# ORGANIC CARBON STOCKS IN THE SOILS OF SERBIA

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**Abstract:** Spatial distribution of soil organic carbon (SOC) and SOC sequestration potentials were investigated in the soils of Republic of Serbia. Organic carbon stocks were estimated for soil layers 0-30 cm and 0-100 cm based on the results from a database and using soil and land use maps. The database included a total of 1,140 soil profiles which corresponded to 4335 soil horizons. To establish the relationship between organic carbon content and soil type, a soil map of Serbia was adapted to the WRB classification and divided into 15,437 polygons (map units). We calculated the SOC stock values for each reference soil group based on mean values of SOC at 0-30 and 0-100 cm and their areas. The largest SOC stocks for the soil layers 0-30 cm were found in Cambisol 194.76 x $10^{12}$ g and Leptosol 186.43 x $10^{12}$ g, and for the soil layers 0-100 cm in Cambisol 274.87 x $10^{12}$ g and Chermozem 230.43 x $10^{12}$ g. Based on the size of the reference groups, total area of Republic of Serbia, and the mean SOC values for each reference group, we calculated the total SOC stocks. The obtained values for the soil layers 0-30 cm and 0-100 cm amounted to 695.31 x $10^{12}$ g and 1142.42 x $10^{12}$ g, respectively. The analysis of SOC stocks according to land use showed that SOC stocks were higher in forestland and semi-natural areas than in agricultural soil by 40.71% and 11.43% at 0-30 cm and 0-100 cm, respectively.

**Key words:** Organic carbon stocks, map unit, soil group, land use map, SOC content, Republic of Serbia

## 1. INTRODUCTION

Soil plays an important role in the carbon cycle on Earth. Except for carbonate rocks, soil is the largest terrestrial carbon reservoir whose size ranges between 1,400 x $10^{15}$ g (Post et al., 1982) and 1,500 x $10^{15}$ g of carbon (Batjes, 1996). This amount is about twice the size of atmospheric carbon or three times the amount contained in terrestrial vegetation (Milne et al., 2006). The global soil carbon pool is about 2,500 Gt ($10^{15}$ g) (1,550 Gt of SOC and 950 Gt of soil inorganic carbon) (Lal, 2004). In most soil types (except for calcareous ones), carbon is typically contained in organic compounds, i.e., in the form of organic carbon (Batjes & Sombroek, 1997). This suggests that changes in organic carbon stocks in the soil (increases or decreases) may be of global significance and they may mitigate or exacerbate climate changes. In addition to soil organic carbon having a positive impact on climate changes, proper land management aimed at raising the level of organic carbon can increase the productivity and sustainability of agricultural ecosystems (Cole et al., 1997).

To evaluate the role of soil in carbon cycling, it is necessary to estimate organic carbon stocks (Yang et al., 2007). Such assessment is necessary from the points of both, environmental protection and agricultural production.

This paper presents an assessment of organic carbon stocks in the soils in Republic of Serbia. The assessment was based on long-term research data and data from Soil Information System of Environmental Protection Agency (Vidojević & Manojlović, 2010). Estimation of organic carbon stocks in the soil is important for Republic of Serbia for several reasons. Of the total territory of Republic of Serbia, 65.6% are

agricultural land and 32% are forest land (State of Soil in the Republic of Serbia for 2012, 2013). Considering the vital importance of organic carbon for the functioning of ecosystems, its effect on soil structure and soil water capacity, and its role in numerous chemical and physical soil properties, it is important to establish its baseline status in order to be able to monitor its variations over time. In the case of agricultural soils, the mean value of organic carbon up to the depth of 30 cm was found to be 68.99 t ha$^{-1}$, or 1.58%, which is considered as low (1-2%) (Vidojević et al., 2014). In the most frequent soil types under forest ecosystems in Central Serbia, eutric ranker (humic silicate soil), eutric cambisol and distric cambisol, the average content of organic carbon in the surface layer (0-20 cm, organic and mineral layers included), the value of organic carbon was 5.77 kg m$^{-2}$ (Kadović et al., 2012). Statistically significant differences in the vartiations of organic matter content over time can be obtained only when an adequate database is available (Sleutel et al., 2003; Van Meirvenne et al., 1996).

The objective of this paper was to describe the assessment of organic carbon stocks conducted in Republic of Serbia. The assessment was made in soil layers 0-30 cm and 0-100 cm and it was based on soil type and land use method.

## 2. MATERIALS AND METHODS

### 2.1. Study location

The assessment of organic carbon stocks in the soils in Republic of Serbia was carried out in the period 2009-2013. Republic of Serbia is located in the northwestern part of the Balkan Peninsula, in the southern part of Central and Eastern Europe. Extending in the direction south - north between 41°52' and 46°11' north latitude and 18°06' and 23°01' east longitude, Serbia covers the territory of 88,361 km$^2$. According to its geographic location and natural characteristics, Republic of Serbia is a Central European, Balkan, Pannonian and Danubian country.

