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Fruška Gora mountainous environments – assessing the impact of geological setting and land use on soil properties

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Abstract: On a global scale, it was found that the surface of the vulnerable land and land affected by degradation has been increasing in the last decades and that unsustainable land management is one of the key drivers of land degradation. In order to assess the effect that these changes have on biodiversity and ecosystem services, and to realize appropriate planning and management actions for the conservation of the environment, it is essential to identify and quantify changes caused by land degradation. The aim of this study was to determine the impact of the geological setting, *i.e.*, the type of bedrock, and land use on the physicochemical properties of soil in the vulnerable mountainous areas of Fruška Gora. For the purpose of this study, 30 soil samples were collected from a depth of 0–20 cm at four locations on the Fruška Gora Mt. The geological setting was serpentinite and marl and land cover was forest and meadow. The following soil properties were determined: pH, redox potential (*Eh*), electrical conductivity (*EC*), total dissolved solids (*TDS*), concentrations of available cations Ca, Mg, K, Na, contents of organic carbon (C_{org}) and nitrogen (*N*). The correlation between the obtained parameters was tested with two-way ANOVA and principal component analyses (PCA). All of the obtained results indicated that the soil physicochemical properties depended on the geological setting and that rock composition has to be taken into consideration during land management.

Keywords: soil; environmental changes; rock type; land cover.

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INTRODUCTION

The two main components of land degradation, which are dependent on each other, are damage to plant communities and deterioration of soil.[1] One of the biggest recognized environmental problems is destruction of forests, which are one of the most complex ecosystems. Cleared land is used either as a construction site or it is converted to arable land. In terms of the human activity, land use change seems to be one important factor that could fundamentally change carbon cycling in ecosystems and their response to climate warming.[2]

In order to regulate patterns of erosion and raise awareness about the importance of soil, a number of studies about the influence of land use change on soil properties and soil management have been conducted.[3–8] Information concerning the influence of the geological setting on the physicochemical properties of soil in dependence on the type of land use is limited. The geological setting is of importance since it is one of the five essential factors, together with topography, vegetation, climate and time, that effect soil formation. Geomorphologically, the rock type could be considered as a constant landscape variable, so soil and vegetation co-evolve with topography under a changing climate and strong interaction with bedrock through weathering–erosion–deposition cycles.[9]

To determine how land use changes could influence the physicochemical properties of soil, it is essential to evaluate the differences in soil properties under natural conditions. The aim of this study was to determine the physicochemical properties of soil above two types of bedrock (serpentinite and marls) and below two types of land use (forest and meadow). The following soil properties were determined: pH, redox potential (*Eh*), electrical conductivity (*EC*), total dissolved solids (*TDS*), concentrations of available cations Ca, Mg, K, Na, contents of organic carbon (C_{org}) and nitrogen (*N*).

Both serpentinites and marls are rocks that easily undergo weathering processes. The weathering processes on serpentinites can differ depending mostly on the climatic conditions, but also on other factors as well, including topography, biota, time and tectonic activity.[10] Similarly, soils on marls can develop with various physicochemical properties depending on composition and climatic setting and can pose serious management problems.[11]

The pH, as an indicator of acidity or alkalinity, is also a rough indicator of the availability of nutrients within the soil to plants. The redox potential is a measure of the tendency of a chemical species to acquire electrons and thereby be reduced or release electrons and thereby be oxidized. The parameter *TDS* is used to describe the total contents of dissolved salts in the form of ions and the electrical conductivity of soil solution is an often used indicator of its solute (cation or anion) concentration. There are many factors affecting *EC* value, such as, porosity, water content, structure, particle shape and orientation, particle-size distribution, cation exchange capacity, wettability, ionic strength, cation composition and temperature.[12] A change in land use influences the amount of carbon stored both in vegetation and soil[13] and it may influence C input as well as output fluxes from ecosystems.[14] It is also known that the affects of conversion of a forest to an agricultural ecosystem cause depletion of the organic carbon concentration of the soil by 20–50 %.[15]

In order to assess the influence of land usage and the type of bedrock on the physicochemical properties of soil, soil from the Fruška Gora Mt., Serbia, were analysed (geological details are presented in Supplementary material to this paper).

