samples have a low susceptibility to produce landslides. The main causes for the landslide investigated therefore relate to external factors rather than to the geological background characteristics.

MAGNETIC SUSCEPTIBILITY

The magnetic properties of the soil relate to the presence of iron compounds, mostly iron oxides and iron sulphides. The level of iron oxides in the soil depends on the age and nature of the soil, biological and pedological activity, and soil temperature (Boadi et al., 2014). The main sources of iron are primary minerals in the parent material due to its low solubility under oxidative conditions at a neutral pH. The soil particles differ in their degree of magnetism due to differences in ferrous compound concentrations, controlling the magnetism value within the soil (Parker, 1983). In stable soils the MS increases gradually from the deeper layers to the surface but in degraded soils this pattern is absent and the MS is low (Boadi et al., 2014). In this study, the MS in profile 1 has higher values in the upper part (to 60 cm in depth) and this can be related to the secondary formation of ferromagnetic minerals (Dearing et al., 1986). The MS has values between 2 and 4 in the upper part of the profile, decreasing to 0.11 into the basal part. In the second profile (inside the landslide body) the lower values (<5) of MS were registered in the upper part and higher values (>6) in the deeper layers, suggesting movement of the soil mass with the secondary formation of ferromagnetic minerals and/or their transport into deeper layers during movement. For profile 3 (outside the landslide body) the MS values are higher (4–5) in the upper part decreasing with depth to 3.35.

Thus, based on MS values, degradation of the soil inside the landslide body can be observed.

Some studies (Le Borgne, 1955) showed that the MS is higher in the upper part of the slope and lower in the basal part. In the current study the MS is higher in the basal part of the slope and this can be related to the movement of the soil mass and deposition in the basal part, or due to the presence of carbonates. The MS can be "diluted" by water, humus, and carbonates (Mullins, 1977).

Regarding the iron content, measured inside and outside the landslide, the values are similar, with a slight increase outside the landslide (Fig. 4). Inside the landslide, the iron concentration has an average value of 14,321.1 mg/kg while outside the landslide the mean value of iron concentration is 14,971.1 mg/kg. In the soil, iron is frequently present in ferrous (Fe^{2+}) form in primary minerals and a few phyllosilicates while its oxidation to the ferric form (Fe^{3+}) shows significant pedogenetic variation (Adriano, 2001; Stucki et al., 2002). In well-drained soils the most abundant minerals as a source of crystalline Fe oxides are goethite and hematite. Other Fe oxides can be seen in poorly drained soils as crystalline minerals (magnetite, lepidocrocite and maghemite) or short-range ordered crystalline minerals (ferroxite and ferrihydrite) or non-crystalline precipitates (Cornell and Schwertmann, 2003). Redox potential and pH are the two factors that govern the behaviour of Fe in soil. Precipitation of poorly ordered Fe minerals (ferrihydrite) is promoted by neutral pH, while acidic and reduced conditions facilitate the mobilization of Fe minerals (Schwertmann, 1988). A positive correlation was observed in our samples between pH and Fe concentration, the lowest values of Fe being identified in the samples with a slightly acidic pH and higher ones in those

