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PEDO-ECOLOGICAL SIGNIFICANCE OF SOIL ORGANIC CARBON STOCK IN SOUTH-EASTERN PANNONIAN BASIN

Milivoj BELIĆ[1], Maja MANOJLOVIĆ[1], Ljiljana NEŠIĆ[1], Vladimir ĆIRIĆ[1], Jovica VASIN[2], Pavel BENKA[1], & Srđan ŠEREMEŠIĆ[1]

[1] *University of Novi Sad, Faculty of Agriculture, DositejObradovića Sq. 8, 21000 Novi Sad, Serbia*
belicm@polj.uns.ac.rs
[2]*Institute of Field and Vegetable Crops, Sq. MaksimaGorkog 30, 21000 Novi Sad, Serbia*

Abstract: The aim of this research is to examine soil organic carbon (SOC) stock in the South-eastern Panonnian Basin. For estimating the SOC stock 10 different soil types were accessed with 400 soil profiles representing different locations in Vojvodina at 0-30, 30-60 and 60-100 cm depths. Three factors were taken into consideration, soil type being the one with the largest influence on the SOC content. Data collected were plotted on a map by using the Ordinary Kriging method. The results showed differences between soil types and soil depths. At 0-100 cm soil depth, the highest SOC levels were found in Regosols, Vertisols, Gleysols and Chernozems and the lowest in Solonchaks, Fluvisols and Arenosols. On the total of 1,807,073 ha examined, the SOC reserves at 0-30 cm depth were estimated to 122 Mt, whereas total stock in 0-100 cm soil layer was 270 Mt. The results obtained could be valuable for monitoring SOC change and to recommend measures for the conservation of SOC.

Keywords: soil types, land use, carbon stock, soil productivity.

1. INTRODUCTION

In the last decade there has been an increasing interest in soil organic carbon (SOC) dynamics as a result of global warming and climate change (Smith, 2008). Global warming has been induced by increased levels of gases that cause the greenhouse effect in the atmosphere. Among the most important gases causing global warming there is CO_2, which is produced when the SOC from organic matter is degraded and CO_2 released from the soil. According to Lal (2004) the global soil carbon pool is about 2,500 Gt (1,550 Gt of SOC and 950 Gt of soil inorganic carbon). In 2011 global atmospheric CO_2 concentration reached 388 ppm mainly as consequence of increasing emissions of greenhouse gases due to human activities which makes an increase of 138 ppm in comparison to pre-industrial times (IPCC, 2007). Blum (2008) stressed that the soil organic carbon loss is one of the eight major threats to the soil degradation. In addition to that, “Thematic Strategy for Soil Protection” estimated that 45% of European soils have a low SOC content, which poses a threat to all soil functions.

In order to mitigate global warming and soil degradation and to improve soil quality we have to perform detailed analyses and monitor SOC concentrations and pools (Manojlović et al., 2010). Carbon reserves in agricultural soils reflect changes in the method of soil use or land management system. For a long time, favorable soil conditions in South-eastern part of Pannonian Basin were not considered as a limiting factor in crop production. Recently, SOC decrease was observed primarily as a result of intensive soil cultivation (Belić et al., 2003; Manojlović et al., 2008; Šeremesić et al., 2011). On contrary, arable soil could be a reservoir and an important sink for sequestering the atmospheric CO_2. Practices used to increase carbon bonding in agricultural soils include conservation tillage, mulching, intercropping, and growing forage crops in rotation with row crops. Incorporation of mineral and organic fertilizers increases yields and biomass and larger amounts of organic matter are returned to the soil, resulting in an increased SOC content (Čuvardić et al., 2004). Puget and Lal (2005) elucidate that biomass production by diverse cropping pattern affects SOC content because of the differences among cropping systems used and amount of plant residues left after harvest. Apart from the soil management influence, Don et al., (2009) stipulated that parent material and pedogenetic processes are the two most influential factors determining SOC reserves. Recently, trends of agricultural land use change could significantly contribute to soil quality decline, particularly SOC change (Szillassi et al., 2012).