In administrative terms, Republic of Serbia is comprised of Central Serbia and two autonomous provinces: Vojvodina (21,506 km$^2$) and Kosovo and Metohija (10,887 km$^2$).

Large heterogeneity in geological substrate, climate, vegetation cover and soil fauna had resulted in the formation of a large variety of soil types. Accordingly, the area of Serbia was divided into nine edaphic-climatic regions (Vidojević & Manojlović, 2007). Each region includes several soil types whose combination defines the general characteristics of these regions (Fig. 1).
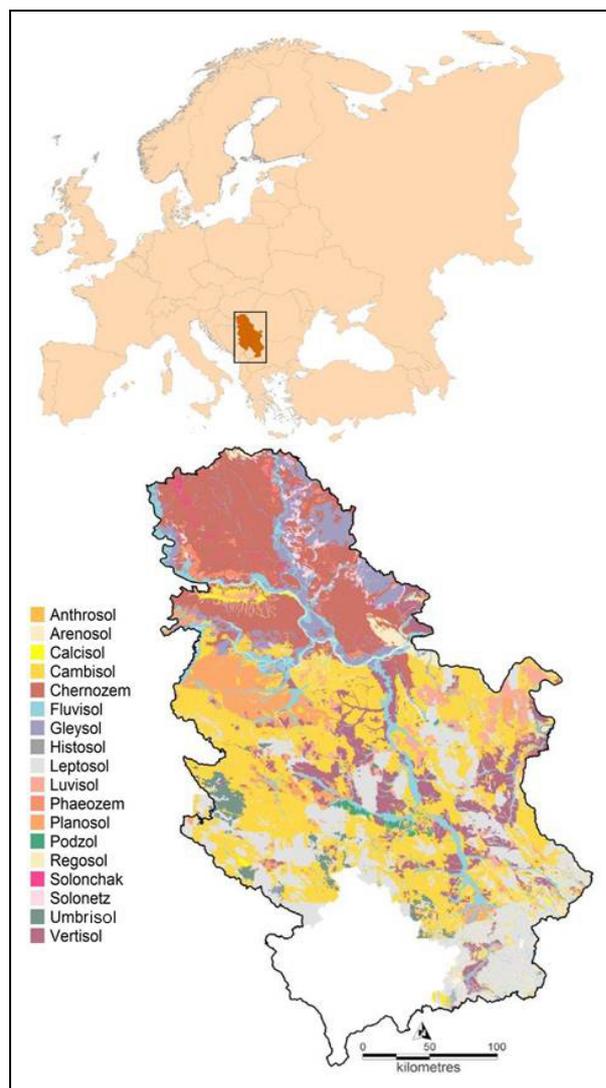


Figure 1. Location of Republic of Serbia and soil map according to WRB classification system

### 2.2. Soil database

In the period 2009-2011, a database was established which served as the basis for further research. Its objective was to collate all available data and to adapt them to fit the base. Presently, the database includes a total of 1140 soil profiles which involve 4335 horizons.

Data that comprise the database for analytical study were collected in the period 1962-2010. The base contains a set of data on organic carbon content, soil bulk density, particle size distribution (clay, silt, sand), land use, and altitude. When establishing the relationship between organic carbon content and soil type, we used the WRB classification described by IUSS Working Group WRB (2007). To comply with the WRB classification, a soil map of Serbia (Škorić et al., 1985) was divided into 15437 map units. Bernoux et al., (2002) defined map units as individual polygons that comprise a digital map. All polygons were divided

into eighteen WRB groups. Table 1 shows the areas and proportion of the Reference Soil Groups in Republic of Serbia according to the WRB classification.

Table 1. Soil groups in Republic of Serbia according to the WRB classification

| Reference Soil Group Code | | Area | |
|---|---|---|---|
| | | ha | % |
| AT | Anthrosol | 11,519 | 0.15 |
| AR | Arenosol | 55,836 | 0.72 |
| CL | Calcisol | 27,284 | 0.35 |
| CM | Cambisol | 2,168,581 | 27.99 |
| CH | Chernozem | 1,369,962 | 17.68 |
| FL | Fluvisol | 586,221 | 7.57 |
| GL | Gleysol | 484,545 | 6.25 |
| HS | Histosol | 442 | 0.01 |
| LP | Leptosol | 1,231,952 | 15.90 |
| LV | Luvisol | 219,583 | 2.83 |
| PH | Phaeozem | 72,840 | 0.94 |
| PL | Planosol | 429,472 | 5.54 |
| PZ | Podzol | 34,313 | 0.44 |
| RG | Regosol | 168,689 | 2.18 |
| SC | Solonchak | 25,022 | 0.32 |
| SN | Solonetz | 85,858 | 1.11 |
| UM | Umbrisol | 13,093 | 1.69 |
| VR | Vertisol | 644,689 | 8.32 |
| Total | | 7,747,401 | 100.00 |

The map shows that the reference groups Histosol, Anthrosol, Calcisol, Podzol, Phaeozem and Umbrisol are distributed over a limited area in the country, totaling 3.58%. The most extensive groups are Cambisols (27.99%), Chernozems (17.68%) and Leptosols (15.9%).

