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Isolating the soil type effect on the organic carbon content in a Rendzic Leptosol and an Andosol on a limestone plateau with andesite protrusions

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ABSTRACT

The aim of the paper is to compare soil organic carbon (SOC) concentration and stock in a Rendzic Leptosol and a Dystric Andosol as two SOC-rich soil types. Because SOC differences between them are difficult to determine from soil databases, a suitable surface geological configuration of andesite lenses embedded within a flat limestone plateau was used for a direct comparison. All the other site conditions were identical, including topography, vegetation cover, and forest management. Twelve soil profiles, 0.6 m in depth, were opened in the study area according to parent material and soil types, six profiles on limestone (Rendzic Leptosols) and six profiles on andesite (Dystric Andosol), respectively. Soil samples were taken from 0.1 m layers within 0.0–0.6 m depth and then analysed for SOC concentration by dry combustion method. The Student's *t*-test did not detect differences in SOC concentration between the two soil types. The only difference was found in the SOC stock and it was limited to the subsoil ($P < 0.05$). Differences in the depth of 0.3–0.6 m can be attributed to higher Rendzic Leptosol bulk density, resulting from its higher clay content at that depth. Both soil types have the same capacity to sequester organic carbon under the same climatic conditions.

1. Introduction

Andosols and Rendzic Leptosols belong to carbon rich forest soils (Dinca et al., 2012; Juráni and Balkovič, 2007). For instance, Pichler et al. (2013) showed that an allophanic Andosol retained additional organic matter (OM) input from coarse woody debris in the form of a quantitative soil organic carbon (SOC) imprint. On the other hand, calcareous soils were shown to maintain high SOC stocks under centuries-long agroforestry management (Ahmed et al., 2012). Owing to their potential to support important ecological processes, both soil types are represented in many biodiversity hot-spot areas, biosphere reserves, and in elements of some World Natural Heritage sites (UNESCO, 2011). SOC-dependent ecological processes in some of these sites were designated as a baseline or ecological indicators for forest management and conservation within corresponding biogeographical zones (Osipova et al., 2014; Pandey, 2012; UNESCO, 2005). However, possible applications of SOC as an ecological indicator across different areas presuppose knowledge about the underlying mechanisms affecting SOC retention and stabilization in local soils, as well as sufficient knowledge of SOC spatial variability (e.g. Moffat, 2003; Page-Dumroese et al., 2000; Waring et al., 2014). This is often not so, because some soil units, notably Andosols and Rendzic Leptosols, were either omitted or underrepresented in some major carbon sequestration surveys and studies (e.g. Ahmed et al., 2012; Baritz et al., 2010; Vanguelova et al., 2013). It is therefore often difficult to extract effects of individual factors such as soil type, management or others, on SOC due to their high spatio-temporal variability.

Given that situation, a direct comparison of SOC between certain soil types under purposefully selected site conditions could provide a valuable auxiliary information about the effect of soil type, featuring its characteristic organic carbon (OC)-binding mechanism, on SOC. Mostly, they include organomineral interactions that depend on cation bridges involving mainly Ca^{2+} in neutral to alkaline soils, Al^{3+} in acid soils, and adsorption of organic materials on iron oxide surfaces (Oades, 1988).

Specifically, our study aimed to compare SOC in an allophanic Dystric Andosol and a Rendzic Leptosol. These soils are particularly rich in SOC and their mutual rank on the SOC concentration scale was not yet addressed. It was therefore our goal to assess the relative capacity of their SOC-binding mechanisms, i.e. the cation bridges involving mainly Ca^{2+}, as typical of Rendzic Leptosols on one hand, and the SOC complexation with Al^{3+}, known from Andosols (Nanzyo, 2002; Takahashi and Dahlgren, 2016) on the other hand. This was to be achieved under practically identical site conditions predetermined by spatial juxtaposition of the two soils, in which the variability of other factors affecting SOC was substantially reduced. Such an approach

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could be used for assessing the need to assign soil-specific values to SOC-based ecological indicators within areas that feature various soil units. Such decisions can have environmental and economic implications.

2. Material and methods

2.1. Study area

We took advantage of a convenient occurrence of a fully developed Dystric Andosols and a Rendzic Leptosols under otherwise identical site conditions and forest management at a mutual distance of only approximately 50–100 m apart. This rare configuration was formed by spot-like andesite intrusions into Muránska Planina, a massive karst plateau located in the West Carpathians, Slovakia (48°46.759′ N, 19°57,978′ E, 1409 m a. s. l.). The distinctly flat plateau formed from Middle Triassic limestone-dolomite complex, interspersed by Tertiary andesite lenses (Vološčuk and Pelikán, 1991). The plateau is covered by a 130 years old Norway spruce forest (*Picea abies* [L.] Karst.) managed by a shelterwood system with a rotation period of over one hundred years. The study area falls to middle cool and cool mountains and very humid region with mean annual temperature 2–4 °C and the annual precipitation ranging between 800 and 1200 mm (Faško and Šťastný, 2002; Šťastný et al., 2002). Mesoscale variability of the soil units depends on local geology. The allophanic Dystric Andosol developed on the andesite lenses, while the Rendzic Leptosol was formed on limestone that encompasses them (both soil units are given according to WRB, 2014). The presence of allophane in Dystric Andosol was presented by the Fieldes and Perrott test (Fieldes and Perrott, 1966). The surface humus form is moder.

