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SOIL ORGANIC CARBON STORAGE IN MOUTAIN GRASSLANDS OF THE LAKE PLTEAU AT MT. DURMITOR IN MONTENEGRO

Abstract: Soil organic C storage in mountain areas is highly heterogeneous, mainly as a result of local-scale variability in the soil environment and microclimate. The aims of the present study were to estimate soil organic carbon density (SOCD) and stocks in leptosol on morainic deposits of high-altitude grasslands of the Lake Plateau of Mt. Durmitor National Park in Montenegro, and determine the soil variables that can be used as factors to determine the SOCD at 28 soil profiles. Our results indicated that SOC storage in the top 40 cm of the alpine grasslands were estimated at 560 414.86 t C, or 152.66 t·ha^{-1}, with an average density of 15.27 kg·m^{-2}. The soil organic carbon density increased significantly with soil moisture, clay and silt content, but only moderately with mean annual temperature. In conjunction, these variables could explain approximately 51% of the total variation in SOC density.

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Key words: alpine grasslands, mean annual temperature, soil moisture, soil organic carbon, soil texture

АКУМУЛАЦИЈА ОРГАНСКОГ УГЉЕНИКА У ЗЕМЉИШТИМА ПЛАНИНСКИХ ТРАВЊАКА ЈЕЗЕРСКЕ ПОВРШИ НА ДУРМИТОРУ

Извод: Садржај органског угљеника у земљиштима планинских области је веома хетероген, што је углавном резултат варијабилности земљишне средине и микроклиме у локалним размерама. Циљ овог истраживања је одређивање густине земљишног органског угљеника (SOCD) и његовог садржаја у лептосолу на моренским наносима под травњацима који се налазе на високој надморској висини језерске површи у Националном парку „Дурмитор" у Црној Гори, као и дефинисање варијабли земљишта које се могу користити као фактори за одређивање густине земљишног органског угљеника (SOCD) на 28 земљишних профила. Наши резултати указују на то да је садржај земљишног органског угљљеника (SOC) у првих 40 цм алпских пашњака процењен на 560 414,86 t C, или 152,66 t·ha^{-1}, са просечном густином од 15,27 kg·m–2. Густина земљишног органског угљеника значајно се повећала са порастом влажности земљишта, повећањем садржаја глине и праха, и само умерено са порастом средње годишње температуре. Ове променљиве у комбинацији дају објашњење за око 51% укупне варијације густине земљишног органског угљеника (SOC).

Кључне речи: алпски пашњаци, средња годишња температура, влажност земљишта, земљишни органски угљеник, текстура земљишта

1. INTRODUCTION

Soils contain a huge and dynamic pool of carbon (C), that is a critical regulator of the global carbon budget. As the repository for more than three-fourths of the earth's terrestrial C, soils store 4.5 times the amount of C contained in vegetation (Lal, 2004). Increasing carbon storage in soils is one option helping to mitigate increasing atmospheric CO_2 concentrations and global climate change.

In terrestrial ecosystems the amount of carbon in soil is usually greater than the amount in vegetation. It is therefore important to understand the dynamics of soil carbon, as well as its role in terrestrial ecosystem, carbon balance and the global carbon cycle (Post and Kwon, 2000). Soil carbon content and its changes represent some of the basic indicators of terrestrial ecosystem status. Numerous investigations have shown that organic carbon stocks in soils are determined by the land use.

Grasslands are a significant type of natural vegetation, covering approximately 24% of the Earth's vegetated area. They occur over a very broad range of climatic and soil conditions and vary from natural grasslands to intensively managed sown pastures. Grasslands account for about 12% of the total carbon storage in the terrestrial biosphere, and therefore changes in the cycling of carbon in these ecosystems may be considered globally significant (Campbell and Smith, 2000).

Changing arable fields to managed grasslands increase carbon concentrations in soil within a few years (Lal, 2004). The input of plant material to soil in grasslands is controlled by the aboveground litter layer and the root distribution. At the same time the carbon distribution in the soil profile changes. As 70 to 75% of the root biomass in grasslands is located in the top 15 cm of the soil (Gleixner *et al.*, 2005), organic carbon concentrations increase in the main rooting zone but decrease beneath this input source. Recent experimental evidence demonstrates that the type and diversity of plant species in grasslands plays an important role for carbon transfer into the soil and is able to modify carbon storage under a given land use scheme (Steinbeiss *et al.*, 2007; Tilman *et al.*, 2006).

Considerably more carbon is stored in the soil of grasslands than in the vegetation alone. And additionally, more carbon is stored in high- and low-latitude grasslands than in mid-latitude grasslands. In high-latitudes, grassland soils high in organic matter make up for this difference; in low latitudes, grassland vegetation is more extensive than in mid-latitudes (White *at al.* 2000).

The SOC storage in high-altitude ecosystems is of special interest because of the high C density (soil C storage per area) (Davidson and Janssens 2006) and potential feedbacks to climate warming (Goulden *et al.* 1998; Zimov *et al.* 2006). However, the storage and spatial patterns of SOC in high-latitude ecosystems remain largely uncertain, due to insufficient field observations and extensive spatial heterogeneity (Yang *et al.* 2008).