Apart from its role in the food systems, SOC has a great potential for providing ecosystem services through the output of ecosystem functions or processes that support (directly or indirectly) human welfare. At the same time SOC also has a role in sustainability of natural systems. Therefore an insight in the SOC stocks and cycling could have significant implication in global ecosystem protection.

The objectives of this paper were to determine SOC reserves in Vojvodina as affected by soil type, parent material, and land use and to assess the potential of these reserves for the accumulation of SOC.

2. MATERIALS AND METHODS

The province of Vojvodina occupies the northernmost part of Serbia and is situated in the south-eastern part of the Pannonian Basin between 44° 38' and 46° 10' northern latitude and 18° 10' and 21° 15' eastern longitude, covering a total area of 21 506 km^2 (Ćalić et al., 2012). Vojvodina is extremely low in altitude and for the most part ranges from 68 to 120 m, the only exceptions being the Fruška Gora (538 m) and Vršac (639 m) mountains. The province of Vojvodina is the most important agricultural region in Serbia, covering the South-eastern part of Pannonian Basin, with 88% of its total area being arable Vidojević & Manojlović (2007). The diverse soil cover of Vojvodina is the result of certain constellation of pedogenetic factors and their influences of varying intensity. Alluvial deposits on river terraces were the substrate for fluvisols, gleyed soils, solonetz, and solonchaks; loess plateaus for chernozems; loess terraces for gleyed chernozems and saline soils; aeolian sand for arenosols, rendzinas and chernozems; heterogenous substrate of the Fruška Gora and Vršac mountains for rendzinas, rankers, cambisols, and loess and colluvial soils. Soil genesis and evolution in the Pannonian Basin has been strongly influenced by bioclimatic factors, the temperate continental climate, and steppe vegetation.

In hydrographic terms, the most important rivers in the province are the Danube, Sava, Tisza and the Tamis, all of which are characterized by slow currents and pronounced lateral as opposed to vertical erosion. For estimation of a SOC stock a total of 400 soil profiles were analyzed in various locations in Vojvodina representing different landforms and soil types and 1,200 individual samples were included from 0-30, 30-60 and 60-100 cm depth and tested for SOC content. This study covers the period of about 30 years during which the following publications was considered (Živković et al., 1972). Bulk density was determined at the same depths using 100 cm^3 cylinders according to Kopecky. The following referent soil groups from the WRB classification were identified in the study: Arenosols, Chernozems, Cambisols, Fluvisols, Gleysols, Planosols, Regosols, Solonchaks, Solonetz and Vertisols.

For determination of SOC, the Tyrin titrimetric wet combustion method was used, where organic matter is oxidized by 0.2 M potassium dichromate ($K_2Cr_2O_7$) solution with sulphuric acid and heated at boiling point for 5 minutes. After oxidation, excess dichromate is determined by titration with ammonium ferrous sulphate (Mohr`s salt solution $[Fe(NH_4)_2(SO_4)_2*6H_2O]$). Concentration of organic matter (humus) can be calculated by multiplying the SOC content by the alteration factor f=1.724. This factor is based on the assumption that organic matter contains 58% organic carbon (USDA, 1996). Chemical analyses of soils were done according to national standards. The average SOC (g kg^{-1}) of the South-eastern Pannonian Basin was calculated using the following equation:

$$SOC = \frac{\Sigma SOC_i}{i}$$

(ΣSOCi -Sum of SOC; i- number of samples)

SOC stock was calculated using the equation:

$$\text{SOC stock}\,(t/\text{ha}^{-1}) = \frac{\text{SOC } g/\text{kg}^{-1}}{1000000} \text{ x depth(m) x}$$

$$\text{BD}\,(kg/\text{m}^{-3}) \text{ x } 10000\,(\text{m}^2/\text{ha}^{-1}) \text{ x } 1000\,(kg/\text{t}^{-1})$$

Mean values and standard deviation of SOC reserves were calculated using Statistica 8.0 software for the depths of 0-30, 30-60 and 60-100 cm and for each soil type, land use and parent material.