EXPERIMENTAL

Details about the sampling location and the corresponding map are given in Supplementary material to this paper.

Methodology

The bulk soil samples were cleaned of debris and air dried for 4 days. The quartering method was used to obtain representative samples. These samples were ground and in all samples, following parameters were determined: pH, redox potential (*Eh*), electrical conductivity (*EC*), total dissolved solids (*TDS*), concentrations of available ions Na, K, Mg, Ca, and the content of organic carbon and nitrogen.

The pH, *Eh*, EC and TDS were determined using standard laboratory meters for these parameters by mixing 1 g of each sample with 10 mL boiled and cooled distilled water at room temperature.

The available ions were determined according to the method proposed by Faulkner *et al.*[16] Each sample (5 g) was mixed with 50 mL of water for 1 h. The samples were then filtered and the filtrate was analysed using inductively coupled plasma optical emission spectrometry (ICP-OES) in order to determine the concentrations of the available ions Na, K, Ca and Mg. The ICP-OES analyses were performed using a SPECTRO AR COS instrument, while a Perkin–Elmer ELAN 9000 instrument was employed for the ICP-MS analysis.

Elemental analysis was applied to determine the contents of carbon (C_{org}) and nitrogen (*N*). The C_{org} content was determined after removal of carbonates with dilute hydrochloric acid (1:3). The measurements were realised on a Vario EL III, CHNOS elemental analyser (Elementar Analysen System GmbH).

Statistical analysis

The obtained results were statistically evaluated. The design of the experiments corresponds to a two-factor analysis of variance (two-way ANOVA, rock type and land use), the factor rock type with two levels: serpentinite and marls, and the factor land use also with two levels: meadow and forest. The two-way ANOVA assessed the main effect of each independent factor, and whether there was any interaction between them. The basic sample included 30 soil samples for which 10 properties were measured: pH, *Eh*, *EC*, *TDS* and concentrations of available ions Na, K, Mg and Ca, and C_{org} and *N*. The multivariate analysis principal component analyses (PCA) was used to provide an objective summarization of the complex data represented by 4 data sets: forest and meadow serpentinite soils, and forest and meadow marl soils.

RESULTS AND DISCUSSION

The results of the determination of the physicochemical properties of the Fruška Gora forest and meadow soils developed on serpentinite and marls are presented in Tables S-I–S-III of the Supplementary material. According to the obtained results, all the tested soils, depending on geological setting and land use, varied from slightly acidic to slightly alkaline, with varying oxidation–reduction potentials. The electrical conductivity varied from 49.3 to 288 μS cm^{-3} and the total dissolved solids were in the range between 16.0 and 125.0 ppm (Table S-I). The concentrations of available cations varied over a wide range: Ca 5.71–255.30 ppm, K 10.13–77.10 ppm, Mg 4.06–46.56 ppm and Na 7.15–41.64 ppm (Table S-II). Furthermore, the tested soils differed in their content of organic matter, C_{org} varied between 1.06 and 3.34 %, and content of *N*, between 0.08 and 0.21 %. In the tested soils, the C/N atomic ratio varied between 13.25 and 17.50. However, forest soils both on marls and serpentinite showed higher *C*/*N* atomic rations than both meadow soils, indicating that the forest soils were richer in organic matter (Table S-III).