The amount of C stored in agricultural soils depends on local climatic and other site-specific conditions, as well as the type and impacts of land-use and land management (Leifeld *et al.* 2005). Although grasslands offer an extensive area for carbon storage, more information is needed on how variations in their composition (non-woody vegetation, shrubs, trees, and soil types) affect the quantities of carbon that they can store (White *at al.* 2000).

Mt. Durmitor is one of the most important refugia of arctic-tertiary flora. Numerous endemic, relic and endemic-relic species are the best example. The flora of NP Durmitor consists of 700 species of vascular plants. There are 37 taxa endemic to the area, and 6 specific to Durmitor. The vegetation zones in the park range from deciduous valley forests, Mediterranean conifer forests, sub-alpine *Fagetum subalpinum* and *Pinetum mughi* forests, subalpine heath and peat bogs, to alpine meadows. The dominant species include *Pinus sylvestris*, *P. resinosa, P. mugo, Abies alba, Fagus sylvatica, Betula alba, Juniperus communis* and *Pinus heldreichii*. The Park contains one of the last virgin forests of very old, tall black pine *Pinus nigra ssp.illyrica* in Europe, on soils that would usually develop beech woodland. The Park also supports a rich karstic and calcareous grassland flora with many rare and endemic species including *Verbascum durmitoreum, Gentiana levicalix, Edraianthus glisicii, E.sutjeskae, Valeriana braun-blanquetii, Daphne malyiana, Carum velenovskyi, Saxifraga prenja, Trifolium durmitoreum, Oxytropis dinarica, Silene graminea, Plantago durmitorea and Viola zoysii* (UNEP, WCMC, 2005).

In the Durmitor region the pressure of anthropogenic activities (urbanization and exploitation of nature) have exerted a greater negative impact on highly complex and important forests and grassland ecosystems, than on water quality and resources, soil resources, biodiversity (collection, use and trade of commercially important species). The SOC content of surface soils is sensitive to human interference. The future policies of the National Park management and the decision making processes which will direct the changes in land-use and land management could become crucial in the protection and may even potentially increase the existing pool of soil C.

The aim of this study was to quantify SOC stocks (SOCS) in the surface layers of alpine grassland soils in the Lake Plateau of Mt. Durmitor and to determine to what extend soil texture and soil moisture variables are sensitive to the variability of SOCS in soil. In addition, we aim to understand the C variability of the topsoil layers.

2. MATERIALS AND METHODS

2.1. Study area

The Durmitor region is a rare and authentic work of nature, situated in the northwestern Montenegro (Fig. 1). It was proclaimed a National Park in 1952. The Park occupies a large area of the Durmitor massif with the canyons of the rivers Tara, Draga and Susica and the upper part of the river Komarnica canyon, covering 39 000 hectares. From 1980, the Park and the Tara Canyon are under the protection of UNESCO. The investigaed area of the Lake Plateau is 5105 ha. The alpine grasslands are the most dominant ecosystems on the Plateau, occupying 3 671 ha or 72%, and forests (non grasslands) 1 431 ha or 28% of the total area.

The climate conditions were typically alpine, with low mean annual temperatures. According to the isotherm map, the mean annual temperature (MAT) varies between 4-6°C, with an average temperature of 5°C. Annual precipitation is 1 458 mm and during the growing season the precipitation is 618 mm, or 42.3% (Anđelić, 2001).

The unique climate and vegetation types, together with possible negative

Figure 1. Study area of Mt. Durmitor in Montenegro

Слика 1. Проучавано подручје Дурмитора у Црној Гори impacts of human disturbance, make the plateau an interesting region for investigating spatial patterns and environmental controls of SOC storage in high-altitude ecosystems. In this study, we conducted two field sampling campaigns during the summers (June and July) of 2005 and 2006, and during the summer (July) of 2009, to investigate the soils and vegetation.

2.2. Soil and biomass survey

The site is represented by rendzic leptosol on morainic deposits. On this substrate, the soils are weakly to moderately skeletal, and the percentage of skeleton increases with depth. The soil textual class is sandy loam. The dominant fractions are fine sand and silt, the percentage of colloid clay accounts for maximally 15%. The soil pH ranges from weak acid to weak alkaline, though the greatest number of cases, based on the pH in H_20, belongs to the class of neutral soils (Fuštić and Đuretić, 2000).

In order to estimate the storage and patterns of SOC in alpine grasslands, we sampled 28 soil profiles on the Lake Plateau of Mt. Durmitor.