Coordinates of each profile were determined using a GPS receiver or a map. Data collected from the 400 profiles during the study were used to draw a map of the carbon content of the soils of Vojvodina (Fig. 1). The values in the map were grouped into eight classes and each was marked with a different shade of grey. Ordinary Kriging method is used for interpolation as appropriate for variables without explicit spatial trend or correlation with other external variables. Ordinary Kriging represent estimating the most probable values of a function in a point x based upon known values (samples) in points x_i.

Interpolated value can be expressed as follows:

$$\hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i * Z(x_i) \quad \text{where}$$

$\sum_{i=1}^{n} \lambda_i = 1$,

$\hat{Z}(x_0)$ -estimated value for point x_0,

$Z(x_i)$ - is known value of the given point x_i,

w_i - weight coefficient of the given point x_i.

During determination of weight coefficients it is hypothesized that there is spatial relationship between values of given points. In order to calculate weight coefficients of Ordinary Kriging we produced variogram $\gamma(x, y)$ which will define spatial relationship between points. Weight coefficients are determined using following expression Al-Shaery et al. (2010):

$$\begin{bmatrix} \lambda_1 \\ \cdots \\ \lambda_n \\ \mu \end{bmatrix} = \begin{bmatrix} \gamma(x_1,x_1) & \cdots & \gamma(x_1,x_n) & 1 \\ \cdots & \cdots & \cdots & \cdots \\ \gamma(x_n,x_1) & \cdots & \gamma(x_n,x_n) & 1 \\ 1 & \cdots & 1 & \mu \end{bmatrix}^{-1} \begin{bmatrix} \gamma(x_1,x_0) \\ \cdots \\ \gamma(x_n,x_0) \\ 1 \end{bmatrix}$$

More known models could be used for variogram which will best represent spatial dependence. The following exponential model was used in this research (Smith et al., 2010; Al-Shaery et al., 2010):

$$\gamma(h) = C_0 + C_1\left(1 - e^{-\frac{kh}{a}}\right) \text{ when } |h| > 0$$

$$\gamma(h) = 0 \text{ when } |h| = 0$$

For exponential model of variogram it is necessary to determine tree parameters: C_0 - nugget, a - range and C_0+C_1 - Sill. Choice of model which will define spatial dependence is based upon experimental variogram calculated from given points.

3. RESULTS AND DISSCUSION

3.1. Study area

The SOC concentration of agricultural soils in our study ranges between 0.5 and 3%, with most soils containing between 1 and 2% SOC. Although SOC has relatively small variation, the existing national classification of SOC is unclear in terms of wide intervals for low and high SOC content (Sekulić et al., 2010). That could lead to a misinterpretation of the results obtained, since soil fertility is commonly explained with SOC concentration. Likewise, studies in Southeastern Europe have shown alterations in chemical properties of soil, particularly SOC losses (Hengl et al., 2007) and generally this trend was also confirmed in Serbia (Bogdanović et al. 1993; Sekulić et al. 2010). Ecosystem productivity (net primary production) as well as organic matter decomposition is strongly determined by environmental conditions. Total annual input of carbon with plant residues is expected to be most important for the increase and accumulation of SOC (Buyanovsky et al., 1987), however in the future climate change and drought occurrence described in Rajić & Bezdan (2012) could play a significant role in SOC change.