### 2.3. Description of method

The content of SOC was determined by Tyrin's titrimetric wet combustion method, where organic matter was oxidized by 0.2 M potassium dichromate $(K_2Cr_2O_7)$ solution in sulphuric acid and heated to the boiling point for 5 minutes. After oxidation, excess dichromate was determined by titration with ferrous ammonium sulphate (Mohr`s salt solution $[Fe(NH_4)_2(SO_4)_2*6H_2O]$). Concentration of organic matter was 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).

Soil mechanical structure was determined by the pipette method, preparation of samples was done with Na-pyrophosphate after Thun et al., (1955). The soil form was determined according to the ISSS

(International Society of Soil Science) soil texture classification (Verheye & Ameryckx, 1984).

Soil bulk density was determined in 100 $cm^3$ Kopecky cylinders (ISO 11272). Organic carbon stocks depending on land use method were calculated on the basis of 2006 Corine Land Cover (CLC) database. Mean values of the content of organic carbon in the soil and standard deviation were calculated with Statistica Version 8,0 (2007) for 0-30 and 0-100 cm soil layers and for each soil type and land use category.

Organic carbon content (%) on the surface of the 0-30 cm soil layer was determined according to the distribution of Van Ranst et al., (1995)

### 2.4. Calculation of organic carbon stocks

The calculation of organic carbon stocks was made according to the WRB reference soil groups.

Organic carbon stocks in soil (SOC t $ha^{-1}$) were calculated on the basis of the values of SOC g $kg^{-1}$, bulk density and soil depth applying the following formula:

$$SOC(t\ ha^{-1}) = \frac{SOC(g\ kg^{-1})}{1000000} x depth(m) x$$
$$BD(Mgm^3) x 10000(m^2 ha^{-1}) x 1000(kgMg^{-1})$$

The formula was derived after the method of Evrendilek & Wali (2001):
(1) soil weight (kg $ha^{-1}$) = depth (m) x bulk density (Mg $m^{-3}$) x 10,000 ($m^2$ $ha^{-1}$) x 1,000 (kg $Mg^{-1}$)
(2) SOC stocks (Mg $ha^{-1}$)= (g $SOCkg^{-1}$/1,000,000) x soil bulk (kg $ha^{-1}$)

A median point was calculated for each horizon which was then taken as the depth value. The general assumption was that the relationship between organic carbon content in the soil and depth could be represented by linear regression (y = ax + b) from horizon to horizon. Organic carbon content was calculated for the soil layers of 0-30 cm and 0-100 cm.

When we consider the change in the content of organic carbon with soil depth, the applied method of soil sampling may be of importance when comparing the obtained results. A disagreement between the results may occur because of the non-linear change in the content of organic carbon along the depth and taking the median point as the depth for which a particular organic carbon content was calculated.

Organic carbon content was determined on the basis of the thickness of horizons within the layer, as in Hiederer (2009):

$$OC_L = \sum_{i=1}^{n} OC_H^i x P_H^i$$

Where:

$OC_L$: organic carbon content in layer $L$

$OC_H$: organic carbon content in layer $H$

$p_H$: relation of horizon H within layer $L$

$i$: horizon within layer

## 2.5. Studied area

Organic carbon stocks in the soils of Republic of Serbia were calculated on the basis of the mean values for each WRB reference soil group and Corine Land Cover (CLC) categories of land use. Content was calculated to the depths of 30 cm and 100 cm and expressed in tons per hectare. Organic carbon stocks were calculated for the area of 77,474 km², i.e., for the territory of Republic of Serbia excluding Kosovo and Metohija Province (Statistical Yearbook of the Republic of Serbia, 2010). The territory of Kosovo and Metohija Province was excluded from calculation because of unavailable data.