At each sampling site, soil pits were excavated to collect the samples for analyses of physical and chemical properties. For each pit, the soil samples were collected at the depths of 0-10, 10-20 and 20-40 cm. Bulk density samples were obtained for each layer using a standard container with 100 cm^3 in volume (55.50 mm in diameter and 41.40 mm in height) and weighed to the nearest 0.1 g. Soil moisture was measured gravimetrically after 24 h of desiccation at 105°C. Bulk density was calculated as the ratio of the oven-dry soil mass to the container volume. Soil samples for C analysis were air-dried, sieved (2 mm mesh), handpicked to remove fine roots, and then ground in a ball mill. SOC was measured using the Turin method (for mineral layers). The soil granulometric fractions were separated using the combined method of sieving using 0.2 mm mesh sieves and by the pyrophosphate pipette B-method, after the removal of organic matter and calcium carbonates. Additionally, all plants in three plots (0.50×0.50 m) in each site were harvested to measure the aboveground biomass (AGB). The biomass samples were oven-dried at 65°C to a constant weight, and weighed to the nearest 0.1 g.

2.3. SOC density estimation

We calculated *SOC* density for each soil profile using the Eon (1) (Vladimir S., *et. al.*, 2003):

$$SOCD = \sum_{i=1}^{n} T_i \cdot BD_i \cdot SOC_i \cdot (1 - \frac{C_i}{100}), \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where SOCD, T_i, Bi_d, Soc_{hi}, and C_{hi} are SOC density ($kg \cdot m^{-2}$), soil thickness (cm), bulk density ($g \cdot cm^{-3}$), SOC ($g \cdot kg^{-1}$), and volume percentage of the fraction >2 mm at layer *i*, respectively.

The *SOCD* provides a value for the sampling site. The guidance follows the general requirements of the International Standard ISO/FDIS 10381-1:2002(E). It is particularly relevant to ISO 10381-4 devoted to “Sampling to support legal or regulatory action” that covers the requirements to establish baseline conditions prior to an activity, which might affect the composition or the quality of soils. Sampling strategies included in the protocol are consistent with the IPCC LULUCF’s good practical guidance (IPCC, 2003, p.1.6).

2.4. Floristic survey

The floristic research was performed in 2005 and 2006. All plants were collected, identified and vouchers were stored at the herbarium of the Department of Landscape Architecture and Horticulture, Faculty of Forestry, University of Belgrade, Serbia. The plant material was identified using the relevant literature (Josifović, 1970-1977, Sarić and Diklić, 1986, Sarić, 1992, Tutin, 1964-1980).

2.5. Statistical analysis

The ordinary least squares (OLS) regression analyses were conducted to evaluate the relationships between SOC density, as a dependent variable, and soil moisture and soil texture, and MAT (mean annual temperature), as independent variables. A general linear model (GLM) was used to assess integrative effects of soil moisture, soil texture and MAT on the SOC spatial distribution.

The cartographic data were processed using the ArcGIS program, primarily the extensions Spatial Analyst and Geostatistical Analyst, and the geostatistical analysis of samples was performed by the Inverse distance weighting (IDW) interpolation module.

3. RESULTS

The grasslands contained varying numbers of plant species with different morphological, biological, and production characteristics. The floristic mixture of the study grasslands consisted of the species of the families *Gramineae, Leguminosae, Compositae, Rosaceae, Caryophyllaceae, Cyperaceae, Juncaceae* etc.

The percentage of individual grassland components was: 29.2% grasses, 15.4% legumes and 55.4% herbaceous plants. The aboveground biomass (AGB) varied markedly across 28 sampling sites. The AGB for alpine meadows ranged from 76.20 to 173.68 $g{\cdot}m^{-2}$, with an average of 114.08 $g{\cdot}m^{-2}$ C content in dry mass which ranged from 47.2 to 50.4%.

SOC density in alpine grasslands exhibited large variations, ranging from 2.14 to 8.64 $kg{\cdot}m^{-2}$ for 10 cm depths, from 2.24 to 14.63 $kg{\cdot}m^{-2}$ for 20 cm, and from 3.24 to 28.95 $kg{\cdot}m^{-2}$ for 40 cm, respectively. Mean SOC density of all sites in alpine meadow for the three soil depths (10, 20, and 40 cm) were 5.14 $kg{\cdot}m^{-2}$, 9.16 $kg{\cdot}m^{-2}$ and 15.27 $kg{\cdot}m^{-2}$, respectively.

According to SOC density for the top 40 cm in alpine grasslands of 15.27 $kg{\cdot}m^{-2}$, the total SOC storage in 40 cm grassland soils was estimated at 560 414.86 t C, or

152.66 t·ha^{-1}. The average SOC density in the upper 20 cm of 9.16 kg·m^{-2}, accounted for 336 300.31 t C, or 60.01% of total SOC in the 40 cm top soil.

Fig. 2 presents the relationship between SOC density (SOCD) in the top 40 cm of soil and aboveground biomass (AGB). SOCD increased with an increase in aboveground biomass and is characterized by a linear function.

Fig. 3 presents the spatial distribution of soil organic carbon (SOC) density for different soil depths (0-10, 0-20, and 0-40 cm), (a-c), respectively.

The soil organic carbon density also increased with an increase in soil moisture at all soil depths and then leveled off. The relationship between SOC density and soil moisture for all depths was well characterized by a linear function (Fig. 4 a-c).