Based on the analyses of variance (two-way ANOVA) and least square difference (*LSD post-hoc* test), it was found that there were statistically significant differences between the mean values of certain parameters for the studied factors and their interactions. Differences were statistically significant for pH for rock type ($F_{1,26} = 102.78$, $P < 0.05$), land use ($F_{1,26} = 10.91$, $P < 0.05$) and interaction between these two ($F_{1,26} = 17.20$, $P < 0.05$), for *Eh* for rock type ($F_{1,26} = 87.90$, $P < 0.05$) and interaction (rock type×land use) ($F_{1,26} = 8.72$, $P < 0.05$), for *EC* for rock type ($F_{1,26} = 15.07$, $P < 0.05$) and interaction (rock type×land use) ($F_{1,26} = 10.04$, $P < 0.05$), for *TDS* for rock type ($F_{1,26} = 21.77$, $P < 0.05$) and interaction (rock type×land use) ($F_{1,26} = 11.97$, $P < 0.05$), for Ca for rock type ($F_{1,26} = 22.63$, $P < 0.05$) and interaction (rock type×land use) ($F_{1,26} = 4.69$, $P < 0.05$), for K for rock type ($F_{1,26} = 82.61$, $P < 0.05$), land use ($F_{1,26} = 36.23$, $P < 0.05$) and interaction ($F_{1,26} = 14.70$, $P < 0.05$), for Mg for land use ($F_{1,26} = 12.82$, $P < 0.05$), for C_{org} for rock type ($F_{1,8} = 102.78$, $P < 0.05$), land use ($F_{1,8} = 10.91$, $P < 0.05$) and interaction ($F_{1,8} = 10.64$, $P < 0.05$), for *N* for rock type ($F_{1,8} = 10.08$, $P < 0.05$), land use ($F_{1,8} = 21.33$, $P < 0.05$) and interaction ($F_{1,8} = 21.33$, $P < 0.05$) and for *C*/*N* for rock type ($F_{1,8} = 16.56$, $P < 0.05$) and land use ($F_{1,8} = 74.06$, $P < 0.05$). Only for Na were there no statistically significant differences between mean values for any of the tested factors. The highest number of statistically significant differences between the mean values depended on the rock type (9 parameters).

All of the obtained results indicated that differences existed between the soils depending on type of bedrock and land cover. Therefore, the soil characteristics were further explored with correlations between parameters that are known to have a good correlation: pH–*Eh*, *EC*–*TDS* and *C*–*N* in order to determine whether grouping of samples would occur.

The pH and *Eh* values were closely related and their correlation coefficient for the tested Fruška Gora soils was 0.904 (Fig. 1). However, the tested soils mostly varied in acidity/alkalinity and oxidation/reduction properties according to the geological setting. The Serpentinite soils were slightly acidic with more profound oxidation conditions, while the marl soils were slightly alkaline with reducing conditions. These differences are a consequence of different weathering rates and mineralogical composition of serpentinites and marls.

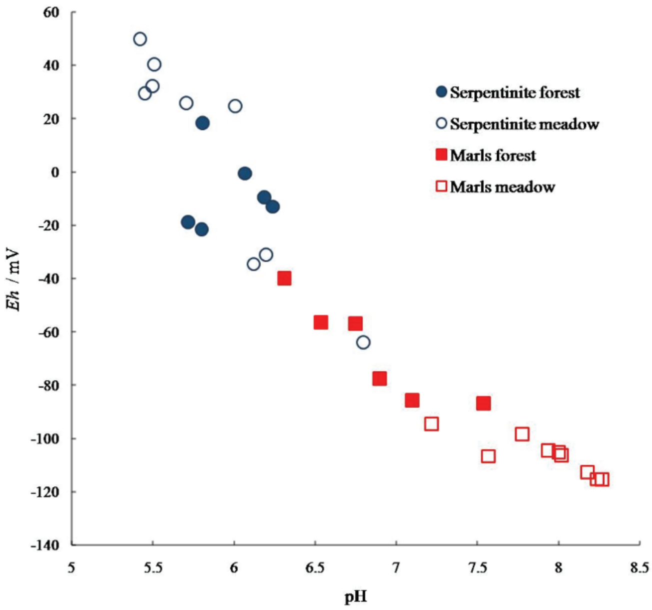

Fig. 1. Correlation between pH and *Eh* in the Fruška Gora serpentinite and marl soils.

The correlation between electrical conductivity and total dissolved solids in tested soils was, as expected, positive (R^2 = 0.962), but it revealed differences between the soils according to geological setting (Fig. 2). The serpentinite soils had lower *EC* and *TDS* values, while marl soils generally had higher *EC* and *TDS* value. This again could be assigned to different weathering rates and mineralogical composition of serpentinites and marls.

The correlation between the content of C_{org} and *N* was positive (R^2 = 0.955), although soils on meadows both on serpentinite and marl had lower *C*/*N* rations than forest soils, indicating that the forest soils were richer in organic matter (Table S-III). The correlation between C/N and pH (R^2 = 0.553) indicated that there was a bigger difference between soils on marls regarding pH and C_{org}, than on serpentinite (Fig. 3). Brady and Weil[1] indicated that the accumulation of organic matter tends to acidify soil, which is in accordance with the present findings.