## 2.6. Calculation of organic carbon stocks per wrb reference groups

Using Soil Map of Serbia, areas of the main WRB reference soil groups were defined (Table 1). Total values of organic carbon stocks for these reference groups were calculated on the basis of the mean values of organic carbon content at 0-30 cm and 0-100 cm and the area of each reference group. The database does not contain the results for organic carbon stocks in the following reference groups: Anthrosol, Calcisol, Histosol, Phaeozem, Podzol and Umbrisol. These groups cover a total area of 276,991 ha, which represents 3.57% of the territory of the country. For the calculation of organic carbon stocks in these groups, we used values which represented the arithmetic means for all reference group at 0- 30 cm and 0-100 cm expressed in t ha⁻¹. The mean values for the main reference groups were 89.59 t ha⁻¹ and 145.69 t ha⁻¹ for the depths of 0-30 cm and 0-100 cm, respectively.

Organic carbon stock at 0-30 cm per reference group was calculated according to the following formula:

SOC 30 cm (t) = Σ {(ẋ) mean value of organic carbon content per reference soil group at 0-30 cm (t ha⁻¹) x area occupied by reference group (ha)}

Organic carbon stock at 0-100 cm was calculated according to the following formula:

SOC 100 cm (t) = Σ {(ẋ) mean value of organic carbon content per reference soil group at 0-100 cm (t ha⁻¹) x area occupied by reference group (ha)}

## 2.7. Calculation of organic carbon stocks per Corine Land Cover categories of land use

Using Corine Land Cover (CLC) database for 2006, we defined areas of the major categories of land use (Table 3). Based on the obtained mean values of organic carbon content at 0-30 and 0-100 cm and the areas indicated by Corine Land Cover categories of land use, we calculated the organic carbon stocks in agricultural land, forest land, semi-natural areas, and artificial areas. The last category includes mostly the urban green areas and recreational areas. The database does not contain the organic carbon data for other categories of land use. Organic carbon stock at 0-30 cm per land use category was calculated according to the following formula:

SOC 30 cm (t) = Σ {(ẋ) mean value of organic carbon content per category of land use at 0-30 cm (t ha⁻¹) x area occupied by land use category (ha)}

Organic carbon stock at 0-100 cm was calculated according to the following formula:

SOC 100 cm (t) = Σ {(ẋ) mean value of organic carbon content per category of land use at 0-100 cm (t ha⁻¹) x area occupied by land use category (ha)}

## 3. RESULTS

### 3.1. SOC distribution depending on soil type

The calculated data indicated that there existed a great variability in the content of organic carbon among the reference soil groups (Table 2). The highest mean values of organic carbon content were found in the reference group Leptosol - 151.33 t ha⁻¹ and 178.95 t ha⁻¹ for the depths of 0-30 cm and 0-100 cm, respectively (Vidojević et al., 2012). The analysis of the coefficients of variation indicated that the mean values were not sufficiently representative for that group (CV > 50%). The lowest mean values of organic carbon content were found in the reference group Arenosol - 41.78 t ha⁻¹ and 96.03 t ha⁻¹ for the depths of 0-30 cm and 0-100 cm, respectively. The analysis of the coefficients of variation showed that the mean values were sufficiently representative for this group (CV <50%). The research showed that the values of organic carbon content had highest variability in the reference groups Leptosol and Regosol.

The result obtained on the basis of the compound area of the reference soil groups and the area of Republic of Serbia (77,474 km²) indicated that the organic carbon stocks at 0-30 cm and 0-100 cm were 695.31 x 10¹² g (Tg) and 1142.42 x 10¹² g (Tg), respectively.

Table 2. Soil organic carbon content (SOC) and SOC stocks in the major WRB soil groups in Republic of Serbia