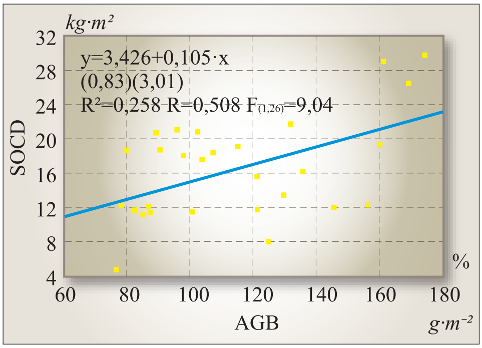

Figure 2. Relationship between SOC density (SOCD) in the top 40 cm of soil and aboveground biomass (AGB) in alpine grasslands of the Lake Plateau at Mt. Durmitor

Слика 2. Регресиона зависност између садржаја органског угљеника (SOCD) до 40 cm дубине и надземне биомасе (AGB) под пашњацима на Језерском платоу на Дурмитору

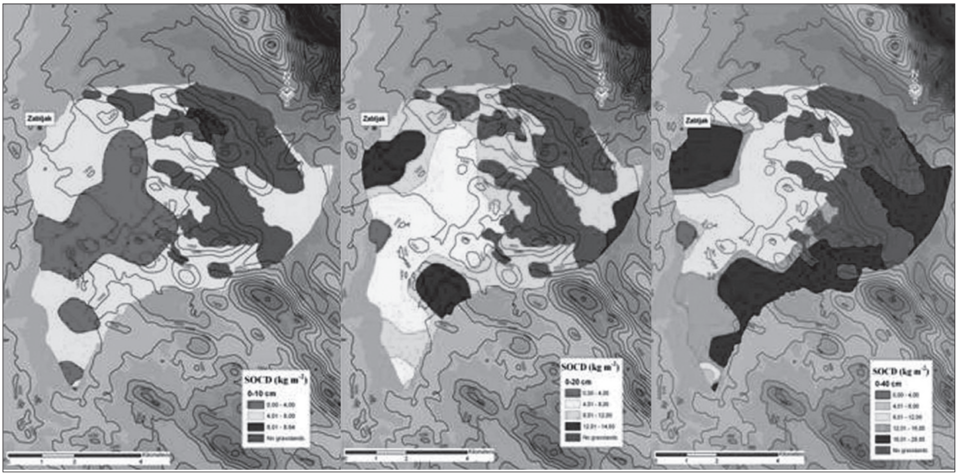

Figure 3. Spatial distribution of soil organic carbon (SOC) density (a-c) for different depths (0-10, 0-20, and 0-40 cm) in alpine grasslands of the Lake Plateau at Mt. Durmitor

Слика 3. Дистрибуција садржаја органског угљеника (SOC) на различитим дубинама (0-10, 0-20, и 0-40 cm) у земљишту под пашњацима на Језерском платоу на Дурмитору

In addition, SOC density was positively correlated with both clay and silt contents (Fig. 5, a-c for clay content and d-f for silt content), at different soil depths.

Although MAT on the Lake Plateau varied between 4 and 6°C, the analysis of regression and correlation of MAT effect on SOCD was performed for the 0-10 and 0-40 cm soil depths.

For the 0-10 cm soil depth, the output shows the results of fitting a linear model to describe the relationship between SOCD and MAT. The equation (2) of the fitted model is:

$$SOCD_{0\text{-}10} = -3.05 + 1.64 \cdot MAT \quad (r^2=0.2569;\ p<0.01), \quad \ldots\ldots (2)$$

For the 0-40 cm soil depth, the output shows the results of fitting a linear model to describe the relationship between SOCD and MAT as the equation (3):

$$SOCD_{0\text{-}40} = -24.10 + 7.87 \cdot MAT \quad (r^2 = 0.3989;\ p < 0.01), \quad \ldots\ldots (3)$$

GLM suggested that soil variables (soil moisture, clay content, silt content) and MAT, explained 51.31% of the overall variation of SOC density in the top 40 cm. The best-fit model of the GLM analysis is expressed in Eqn 4:

$$SOCD = -36{,}534 + 0{,}671 \cdot SM + 0{,}272 \cdot CC + 0{,}307 \cdot SC + 5{,}062 \cdot MAT$$

$$R = 0{,}71629225;$$

$$R^2 = 0{,}51307458;$$

$$\text{Adjusted } R^2 = 0{,}42839190;$$

$$F_{(4,23)} = 6{,}0588;$$

$$p < 0{,}00176, \quad \ldots\ldots\ldots (4)$$

(where - SM - soil moisture, CC - clay content, SC - silt content, MAT - mean annual temperature).