3.2. The influence of soil types on SOC stock

The SOC stocks in the soils of Vojvodina at 0-100 cm soil depth ranged from 87 to 204 t ha^{-1} depending on the type of soil. Soil type plays an important role in determining SOC levels and quality, since this factor often determines how an agricultural soil will be utilized. The SOC reserves decreased with increasing soil depth in all the soils except Regosol, which has often uneven colluvial accumulation of organic matter. In the 0-30 cm soil layer, the largest SOC stocks were found in Gleysols (75 t ha^{-1}), Vertisols (74 t ha^{-1}), Chernozems (72 t ha^{-1}) and Regosols (71 t ha^{-1}), while the smallest were recorded in Arenosols (41 t ha^{-1}), Solonchaks (42 t ha^{-1}) and Fluvisols (46 t ha^{-1}) (Table 1). The lower SOC stock in 0-30 cm depth of Chernozems compared with the Gleysols and Vertisols could be explained with cropping intensity on Chernozems. The content of SOC stock was similar with the depth of 0-100 cm, where Regosols (204 t ha^{-1}), Vertisols (171 t ha^{-1}), Gleysols (165 t ha^{-1}) and Chernozems (165 t ha^{-1}) had the highest SOC content and Solonchaks (87 t ha^{-1}), Fluvisols (93 t ha^{-1}), and Arenosols (99 t ha^{-1}) the lowest. Considering the total area investigated in this study, most SOC stock is found deposited in Chernozems as a prevalent soil type. Compared to other soil types, Chernozems and Gleysols had relatively higher share of SOC (78.29%) against the percentage of the investigated area (70.8%). On the contrary, it was difficult to determine the effects of plant diversity on soil types, which suggests that the relationship between biodiversity and ecosystem function is not straightforward and cannot be generalized across soil types. Recently many researches highlighted the importance of C reserves located below plough layer (>30 cm), because in conditions of global warming can be activated and may provide a potential binding sites for C sequestration (Batjes, 2006; Al-Kaisi & Grothe, 2007). Russian chernozem used as arable land contains 290 t C ha^{-1} to a depth of 100 cm (Mikhailova & Post, 2006), Chernozem in Hungary has 105.6 t C ha^{-1} (Németh et al., 2002) whereas in Bulgaria 142 t C ha^{-1} was observed (Filcheva et al., 2002). Vojvodinian Chernozem developed on loess terrace has average SOC stock of 151 t ha^{-1} within 0-100 cm depth, ranging from 128 to 203 t ha^{-1}. Significant differences in the assessment of the deposited C in chernozem were consequence of initial conditions and the initial level of OM. Therefore it is necessary to conduct regular monitoring to detect SOC changes in soil that occurred on a long-term, but when large areas are affected it could have enormous impact on its fertility.

Table1**.** SOC stocks in most common WRB soil types in South-eastern Pannonian Basin by soil depth

		Area		SOC stock t ha-1			% of total Stock
Soil type	n	(ha)	%	0-30 cm	0-60 cm	0-100 cm	
Arenosols	92	17 054	0,94	41±18	70±17	99±21	0,62
Chernozems	191	933 920	51,68	72±19	126±21	165±24	57,00
Cambisols	3	56 164	3,11	52±36	93±14	132±5	2,74
Fluvisols	17	194 522	10,76	46±14	71±10	93±19	6,69
Gleysols	28	348 846	19,30	75±26	124±25	165±39	21,29
Planosols	12	116 424	6,44	59±17	91±10	118±10	5,08
Regosols	5	3 806	0,21	71±49	129±63	204±82	0,29
Solonchaks	9	19 865	1,10	42±17	66±11	87±10	0,64
Solonetzs	29	80 333	4,45	61±18	91±10	113±12	3,36
Vertisols	14	36 139	2,00	74±28	129±22	171±20	2,29
Total	**400**	**1 807 073**	**100**	**593**	**990**	**1 347**	**100**