| RSGC | n | 0-30cm | | | | | 0-100 cm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SOC content t ha$^{-1}$) | | | | SOC stock (Tg) | SOC content (t ha$^{-1}$) | | | | SOC stock (Tg) |
| | | Mean | Min | Max | SD | | Mean | Min | Max | SD | |
| AT | - | - | - | - | - | 1.03 | - | - | - | - | 1.68 |
| AR | 101 | 41.78 | 3.72 | 101.90 | 20.04 | 2.33 | 96.03 | 10.06 | 308.66 | 47.07 | 5.36 |
| CL | - | - | - | - | - | 2.44 | - | - | - | - | 3.97 |
| CM | 319 | 89.81 | 20.44 | 347.62 | 53.35 | 194.76 | 126.75 | 25.74 | 398.43 | 62.79 | 274.87 |
| CH | 216 | 73.82 | 7.89 | 133.51 | 21.86 | 101.13 | 168.20 | 24.21 | 341.37 | 57.88 | 230.43 |
| FL | 97 | 70.80 | 23.27 | 173.25 | 28.21 | 41.50 | 154.70 | 34.91 | 444.03 | 71.87 | 90.69 |
| GL | 38 | 85.01 | 6.29 | 221.33 | 37.47 | 41.19 | 168.75 | 92.96 | 436.43 | 83.61 | 81.77 |
| HS | - | - | - | - | - | 0.04 | - | - | - | - | 0.06 |
| LP | 211 | 151.33 | 11.06 | 527.22 | 96.95 | 186.43 | 178.95 | 11.06 | 658.40 | 127.33 | 220.46 |
| LV | 32 | 83.31 | 56.41 | 146.62 | 27.75 | 18.29 | 123.20 | 79.12 | 223.87 | 38.08 | 27.05 |
| PH | - | - | - | - | - | 6.53 | - | - | - | - | 10.61 |
| PL | 41 | 61.61 | 14.29 | 162.74 | 27.05 | 26.46 | 109.88 | 43.44 | 232.14 | 38.83 | 47.19 |
| PZ | - | - | - | - | - | 3.07 | - | - | - | - | 5.00 |
| RG | 12 | 93.74 | 26.51 | 298.43 | 87.08 | 15.81 | 160.88 | 26.51 | 425.53 | 157.98 | 27.14 |
| SC | 9 | 48.00 | 14.90 | 100.42 | 22.97 | 1.20 | 102.13 | 32.11 | 178.76 | 40.95 | 2.56 |
| SN | 29 | 71.09 | 30.66 | 126.48 | 24.39 | 6.10 | 126.74 | 55.68 | 215.89 | 33.95 | 10.88 |
| UM | - | - | - | - | - | 1.17 | - | - | - | - | 1.91 |
| VR | 35 | 71.09 | 33.25 | 129.26 | 21.08 | 45.83 | 156.34 | 58.26 | 275.29 | 53.58 | 100.79 |

**RSGC**: Reference Soil Group Code; **n**: Number of soil profiles in the database; **SD**: Standard deviation

### 3.2. SOC distribution depending on land use method

Distribution of soil organic carbon was shown in relation to land use method as defined by Corine Land Cover categories (Table 3). In Republic of Serbia, artificial areas, agricultural land, forests and semi-natural areas, and wetlands and water surfaces cover 257,070 ha, 4,395,186 ha, 2,967,453 ha, and 127,691 ha, respectively. The respective percentages are 3.32%, 56.73%, 38.30%, and 1.65%.

The analysis of organic carbon content in agricultural land showed that, in the layer 0-30 cm, the values ranged from 3.72 t ha$^{-1}$ to 328.23 t ha$^{-1}$. The mean value was 68.99 t ha$^{-1}$ or 1.58%, which placed this category of land use into the class of low carbon content (1-2 %). In the layer 0-100 cm, the values ranged from 18.25 t ha$^{-1}$ to 658.40 t ha$^{-1}$, with the mean value of 136.57 t ha$^{-1}$. The analysis of variation coefficients indicated that the mean values for this land use category were not sufficiently representative (CV > 50%).

The analysis of organic carbon content in the category of forests and semi-natural areas showed that, in the layer 0-30 cm, the values ranged from 4.93 t ha$^{-1}$ to 527.22 t ha$^{-1}$. The mean value was 116.35tha$^{-1}$ or 2.78%, which placed this land use category into the class of medium carbon content (2-6%). In the layer 0-100 cm, the values ranged from 10.06 t ha$^{-1}$ to 646.98 t ha$^{-1}$, with the mean value of 154.19 t ha$^{-1}$.

The analysis of variation coefficients indicated that the mean values for this land use category were not sufficiently representative (CV > 50%).

The analysis of organic carbon content in the category of artificial areas showed that, in the layer 0-30 cm, the values ranged from 30.71 t ha$^{-1}$ to 133.51 t ha$^{-1}$. The mean value was 74.74 t ha$^{-1}$ or 2.08%, which placed this land use category into the class of medium carbon content (2-6%). In the layer 0-100 cm, the values ranged from 45.68 t ha$^{-1}$ to 342.66 t ha$^{-1}$, with the mean value of 161.43 t ha$^{-1}$. The analysis of variation coefficients indicated that these mean values were representative (CV < 50%) for this land use category.

Based on the areas of the different land use categories, we obtained the values of organic carbon stocks for these categories. The results showed that the organic carbon stocks in the category of agricultural land were 303.22 x 10$^{12}$ g (Tg) and 600.25 x 10$^{12}$ g (Tg) at 0-30 cm and 0-100 cm, respectively. In the category of forests and semi-natural areas, the organic carbon stocks were 345.26 x 10$^{12}$ g (Tg) and 457.55 x 10$^{12}$ g (Tg) at 0-30 cm and 0-100 cm, respectively. In the category of artificial areas, which mainly included sites within urban green areas and recreational areas, the organic carbon stocks were 19.21 x 10$^{12}$ g (Tg) and 41.50 x 10$^{12}$ g (Tg) at 0-30 cm and 0-100 cm, respectively. The study did not include the category of wetlands.