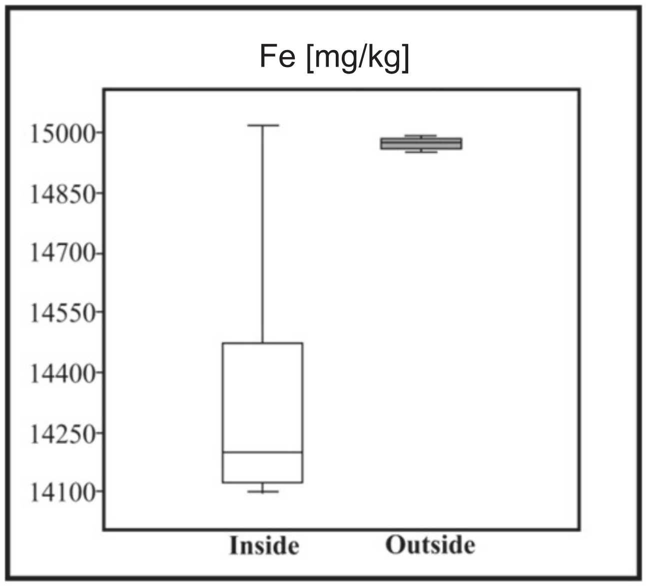

Fig. 4. Iron concentration of the soil from inside and outside the landslide

with a neutral pH. The oxidation-reduction potential (Eh) shows a negative correlation with the Fe values but only in the samples from inside the landslide body. Generally, the pH and Eh values of the samples inside the landslide body indicate conditions for the occurrence of metastable minerals such as lepidocrocite and, possibly, in small amounts, of pyrite. In addition, these minerals characterize a non-equilibrium state in the pedo-environment (Schwertmann, 1988).

PHYSICO-CHEMICAL PARAMETERS OF THE SOIL INSIDE AND OUTSIDE THE LANDSLIDE

As depicted in Figure 5, the pH value for the soil analysed, inside the landslide, is slightly acidic, increasing from surface (6.24) to depth (7.01) and neutral for the soil outside the landslide, varying between 7.01 and 7.40. The same pattern was registered for TDS and EC (Fig. 5) with values between 48–69 mg/l inside the landslide and 63–77 mg/l outside the landslide, and 74.4–108.2 µS/cm inside the landslide and 98.1–119.4 µS/cm outside the landslide respectively.

The values of physico-chemical parameters of disturbed soil are lower than those observed in stable soils (Cheng et al., 2016) and tend to increase with the deposition of the slipped material. Some other studies show that there is not a clear pattern for these values between disturbed and undisturbed soils (van Eynde et al., 2017). The results obtained showed lower values of these parameters for the soil situated inside the landslide, probably due to the fact that the landslide is still active, the soil mass being transported towards the base of the slope.

TOTAL ORGANIC CARBON AND ORGANIC MATTER

The TOC maximum value inside the landslide is 0.68% with a mean value of 0.54%. Outside the landslide, the TOC content has a maximum value of 0.86% with a mean value of 0.53% (Fig. 6). For the organic matter the maximum value is 2.0%, with a mean value of 1.61% for the soil situated inside the landslide, and 2.5%, with a mean value of 1.59% for the undisturbed soil

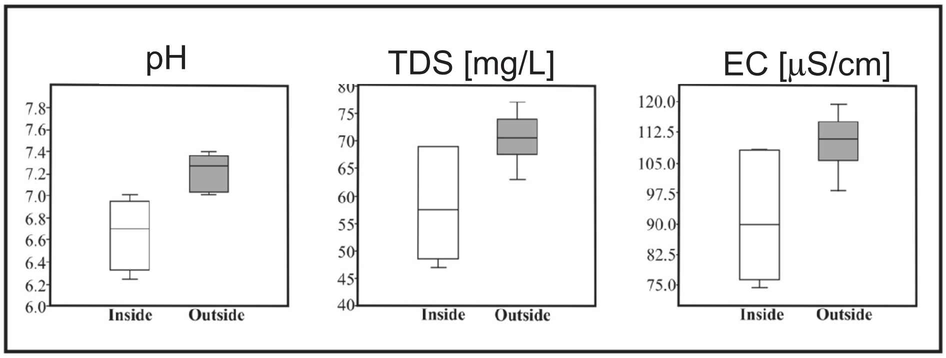

Fig. 5. Value of pH, TDS and EC of the soil from inside and outside the landslide