2.2. Soil sampling and laboratory analysis

Our study was performed on a site scale. Twelve soil profiles were opened within the study area according to parent material, i.e. six profiles on limestone and six profiles on andesite. The soil profiles were excavated on flat terrain surface with close to zero inclination. All soil profiles were exposed to the depth of 0.6 m. A total of 72 soil samples, weighing approx. 500 g each, were collected from 0.1 m soil layers (0.0–0.1 m,…, 0.5–0.6 m) for organic carbon concentration determination. Undisturbed soil samples (400 cm^3) for establishing soil bulk density and stony fraction content were also taken. Soil samples were air-dried, ground, and passed through a 2-mm mesh sieve. Visible plant residues were removed by electrostatically charged stick. The particle size distribution was measured by sedimentation method (Fiala et al., 1999). Soil pH was determined electrometrically by calibrated pH meter after 24 h in suspension consisting of 10 g of fine earth mixed with 25 ml of distilled water or KCl solution (Fiala et al., 1999). Extractable iron oxides were determined by laboratory methods using ammonium oxalate, citrate bicarbonate dithionite, and sodium pyrophosphate solutes according to Jackson et al. (1986). The amount of Fe ions was determined by atomic absorption spectrophotometer (Thermo ICE 3000). The amorphous inorganic Fe ($g{\cdot}kg^{-1}$) was calculated as the difference between ammonium oxalate- and sodium pyrophosphate-extractable Fe, and crystalline Fe ($g{\cdot}kg^{-1}$) represent difference between citrate bicarbonate dithionite- and ammonium oxalate-extractable Fe. The analyses were performed in accredited laboratory of the National Forest Centre in Zvolen (Slovakia). The total C and N concentration in the fine earth (< 2 mm) and C/N ratio were determined by Vario MACRO Elemental Analyzer (CNS Version; Elementar, Hanau, Germany), which employs the dry combustion method. Carbonate content was measured by volumetric device (Fiala et al., 1999) and after that inorganic carbon content was subtracted from the total carbon concentration measured by CNS analyser. Soil organic carbon stock was calculated for all six 0.1-m layers separately according to

$$SOCS = \sum_{i=1}^{j} BD_i \times SOCC_i \times d_i \times (1 - cf_i) \quad (1)$$

where *SOCS* is SOC stock ($kg{\cdot}m^{-2}$), *i* is respective soil layer index, *j* is number of soil layers, BD_i is soil bulk density ($kg{\cdot}m^{-3}$), $SOCC_i$ is SOC concentration ($kg{\cdot}kg^{-1}$), d_i is *i*-th soil layer thickness and cf_i is volume of coarse fraction ($m^3{\cdot}m^{-3}$) in *i*-th soil layer, respectively (according to Pichler et al., 2013). The total volume of the stony fraction was obtained by means of the ARES system (GF Instruments system, Brno) that operates using a non-destructive electrical resistivity method. Electrical resistivity was recorded along 15 m long sections running through the sites and the results were processed into the form of 2-D apparent soil resistivity profiles with the RES2DINV software (Geotomo Software, Gelugor, Malajzia). Then, electrical resistivity values were converted into stony fraction volume through calibration equations for limestone (Eq. (2)) and andesite (Eq. (3)):

$$CFC = -99,26 + 49,28 \log_{10}(x_i) \quad (2)$$

$$CFC = -340,7446 + 104,5678 \log_{10}(x_i) \quad (3)$$

where *CFC* is coarse fraction content ($m^3{\cdot}m^{-3}$) and *x* is measured apparent resistivity in each *i*-th layer. The calibration Eqs. (2) and (3) was obtained from calibration profiles on which the volume of stones and boulders (> 20 mm) was determined according to Folk (1951) and Alexander (1982). The gravel volume (2–20 mm) was measured in undisturbed soil samples taken from calibration profiles. The total coarse fraction volume *cf* was then calculated for each layer on each site from a logarithmic function fitted to total stony fraction volume vs. apparent electrical resistivity in the calibration profiles.

2.3. Statistical analysis

We used the Shapiro-Wilk test (Shapiro and Wilk, 1965) to assess the applicability of the normal distribution to the measured SOC concentration and SOC stock. The Grubbs test (Grubbs, 1950) was used to identify possible outliers in the SOC concentration and SOC stock data sets. The differences between two soil types in SOC concentration and SOC stock and in physical and chemical properties were tested by the Student's *t*-test for independent variables (Sokal and Rohlf, 1995) on the normally distributed data. All statistical analyses were performed in STATISTICA 12 (StatSoft, Inc., Tulsa, USA) software package.

3. Results

Results of the Student's *t*-test between the two soil types pointed to significant differences in the sand, silt, and clay contents at the respective depths, as shown in Table 1. The textural differences gave rise to distinct bulk densities at both depths ($P < 0.001$). Other statistical differences also included those in the skeleton content in the topsoil, as well as in the C/N ratio — an important soil humus quality indicator — in the subsoil ($P < 0.05$).

The SOC concentration decrease with soil depth fitted by the exponential function is displayed in Fig. 1.

The results of Student's *t*-test for possible SOC concentration and SOC stocks differences are summarized in Table 2. Only the differences in SOC stock of the two soil types at the 0.3–0.6 m (subsoil) were statistically significant. As seen in Fig. 1, a slightly steeper, but nonsignificant ($P = 0.965$, Cohen et al., 2003) decline in carbon concentration with depth was observed in Dystric Andosol compared to Rendzic Leptosols.

4. Discussion

In the recent years, sustainable provision of ecosystem functions became a research topic of paramount importance. In this context, SOC is one of the most broadly used indicators of soil quality (Zornoza et al.,