Table 3. Soil organic carbon (SOC) content and SOC stocks by CLC categories in Republic of Serbia

| | Area (ha) | Area (%) | n | 0-30cm | | | | | 0-100 cm | | | | |
| | | | | SOC content (t ha⁻¹) | | | | SOC stock (Tg) | SOC content (t ha⁻¹) | | | | SOC stock (Tg) |
| | | | | Mean | Min | Max | SD | | Mean | Min | Max | SD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Agricultural areas** | 4,395,186 | 56.73 | 577 | 68.99 | 3.72 | 328.23 | 36.68 | 303.22 | 136.57 | 18.25 | 658.40 | 72.86 | 600.25 |
| **Forestland and semi-natural areas** | 2,967,453 | 38.30 | 489 | 116.35 | 4.93 | 527.22 | 79.60 | 345.26 | 154.19 | 10.06 | 646.98 | 93.22 | 457.55 |
| **Artificial areas** | 257,070 | 3.32 | 74 | 74.74 | 30.71 | 133.51 | 22.61 | 19.21 | 161.43 | 45.68 | 342.66 | 65.71 | 41.50 |

**n**: Number of soil profiles in the database. **SD**: Standard deviation

### 3.3. Elaboration of the map of SOC content

In order to present the spatial distribution of SOC, we made maps of SOC contents at 0-30 cm and 0-100 cm depths for WRB reference soil groups (Fig. 2) and CLC land use categories (Fig. 3). The figures show that the distribution of SOC stocks in the soil differed in dependence of several factors: soil type, climate, altitude, geological substrate, and land use method. The SOC contents at 0-30 cm had higher values in Central Serbia, which has large areas of forestland, than in Vojvodina Province, which is a plain with intensive agricultural production located in the north of the country.

### 4. DISCUSSION

The map of organic carbon distribution per soil type, at 0-30 cm, showed that largest organic carbon stocks were present in Central Serbia (southern part), predominantly in the reference group Leptosol. In that reference group, the content of organic carbon at 0-30 cm ranged from 11.06 to 527.22 t ha⁻¹, with the mean value of 151.33 t ha⁻¹. At 0-100 cm, the values ranged from 11.06 to 658.40 t ha⁻¹, with the mean value of 178.95 t ha⁻¹. The soils in this reference group are shallow, so that the values of organic carbon content to the depth of 100 cm represent in fact the value for the entire profile. The reference group Cambisol occupies the largest area in Central Serbia (37.76%). The values of organic carbon content for this reference group, at 0-30 cm, ranged from 20.44 to 347.62 t ha⁻¹, with a mean value of 89.81 t ha⁻¹. The coefficient of variation was 59.40%. The values of organic carbon content at 100 cm ranged from 25.74 to 398.43 tha⁻¹, with the mean value of 126.75 t ha⁻¹. The coefficient of variation was 49.54%. In the north of the country, in Vojvodina Province, the region with the most intensive agricultural production, the organic carbon content at 30 cm was mostly low, amounting to 1.93%. The most common soil type in this part of the country is Chernozem, which covers 57.9% of the area. The values of organic carbon content for this reference group, at 30 cm, ranged from 7.89 to 133.51 t ha⁻¹, with the mean value of 73.82 t ha⁻¹. The organic carbon content at 100 cm ranged from 24.21 to 341.37 t ha⁻¹, with the mean value of 168.20 t ha⁻¹. The obtained values indicated that chernozems have a greater depth of the humus horizon (Ah), which went up to 100 cm, then Cambisols with the humus horizon up to the depth of 60 cm.

Chernozem and Gleysol, the two most common soil reference groups in Vojvodina Province, which occupy 76.03% of the area, were found to have larger organic carbon stocks than Cambisol, the most common soil reference group in Central Serbia. The Chernozem soil in Russia was reported to contain 290 t ha⁻¹ of organic carbon at 0-100 cm (Mikhailova & Post, 2006), while a study in Bulgaria showed 142 t ha⁻¹ (Filcheva et al., 2002). Chernozem in Vojvodina Province, which had developed on loess terraces, has the mean organic carbon content of 151 t ha⁻¹ at 0-100 cm (Belić et al., 2013).