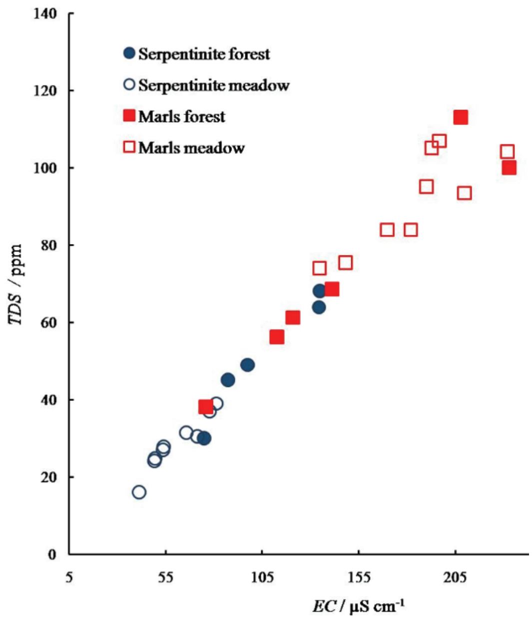

Fig. 2. Correlation between electrical conductivity and total dissolved solids in the Fruška Gora serpentinite and marl soils.

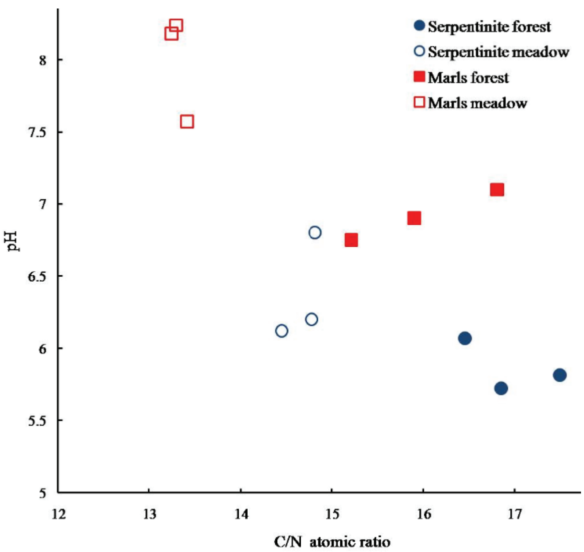

Fig. 3. Correlation between the C/N atomic ratio and pH in the Fruška Gora serpentinite and marl soils.

The differences obtained were a consequence of the influence of different rock types. Weathering of marls produces more solutes and solids than serpentinite soils, and the soils are slightly alkaline with reducing conditions. The higher concentration of available Ca was a consequence of weathering of carbonate minerals, and the higher concentration of available K was a result of the presence of clays in these sediments. The concentration of available Na was, as expected, low in both soil types, since Na-bearing minerals are present in neither serpentinites nor marls. The weathering of serpentinite and marl produced similar concentrations of available Mg. However, the origins of the Mg ions were different in these two rocks. Magnesium in serpentinites is bound in olivine, and in marls in carbonate minerals.

In the tested soils, magnesium was less tightly bound and consequently, more easily leached. Brady and Weil[1] indicated that the soils formed on serpentinites are a drastic example of Ca:Mg imbalance, since these rocks are rich in Mg, but contain little Ca. In the case of the Fruška Gora soils, the Ca:Mg ratio is much higher for the marl soils indicating more intense weathering processes in these sediments. This was also proven by the fact that the lower pH of serpentinites did not cause more leaching of exchangeable ions, which would be expected in slightly acidic soils (Table S-I).

The principal component analyses (PCA) explained 71.3 % of the total variance for the two main axes (axis 1, 40.7 %; axis 2, 30.6 %, Fig. 4). The PCA con-