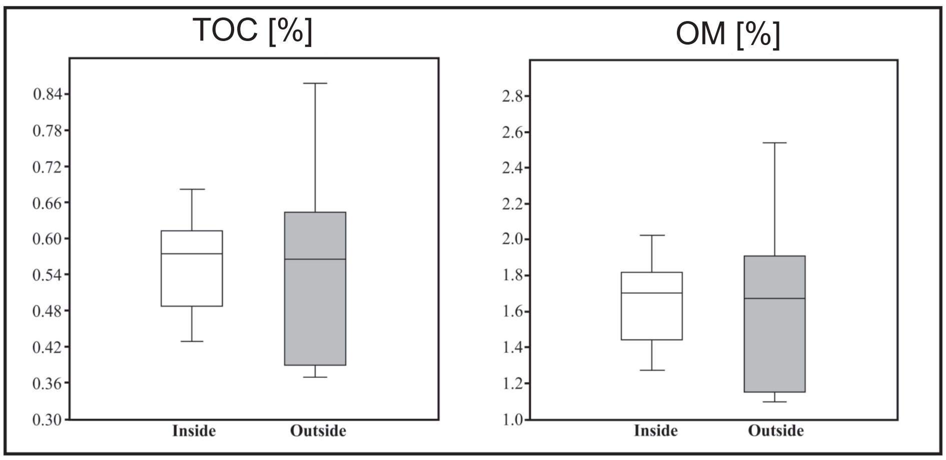

Fig. 6. Total organic carbon and organic matter content of the soil from inside and outside the landslide

(Fig. 6). The content of TOC differs according to the age of the landslide, being higher in the older landslides (van Eynde et al., 2017). Younger landslides have a lower content of TOC (~0.07%) the difference between these landslides and the undisturbed soils being up to 1.5% (Lundgren, 1978; van Eynde et al., 2017). The increasing trend of TOC content over time in the soils from landslides suggest that this parameter can be used as an index for the age of the landslides or for the frequency of their production. Thus, this type of study is essential in the construction of risk maps for landslides (van Eynde et al., 2017).

Organic matter was used as an indicator of soil quality due to the many important interactions within the soil system (Blonska et al., 2018). Changes in the amount of organic soil matter, nutrients and physical properties have different intensification degrees within landslides, and strongly influence the processes of soil cover and vegetation restoration (Pickett et al., 1999; Shiels et al., 2006). The stabilization of organic matter seems to be in direct relation with the texture of the soil in terms of a higher content of organic matter and its stabilization being caused by the low percentage of fine silt fraction and clay (Blonska et al., 2018).

ROCK FRAGMENT

Rock fragment content is low in both cases (1.06% in P2 and 2.77% in P3) but with higher values in the soil from outside the landslide (Fig. 7).

Other studies indicated higher rock fragment contents inside a landslide compared to those situated outside the landslide, especially in young landslides. Decreasing values of this parameter, over time, can be caused by fine colluvial material deposition (Cheng et al., 2016; van Eynde et al., 2017). The presence of rock fragments can be used, in the field, as an indicator of landslide disturbances.

MAJOR CATIONS

Comparing the cations content of the soil analysed outside and inside the landslide, higher concentrations of ammonium, magnesium and calcium were recorded in the soil outside the landslide. In the case of potassium, the higher values were registered within the landslide. For sodium, on the other hand,

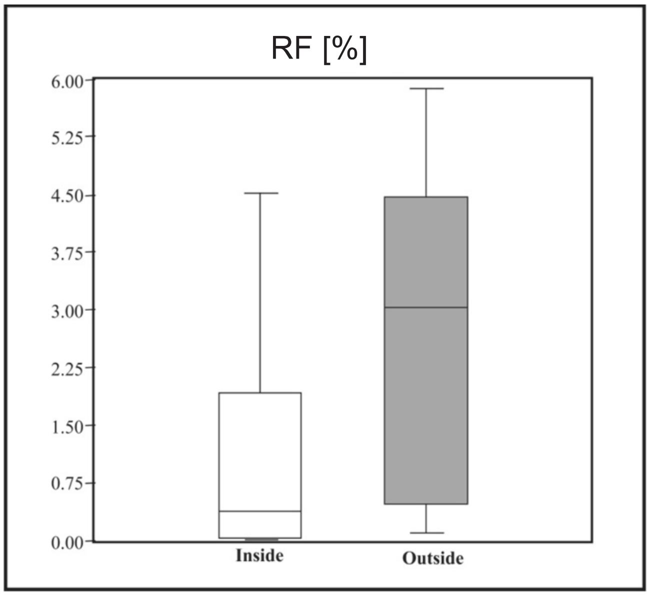

Fig. 7. Rock fragment content of the soil from inside and outside the landslide

the values were almost equal, slightly higher outside the landslide (Fig. 8).