The map of organic carbon distribution depending on land use method indicated that organic carbon stocks were higher in forests and semi-natural areas than in agricultural land, up to 40.71% and 11.43% at 0-30 cm and 0-100 cm, respectively.
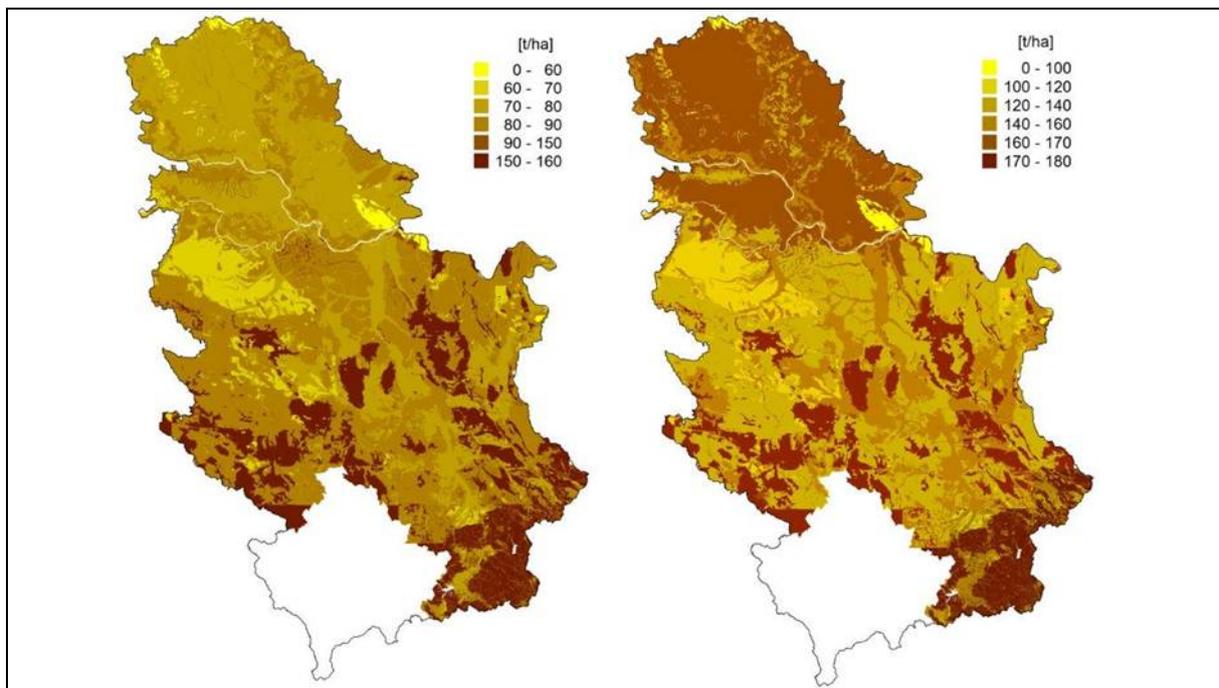
Figure 2. SOC stocks distribution by soil type, to the depths of a) 0-30 cm and b) 0-100 cm
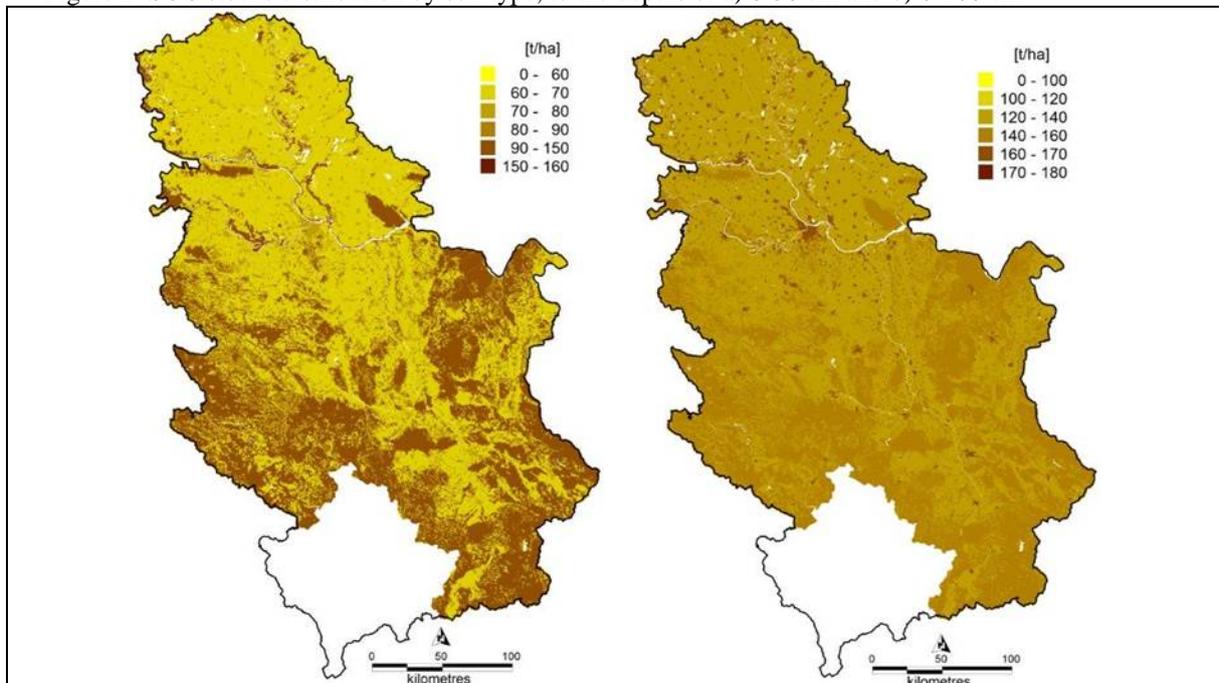