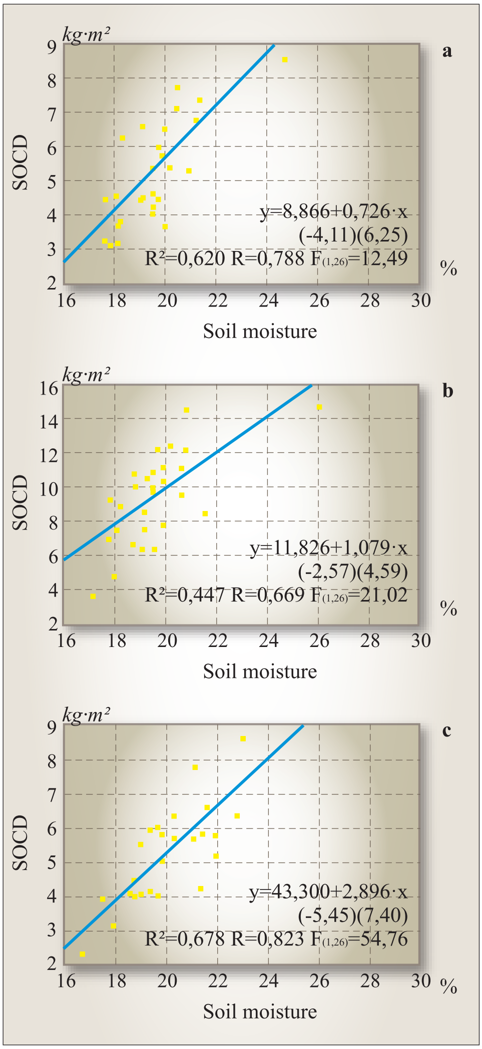

Figure 4. Relationship between SOC density (SOCD) for different soil depths and soil moisture in alpine grasslands of the Lake Plateau at Durmitor (a - 0-10 cm, b - 0-20 and c - 0-40 cm)

Слика 4. Регресиона зависност између садржаја органског угљеника (SOCD) у различитим дубинама и земљишне влаге под пашњацима на Језерском платоу на Дурмитору (a - 0-10 cm, b - 0-20 and c - 0-40 cm)