The results obtained indicate that the landslide has an impact on the physico-chemical characteristics of the soil. The younger landslides, as in this case, register lower values of TOC and K^+ content, and may reach the total exhaustion of these elements. However, this scenario is not visible in the case of old landslides. The TOC and potassium content inside landslides tend to increase over time due to vegetable residues, organic and inorganic fertilizers, and alteration of primary minerals and deposition of colluvial deposits (van Eynde et al., 2017). Some studies (Gottardi and Galli, 1985; van Eynde et al., 2017) indicate higher values of sodium both in younger and older landslides. In this study, the sodium concentrations are similar in both types of soil analysed.

Some studies have shown no differences for calcium and magnesium content between stable and disturbed soils (van Eynde et al., 2017). In this study, the concentrations of these cations are higher in the undisturbed soil than in the disturbed one. Similar results were obtained in some other studies (Guariguata, 1990; Manjusha, 1990; Reddy and Singh, 1993). Their results suggest that landslides have a significant impact on bivalent cations. On the other hand, other authors (Adams and Sidle, 1987; Manjusha, 1990; Shrumpf et al., 2001) have argued that landslides bring up, from the deepest layers, a less altered and nutrient-rich material which leads to the improvement of soil fertility.

TEXTURE

No difference was observed in the textural characteristic of the soil, despite other studies, like the one performed by Zarin and Johnson (1995) who found a lower clay content in landslides located in a mountain forest in Puerto Rico. A similar soil texture, namely clay texture, was determined for most of the samples analysed, except for the sample from 60–80 cm in depth from inside the landslide, where a sandy clay texture was identified. A possible explanation for this small difference is that the profiles analysed are strongly affected by alteration processes and with no clear limits between horizons (Knapen et al., 2006). In conclusion, the disruption process of soil is not very deep in comparison to the entire soil profile, thus the textural dif-