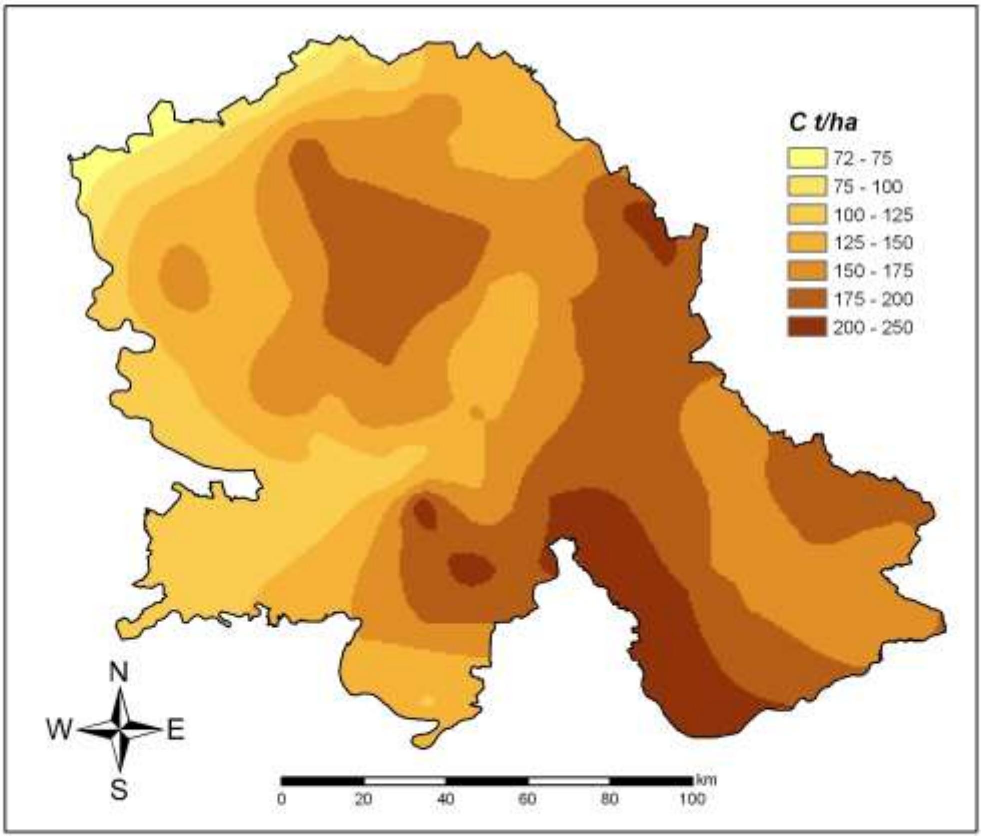

Figure 1. SOC stocks 0-100 cm soil depth in South-eastern Pannonian Basin

It was calculated that the total SOC stock of the 0-100 cm layer on 1,807,073 ha in the province is 270 Mt. Considering that in the earlier period there was no result of C stock reserves in Vojvodina, the results cannot be compared to determine the changes in the deposited C.

3.3. The influence of land use on SOC stock

Looking at the SOC content of the 0-100 cm layer in the soils intended for different uses, the highest levels were found on plough land (157t ha^{-1}) and the lowest in woodlands and vineyards (85 and 88 t ha^{-1}, respectively). Long-time intensive cropping is known to reduce SOC levels, while forests are SOC accumulators.

Shown in figure 2 are SOC reserves at three soil depths depending on the land use. The SOC content decrease with increasing soil depth with all land use except in the case of orchards, where deep primary tillage (deep ploughing) is often employed and soil layers get mixed together. The highest SOC levels in the 0-30 cm layer were found on plough-land (68 t ha^{-1}), followed by pastures (58 t ha^{-1}) and grassland (57 t ha^{-1}), while the lowest were observed in orchards (36 t ha^{-1}), woodlands (39 t ha^{-1}) and vineyards (40 t ha^{-1}). The higher SOC stock in 0-30 cm depth can provide more metabolic energy which drives soil biological processes. Further on at the plough-land cropping technology (fertilization, irrigation or tillage) could have significant influence to SOC content and general soil productivity (Molnar, 2003; Birkás, 2008; Šeremesić et al., 2011). At 0-100 cm depth, SOC levels were the highest on ploughland (157 t ha^{-1}), grassland (121 t ha^{-1}) and pastures (111 t ha^{-1}) and the lowest in woodlands (85 t ha^{-1}), vineyards (88 t ha^{-1}) and orchards (101 t ha^{-1}). In our study pastures and grassland had considerably larger SOC stocks in the 0-30 cm layer as compared to the deeper layers of the soil profile. The presented SOC stock in different land use systems is a result of the fact that in Vojvodina the most fertile soils with highest SOC content are used as plough land, whereas the forests are mostly found in river valleys and on the poorest soil types, which cannot reach the SOC levels of the most fertile soils even when forests grow on them. In addition to that, in practice, areas containing low carbon should be preferred for utilization in carbon storage rather than areas containing high carbon stocks. From the environmental protection point of view, both high production of plant biomass and simultaneously, balanced use of the assimilated carbon through selection of crops and varieties could help in SOC maintenance (Körschens, 2004).