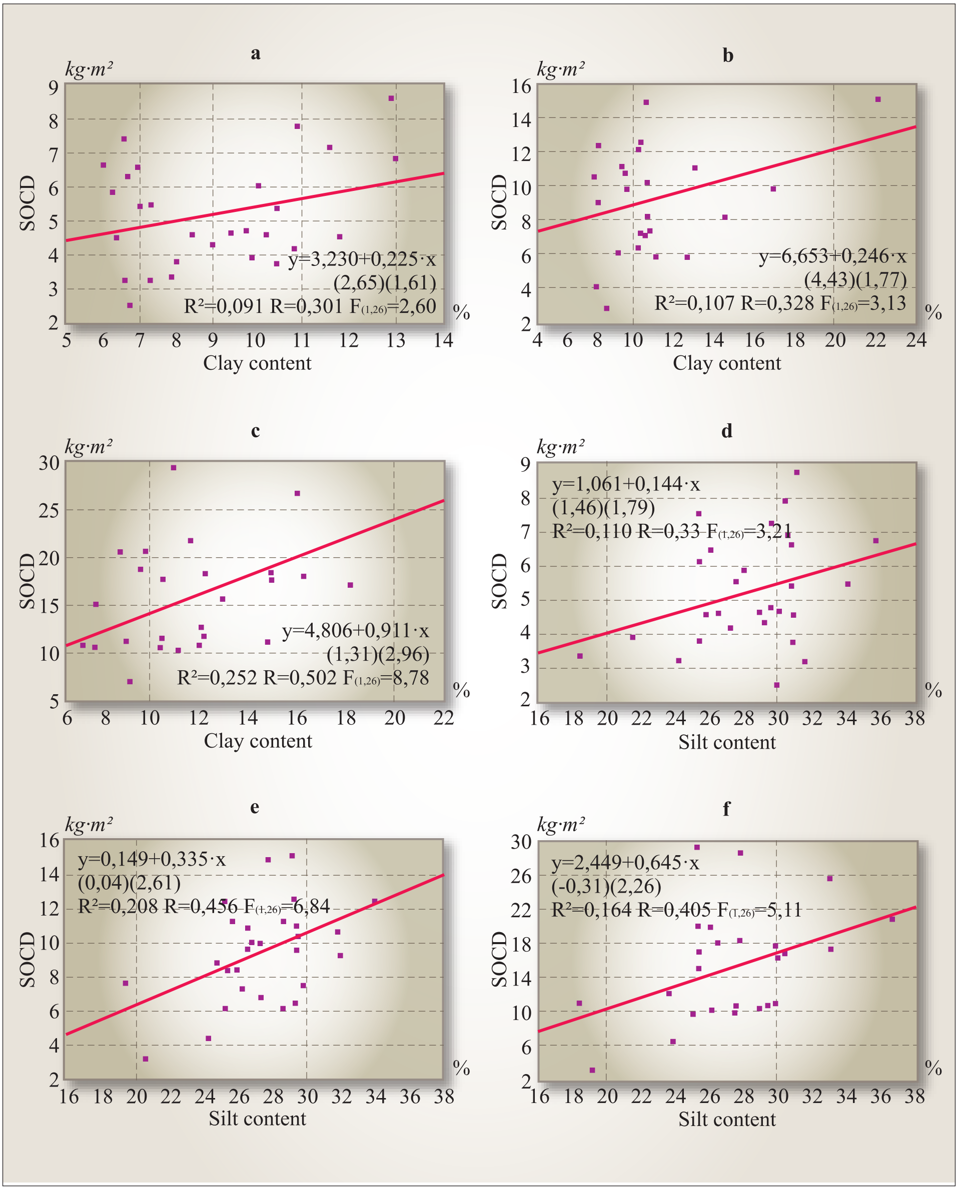

Figure 5. Relationship between SOC density (SOCD) for different soil depths (0-10, 0-20 and 0-40 cm) and clay content (a-c) and silt content (d-f) in alpine grasslands of the Lake Plateau at Mt. Durmitor

Слика 5. Регресиона зависност узмеђу садржаја органског угљеника (SOCD) у различитим дубинама и садржаја глине (a-c) и садржаја праха (d-f) под пашњацима на Језерском платоу на Дурмитору (a - 0-10 cm, b - 0-20 and c - 0-40 cm)

4. DISCUSSION

4.1. Relationship between SOC density and AGB

Photosynthetic plants are the primary source of C incorporated into SOC (Hedges and Ertel 1982), and the rate of C input will depend on land use management. Plant functional types significantly altered the vertical distribution of SOC. The highest percentage of SOC is in the top 20 cm (Wang *at al*, 2008), relative to the whole profile. C_4 species may have an advantage over C_3 species in response to increasing atmospheric CO_2 and more frequent and severe droughts (Ward *et al*. 1999).

According to our data, for 0-40 cm profiles, sandy loam textural class, and mixtures of different grass species, had an average AGB of 114.08 $g{\cdot}m^{-2}$, in the soil profile at 0-20 cm, with a mean SOCD of 9.16 $kg{\cdot}m^{-2}$, and at 0-40 cm, mean SOCD was 15.27 $kg{\cdot}m^{-2}$. The SOC content in the 0-10 cm layer is 33.7%, and in the 10-20 cm layer it amounts to 26.3% of the total content for 0-40 cm depth. Based on the regression and correlation analyses, it can be concluded with high reliability (significant parameter with AGB) that the increase in AGB by 1 $g{\cdot}m^{-2}$ causes an increase in SOCD by 0.105 $kg{\cdot}m^{-2}$.

The depth at which the change in soil type occurs should be available to adjust the SOC content to the fixed depth of the topsoil and subsoil layers. For mineral soils with a more gradual change in SOC content with depth the subsoil SOC content in the 30-100 cm layer is approx. 27% of the topsoil SOC content under forest, 70% for arable land, 60% for grassland and 65% for all other areas. These values are only guides and have to be adjusted by the actual depth of the soil stratum (Hiederer, 2009).

The soil C content in mountain grasslands of the Pyrenees ranges between 5.9-29.9 $kg{\cdot}m^{-2}$, and the mean content of the surface horizon for sandy loam texture class is 16.0 $kg{\cdot}m^{-2}$ (Garcia-Pausas *et al*. 2007). In Swiss agricultural soils, the mean SOC density in the 0-20 cm profile ranged between 40.6 ± 8.9 $t{\cdot}ha^{-1}$ (±95% confidence interval - CI) for arable land and 50.7±12.2 $t{\cdot}ha^{-1}$ for favourable permanent grasslands. In the 0-100 cm profile SOC ranged from 62.9±15.2 $t{\cdot}ha^{-1}$ for unfavourable grassland to 117.4±29.8 $t{\cdot}ha^{-1}$ for temporary grasslands (Leifeld *et al*. 2005).

Distinct associations between the changes in SOC content with depth by land use were obscured by the prevalence of some land uses to occur on specific soil types. For forest soils a tendency for a more rapid decrease in SOC content from the topsoil to the subsoil was found, an effect which is mainly due to an organic upper layer. On average the subsoil SOC content under forest is approx. 25-30% of the topsoil SOC content. The general change in SOC content with depth under grassland is comparable to the one found for forest soils (Hiederer, 2009).

The cheapest, most efficient and most beneficial forms of organic carbon for improving microbial activity and soil structure result from the tandem process of photosynthesis followed by the exudation of carbon compounds from the actively growing roots of plants in the *Gramineae* family. Soil carbon additions are governed by the volume of fibrous roots per unit of soil and their rate of growth. The greater the number of active green leaves and active plant roots, the more carbon is captured from the air, and thus translocated through the plant and exuded into the soil (Jones, 2006).

4.2. Relationship between SOC density and temperature

Temperature is an important variable affecting SOC density (Jobba´gy and Jackson 2000; Callesen *et al.* 2003). Regression models of the regional soil databases indicated that organic C increased with precipitation and clay content, and decreased with temperature (Schimel *et al.* 1994; Burke *et al.* 1989). The SOC density decreased with increasing temperature as a result of accelerated decomposition (Jobba´gy and Jackson 2000).