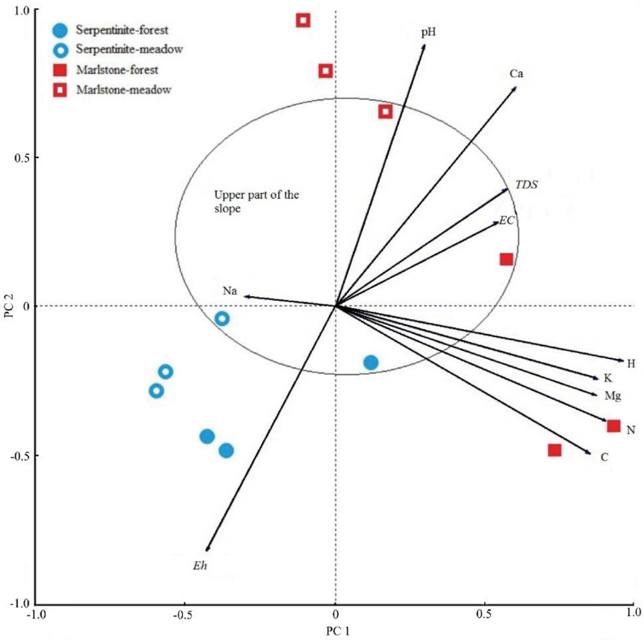

Fig. 4.Multivariate analyses (PCA) of soil parameters for Fruška Gora soils.

firmed the differences discussed above, mainly between all groups of analyzed soils (Fig. 4). However, this analysis showed interesting difference between soil properties depending on the slope position. Soils sampled from the top of the hillslope on all four tested hillslopes (forest and meadow serpentinite and forest and meadow marl) had different characteristics than soils sampled at the middle and at the bottom of the slope. The obtained results are a consequence of hillslope erosion processes and are an indication that the slope position is an important factor for erosion control measures.

CONCLUSIONS

Based on two-way ANOVA and the *LSD post-hoc* test, it was found that there are statistically significant differences between the mean values of certain parameters for the studied factors and their interactions. Differences were statistically significant for the pH, *Eh*, *EC*, *TDS*, the contents of Ca and K, and the values of *N* and *C*/N for rock type, for the pH, contents of K and Mg, and the C_{org}, N and C/N atomic ratio values for land use, and for pH, *Eh*, *E* and *TDS*, for the Ca and K concentrations, and the C_{org} and *N* values for the interaction between these rock type and land use. Only for Na, were there no statistically significant differences between the mean values for any of the tested factors.

This study revealed that the slope position influenced the soil properties. Soils at the top of the all the tested hillslopes had statistically significant different characteristics than soils at the middle or at the bottom of the slope.

All of the obtained results indicated that the physicochemical properties soils depend on geological setting and that the rock composition has to be taken into consideration during land management.

SUPPLEMENTARY MATERIAL

Details about geology of sampling location, sampling procedure and the corresponding map, as well as Tables S-I–S-III, are available electronically from http:// //www.shd.org.rs/JSCS/, or from the corresponding author on request.

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ИЗВОД

ФРУШКА ГОРА – УТИЦАЈ ГЕОЛОШКЕ ПОДЛОГЕ И НАЧИНА КОРИШЋЕЊА ТЕРЕНА НА КАРАКТЕРИСТИКЕ ЗЕМЉИШТА

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На глобалном нивоу, утврђено је да је у последњих неколико деценија дошло до повећања површина деградираног земљишта и да је неодрживо управљање земљиштем један од кључних покретача деградације предела. Стога, неопходно је да се идентификују и квантификују промене узроковане деградацијом земљишта, како би се проценио њихов утицај на биодиверзитет и екосистеме, у циљу планирања и управљања животном средином. Циљ овог истраживања био је да се утврди утицај геолошке подлоге и начина коришћење терена на физичко-хемијске особине земљишта у угроженим планинским областима Фрушке горе. За потребе овог рада анализирано је 30 узорака земљишта са 0–20 cm дубине прикупљена са четири локације на Фрушкој гори. Геолошка подлога су серпентинити и лапораци, а земљишни покривач су шума и ливада. Анализирана су следећа својства земљишта: pH вредност, редокс потенцијал (Eh), електрична проводљивост (EC), укупна растворена материја (TDS), концентрације расположивих катјона Ca, Mg, K, Na, садржај органског угљеника ($C_{\rm org}$) и азота (N). Корелација између добијених параметара је тестирана помоћу статистичких метода two-way ANOVA и principal component analyses (PCA). Сви добијени резултати указују да физичко–хемијска својства земљишта зависе од геолошке подлоге и да се састав стене мора узети у обзир приликом промена у начину коришћења земљишта.

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