3.4. The influence of parent material on SOC stock

According to the parent material as the factor determining SOC stocks, three kinds of soil can be clearly distinguished: those with a high SOC content in the 0-100 cm layer, which have formed on loess (157 t ha^{-1}); those with moderate SOC reserves, formed on alluvial deposits (134 t ha^{-1}); and those with relatively low SOC levels, developed on eolian sand (109 t ha^{-1}). Parent material influences soil texture, which affects soil moisture retention and productivity, decomposition; clay content and mineralogy, which affects SOC stabilization.

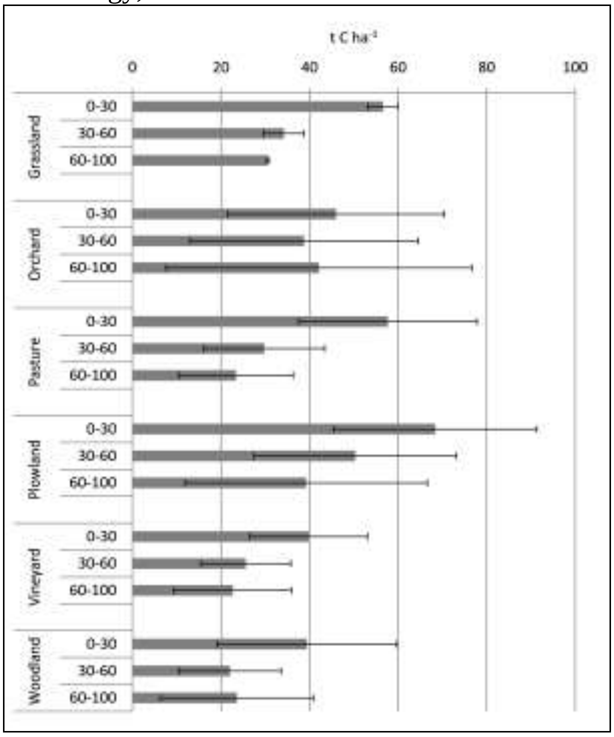

Figure 2. SOC levels with different soil uses

Soil organic carbon reserves decreased with increasing soil depth on all native substrates (Figure 3). The largest reserves in the 0-30 cm layer were recorded in soils formed on loess (70 t ha^{-1}), followed by alluvium (58 t ha^{-1}), and eolian sand (45 t ha^{-1}). At the 0-100 cm depth, SOC stocks were the largest in soil developed on loess (157 t ha^{-1}), alluvium (134 t ha^{-1}), and eolian sand (109 t ha^{-1}). Weak capacity for self-regulation and regeneration of sandy and alluvial soils, lesser adaptation to environmental constraints and, therefore, dependence upon external inputs to maintain crop production were main constrains in SOC accumulation. Soils formed mostly on loess, such as chernozems, which are characterized by a powerful solum and loamy mechanical composition, have a high potential for an increase of SOC content through a change of the mode of use and tillage. According to Miljković (1996) the organic matter content of South-eastern Pannonian chernozem is 4-6%, while the same content of the rare bands of unploughed chernozems under steppe vegetation was 8.5%, which indicates that the original SOC content of this soil may have been twice as high (8-12%). Soils formed on alluvial sediment have a medium potential for increasing their SOC reserves, and this potential varies greatly according to the nature of the sediment, i.e. the clay content. Pekeč et al., (2011) in the central Danube Basin found 60.02-70.26% total clay content in eugley soils. Soils formed on eolian sand have a low potential for SOC stock increase due to their sandy mechanical composition, good aeration, and a humus-accumulating layer that is maintained in the initial stages of formation under the influence of eolian erosion. Clayey soils accumulate carbon relatively fast (Belić et al., 2011), whereas sandy soils may not accumulate this element even after 100 years of its great input (Freibauer et al., 2004). Large inputs of carbon into Arenosol under grassland did not increase SOC content significantly.