Our data indicate that SOC density in the alpine grasslands increases significantly with temperature, in accordance with a linear function of MAT. The correlation coefficients equal to 0.51 (0-10 cm; $r^2 = 0.2569$; $p < 0.01$) and 0.63 (0-40 cm; $r^2 = 0.3989$; $p < 0.01$), indicate a moderately strong relationship between the variables. In the alpine grasslands on the plateau, temperature is a limiting factor for vegetation growth and thus higher temperatures may stimulate greater productivity with respect to vegetation. Low temperatures limit the biological activity and humus mineralization. Although this finding conflicts with the general global trend (Schimel *et al.*, 1994), it is consistent with the studies from the high-latitude regions (Callesen *et al.*, 2003; Piao *et al.*, 2006). Also, it can be presumed that the analysis of the effects of mean temperatures over the growing season would show more realistic results.

4.3. Relationship between SOC density and soil moisture

Soil properties in mountain areas are highly related to their parent material, profile depth and stone content, which are limiting factors for C storage (Leifeld *et al.* 2005). In general, precipitation could stimulate plant production and thus contribute to the accumulation of SOC in a water-limiting area (Jobba´gy & Jackson 2000; Callesen *et al.* 2003). Precipitation clearly has a direct role regionally and globally in the amount of SOC stored (Burke *et al.* 1989).

In our study, significant linear relationships ($r^2 = 0.62$, $p < 0.001$, for the 0-10 cm soil depth; $r^2 = 0.447$, $p < 0.001$, for the 0-20 cm soil depth, and $r^2 = 0.678$, $p < 0.001$, for the 0-40 cm soil depth; Fig. 9 a, b, c) were found between SOC density and soil moisture.

According to the relationship (Fig. 9 a-c), it can be claimed with high reliability (significant parameter with soil moisture) that the increase in SM by 1% causes the increase in SOCD by 2.896 $\text{kg}\cdot\text{m}^{-2}$). The change in SOC density under moist soil conditions is expected because other growth-limiting factors may constrain SOC density in the alpine grasslands, such as temperature and nitrogen availability (Kato *et al.* 2006; Zhao *et al.* 2006). A similar relationship between SOC density and soil moisture has also been observed in temperate regions, such as in the Great Plains of the United States (Burke *et al.* 1989) and Australia (Wynn *et al.* 2006), implying that water availability may be a powerful variable for predicting SOC density across broad biogeographic regions.

4.4. Effect of soil texture on SOC density

Soil texture significantly influences SOC storage at the local scale (Brady and Weil, 2004, Piao *et. al*., 2006; Wynn *et al*., 2006), mainly in two ways. Firstly, the increasing clay and silt content reduces microbial decomposition through stabilizing SOC and decreasing C leaching and thus leads to an accumulation of SOC (Torn *et al*., 1997; Jobba´gy and Jackson, 2000; Wynn *et al*., 2006). Secondly, the increasing clay and silt contents stimulate plant production via increasing water-holding capacity and thus increase C inputs to the soil (Schimel and Parton, 1986; Burke *et al*., 1989; Schimel *et al*., 1994). For permanent grasslands at altitudes >1,000 m a.s.l., the SOC-clay relationship was not significant, thus indicating that for soils with higher SOC concentrations additional stabilisation mechanisms contributed to soil C storage (Leifeld *et al*. 2005). Although precipitation and climate were the best predictors of total SOC in the top 20 cm of soil, clay content was the best predictor in deeper layers (Jobba´gy and Jackson, 2000*)*. Such C pools are strongly associated with clay particles and noncrystalline minerals that stabilize and protect the organic matter (Torn *et al*., 1997).

On the basis of the multiple regression analysis for the 0-40 cm soil layer (Eqn. 4), it can be seen that the effect of the study variables explained 51% of variations in SOCD. The correlation coefficient has a high value ($r = 0.71$) and it is statistically significant ($F_{(4,23)} = 6.0588$; $p < 0.00176$). On the basis of the study model, it can be expected that if the variables were increased by 1%, SOCD would increase by 6.252 $kg{\cdot}m^{-2}$.

5. CONCLUSIONS

The aim of this paper was to quantify SOC stocks (SOCS) in the surface layers of alpine grassland soils in the Lake Plateau of Mt. Durmitor and to determine to what extent the soil texture and soil moisture variables are sensitive to the variability of SOCS in soil. Field work was conducted in two campaigns during the summers (June and July) of 2005 and 2006, and during the summer (July) of 2009, to investigate the soils and vegetation.

The total SOC storage in 40 cm grassland soils was estimated at 152.66 $t{\cdot}ha^{-1}$, and the average SOC density in the upper 20 cm was 9.16 $kg{\cdot}m^{-2}$ (60.01% of total SOC in the 40 cm top soil). Based on the regression and correlation analyses, it was concluded that the increase in AGB by 1 $g{\cdot}m^{-2}$ causes an increase in SOCD by 0.105 $kg{\cdot}m^{-2}$. Soil texture significantly influences SOC storage, it can be concluded that the increase in silt content by 1% causes the increase in SOCD by up to 0.645 $kg{\cdot}m^{-2}$. SOC density was positively correlated with both clay and silt contents at different soil depths. The soil organic carbon density increased with an increase in soil moisture, and the increase in soil moisture by 1% caused the increase in SOCD by 2.896 $kg{\cdot}m^{-2}$. The SOC density in the alpine grasslands increases significantly with temperature, in accordance with a linear function of mean annual temperature.