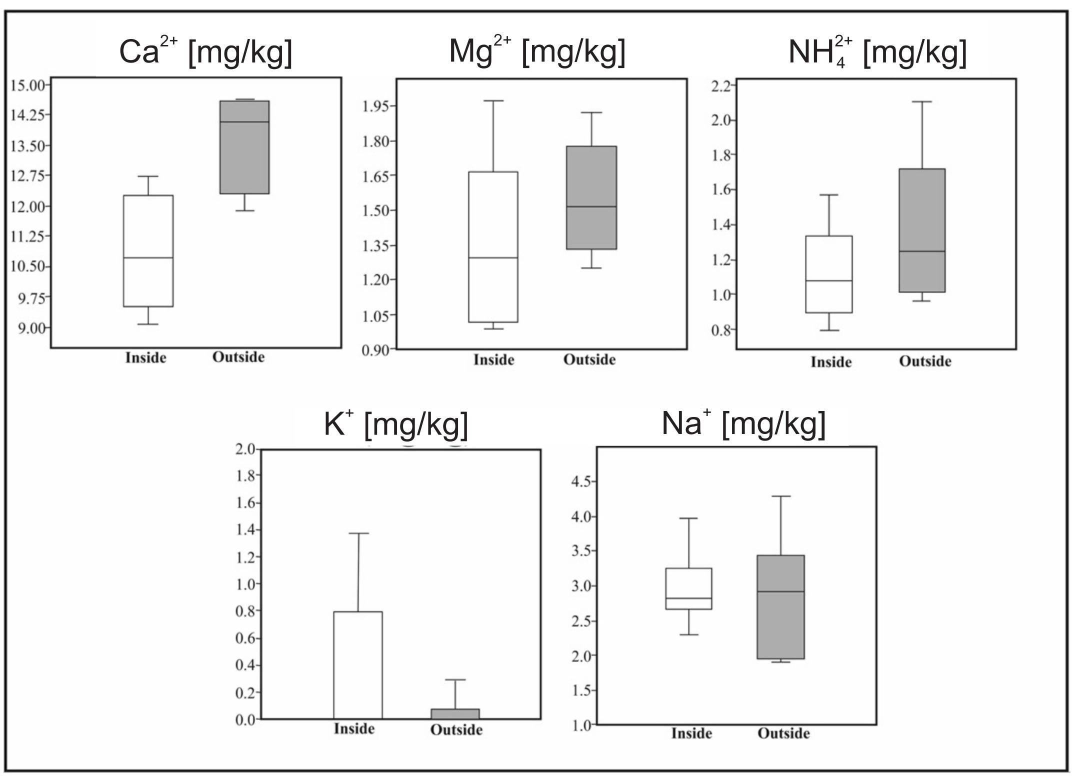

Fig. 8. Cations content of the soil inside and outside the landslide

ferences between disturbed and undisturbed soils are difficult to observe.

Increasing fertility of soils affected by landslides is a long process, covering many years, one of the most important factors in this case being represented by the spatial heterogeneity of the parent material (Walker and Shiels, 2013).

VEGETATION ASSEMBLAGES

The vegetation proved to be an important measure for the mitigation of land degradation due to the fact that it increases the shear strength of the soil through a series of mechanical and hydrological effects (Norris et al., 2008). While the mechanical effect of vegetation on slope stabilization has been extensively studied (Wu, 1979; Mickovski et al., 2009; Bordoni et al., 2016) the hydrological effect, although known, has been rarely reported in the scientific literature (Stokes et al., 2014; Gonzalez-Ollauri and Mickovski, 2017).

Information regarding the behaviour of vegetation from a hydrological point of view may contribute to the efficient and sustainable selection of plant species (McVicar et al., 2010; Duan et al., 2016) in order to reduce slope instability and associated risks (Fell et al., 2005; Lu and Godt, 2013; Gonzalez-Ollauri and Mickovski, 2017).

In our study the vegetation assemblages contain 27 species, 16 of them outside the landslide and 11 inside the landslide. Outside the landslide studied, the plant species form part of two assemblages: *Polygalo majori–Brachypodietum pinnati* and *Poo–Festucetum pratensis*. *Brachypodietum pinnati* is widespread, especially on steep and unfertilized slopes (Lüth et al., 2011), in areas affected by landslides or in abandoned and unmanaged grassland patches (Sojneková and Chytrý, 2015; Magura, 2017). In the area studied this species was observed outside the landslide and a possible explanation may be that, in the past, the part that is now outside the landslide was affected by another landslide, and this specific vegetation developed in that area.

CONCLUSIONS

The results obtained in the present study emphasize the variation in the topsoil physico-chemical characteristics inside and outside of the landslide areas, demonstrating the landslide impact on the topsoil fertility. Taking into the consideration the contrasting results in topsoil properties between the two studied cases (areas), the small difference can be explained in terms of the young age of the landslide.

The landslide caused a decrease in pH, total dissolved solids and electrical conductivity; total organic carbon and organic matter; calcium, magnesium and ammonium content and an increase in potassium content. There were no other specific differences in the parameters analysed. The low amount of organic matter and organic carbon can affect agricultural production and water quality, and at a larger scale, can contribute to global climate change. After agricultural abandonment, the soil was affected by landslides, which led to a decrease in soil capacity to store carbon.

Further investigations will be performed on other landslides, of different ages, in order to establish landslide impact on topsoil properties and to build more precise patterns regarding the level and the distribution of the soil physico-chemical parameters in such areas.

Concerning the main goal of our investigation, namely pointing out the difference between disturbed and undisturbed topsoil, our results show that at least in the case of some parameters, the landslide represents an issue for soil quality and influences the fertility recovery process. Furthermore, the assessment of physico-chemical properties of topsoil is also important in choosing the right strategy for a management plan.

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