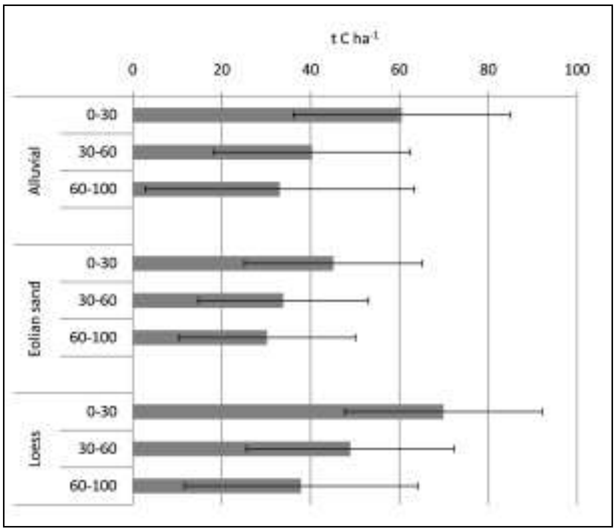

Figure 3. SOC levels with different parent material

When compared three investigated factors the influence of soil type was the most dominant, as the differences in SOC levels among the different types were the largest. Changes in SOC in various soil types have also been observed in other South European countries (Montanarella & Johnes, 2003). Vertical differences in SOC were observed as well. In woodlands, grassland, and pastures, considerably more SOC has accumulated at the surface layer (0-30 cm) than at deeper layers of the soil. There are significant changes in the SOC profile among different types of vegetation, which could be attributed to differences in the distribution of roots and residues above and below the soil (Jobbagy & Jackson, 2000). Parent material affects SOC content indirectly via soil mechanical composition, because soils with a finer texture have a greater potential for increasing their SOC reserves. Natural grassy steppe vegetation had been ploughed up for the past 150 years and that there had been no biological accumulation as in the years before (Škorić, 1986).

4. CONCLUSIONS

SOC content was studied in Vojvodina in the following soil types as per the IUSS Working Group WRB (2006): Arenosols, Chernozems, Cambisols, Fluvisols, Gleysols, Planosols, Regosols, Solonchaks, Solonetzs and Vertisols. Three factors were taken into consideration, soil type being the one with the largest influence on the SOC content. At 0-100 cm depth, the highest SOC levels were found in Regosols, Vertisols, Gleysols, and Chernozems and the lowest in Solonchaks, Fluvisols and Arenosols. As far as the land useis concerned, the highest SOC content was found in ploughland and the smallest in woodlands and vineyards. Based on the criterion of parent material, it was determined that the soils of Vojvodina can be divided into three categories based on SOC levels in the 0-100 cm layer: those with a high SOC content, which have formed on loess; those with moderate SOC reserves formed on alluvial deposits; and those with relatively low SOC levels, developed on eolian sand. Soils formed on loess mostly are characterized by a powerful solum and a high potential for increasing their SOC content, while those formed on alluvial sediment and, especially, eolian sand have no significant potential for the SOC stock increase in the solum thanks to a great extent to their mechanical composition. On the total of 1,807,073 ha covered by the study, the SOC reserves in the 0-100 cm soil layer were 270 Mt.

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