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АКУМУЛАЦИЈА ОРГАНСКОГ УГЉЕНИКА У ЗЕМЉИШТИМА ПЛАНИНСКИХ ТРАВЊАКА ЈЕЗЕРСКЕ ПОВРШИ НА ДУРМИТОРУ (ЦРНА ГОРА)

Резиме

Регион Дурмитора представља јединствено и аутентично природно подручје које се налази у северозападном делу Црне Горе. За Национални парк је проглашен 1952. године. Обухвата масив планине Дурмитор, кањоне река: Таре, Драге, Сушице и највиши део кањонске долине Комарнице, укупне површине 39.000 ha. Од 1980. године Национални парк и кањон Таре се налазе на Листи светске природне и културне баштине УНЕСКО.

Централни део региона Дурмитора, Језерска површ је компактна целина површине од 5105 ha. Доминантни екосистеми су планински травњаци на површини од 36701 ha или 72%, док се под шумама налази 1431 ha или 28% укупне површине. Простире се између 1350 и 1550 мнм, чине је, највећим делом, планински травњаци, а простире се између следећих координата: 43°4` и 43° 9` N и 19°7` и 19° 14` E. Са ове висоравни се уздижу бројни

плански врхови, од којих је њих 48 са преко 2.000 мнм. Највећи врх је Боботов кук 2.525 мнм. Дурмитор краси 18 ледничких језера названих „горске очи“.

Клима подручја је типична алпска коју карактерише средња годишња температура између 4-6^{o}C, просечно 5^{o}C. Годишња сума падавина је 1,458 mm а током вегетационог периода таложи се сума од 618 mm или 42,3% (Анђелић, 2001).

Језерска површ је настала на моренским наносима ледника. На овом супстрату формирана је рендзина различитог степена педогенезе. Земљиште је слабо до умерено скелетно, а учешће скелета са дубином се повећава. Текстурно, земљиште припада класи песковите иловаче. Доминирају фракције ситног песка и праха док учешће колоидне глине максимално износи 15%. Реакција земљишта се креће од слабо киселе до слабо алкалне, при чему највећи број слојева, према величини pH вредности у H_2O, припада класи неутралних земљишта (Фуштић и Ђуретић, 2000).

У овим условима су формирани планински травњаци које чине велики број врста различитих морфолошких, биолошких и производних карактеристика. У флористичком смислу, проучавани травњаци су састављени од мешавине врста више фамилија и то: *Poaceae, Fabaceae, Asteraceae, Rosaceae, Caryophyllaceae, Cyperaceae, Juncaceae,* итд.

На подручју Дурмитора, антропогени фактор се примарно манифестује преко негативног утицаја (урбанизација, сакупљање и прекомерно коришћење комерцијалних биљних врста, пре свега), на шуме и травњаке као најкомплексније и најзначајније екосистеме, који битно утичу на стање и квалитет вода, земљишта и биодиверзитета. У овом смислу, садржај земљишног органског угљеника (SOC) у површинским слојевима земљишта је врло осетљив на антропогене утицаје који условљавају промене начина коришћења и управљања земљишним простором. Заштита и повећање постојећих резерви постојећег земљишног угљеника постаје од посебног значаја у смислу будућих приступа у управљању Националним парком.

Имајући наведено у виду, основни циљ овог рада је да се квантификује акумулација земљишног органског угљеника у површинским слојевима планинских травњака на подручју Језерске површи и да се утврди утицај појединих варијабли на осетљивост и варијабилност густине земљишног органског угљеника (SOCS) у површинским слојевима проучаваног земљишта. Проучавања су вршена током летњих месеци (јун и јул) 2005-2006. и током лета (јул) 2009. год. Проучавања су вршена на узорцима земљишта из 28 профила, а узорци су узимани из фиксних дубина: 0-10, 10-20 и 20-40 cm.

На основу добијених резултата, утврђено је да је у слоју 0-40 cm земљишта планинских травњака акумулирано 560,414.86 t органског угљеника или 152.66 $tC.ha^{-1}$, са средњом густином од 15,27 $kg.m^{-2}$. Густина земљишног органског угљеника (SOCD) се значајно повећава са повећањем влажности земљишта, садржајем фракција глине и праха. За разлику од глобалног тренда, густина земљишног органског угљеника (SOCD) у планинским травњацима се средње јако повећава са повећањем средње годишње температуре (MAT), вероватно услед индиректног ефекта повећања биљне продукције. Ове варијабле заједно објашњавају 51% укупне варијабилности густине земљишног органског угљеника (SOCD).