Figure 3. SOC stocks distribution by land use, to the depths of a) 0-30 cm and b) 0-100 cm

Organic carbon content was found to be higher in artificial areas than in agricultural land, forestland and semi-natural areas. The reasons for this are manifold, but the safest explanation is that the samples for this category were taken from urban green areas and recreational areas which are intensively fertilized and the removal of organic carbon is reduced.

This study showed that there occurred a great variability in results when categories of land use were analyzed. Only the sites belonging to the category of artificial areas, at 0-30 cm, produced sufficiently representative values of the mean content of organic carbon. It appears that organic carbon content depends more on other factors, such as soil type, climatic conditions, and altitude, than on land use parameters.

Distribution of organic carbon stocks confirmed that long-term intensive tillage reduces the content of organic carbon in the soil while forest ecosystems keep accumulating organic carbon in the soil.

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## 5. CONCLUSION

According to the analysis of the soil map, the soils of Serbia were found to store 695.31 x $10^{12}$g (Tg) of organic carbon at 0-30 cm and 1142.42 x $10^{12}$ g (Tg) at 0-100 cm. The mean organic carbon content for the major WRB reference soil groups was 89.59 t ha$^{-1}$ at 0-30 cm and 145.69 t ha$^{-1}$ at 0-100 cm. Based on the map of land use categories, organic carbon stocks in the category of agricultural land were 303.22 x $10^{12}$ g (Tg) at 0-30 cm and 600.25 x $10^{12}$ g (Tg) at 0-100 cm. Forestlands and semi-natural areas had organic carbon stocks of 345.26 x $10^{12}$ g (Tg) at 0-30 cm and 457.55 x $10^{12}$ g (Tg) at 0-100 cm. The mean values of organic carbon content in the category of agricultural land amounted to 68.99 t ha$^{-1}$ and 136.57 t ha$^{-1}$ at 0-30 cm and 0- 100 cm, respectively. The mean values in the category of forestland were 116.35 t ha$^{-1}$ to 30 cm and 154.19 t ha$^{-1}$ to 100 cm in depth. The spatial distribution of organic carbon stocks and its variability is caused by various factors, such as clay content, land use pattern, altitude, and climate. In general, the distribution of the content of organic carbon at 0-30 cm showed higher values in Central Serbia, where forestland occupied a larger area than agricultural land.

Republic of Serbia has a variety of soils which differ in profile structure and depth. In the case of the reference soil groups with the profile depth less than 100 cm, the content of organic carbon was still presented for the depth of 0-100 cm although it was not true for the actual situation.

As the data for organic carbon content come from a total of 1140 soil profiles, we believe that the results of the this study are accurate and reliable. This study is the first comprehensive assessment of organic carbon stocks in the soils layers 0-30 cm and 0-100 cm done in Republic of Serbia. The compilation of data on organic carbon stocks and its distribution in the different soil reference groups and land use categories is the first step in the evaluation and monitoring of changes of organic carbon stocks in the soils of Republic of Serbia.

### REFERENCES

**Batjes, N.H.**, 1996. *Total carbon and nitrogen in the soils of the world. European Journal of Soil Science,* 47, 2, 151–163.

**Batjes, N.H. & Sombroek, W.G.**, 1997. *Possibilities for carbon sequestration in tropical and subtropical soils. Global Change Biology*, 3, 2, 161-173.

**Belić, M., Manojlović, M., Nešić, Lj., Ćirić, V., Vasin, J., Benka, P. & Šeremešić, S.**, *2013. Pedoecological Significance of Soil Organic Carbon Stock in Southe-Eastern Panonnian Basin. Carpathian Journal of Earth and Environmental Sciences,* 8, 1, 171–178.

**Bernoux, M., Carvalho, M.D.S., Volkoff, B. & Cerri, C.C.**, 2002. *Brazils soil carbon stocks. Soil Sci. Soc. Am. J.* 66, 888-896.

**Cole, C.V., Duxbury J., Freney J., Heinemeyer, O., Minami, K., Mosier, A., Paustian, K., Rosenburg, N., Sampson, N., Sauerbeck, D. & Zhao, Q.**, 1997. *Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems,* 49, 1-3, 221-228.

**Evrendilek F. & Wali M.**, 2001. *Modelling long-term C dynamics in croplands in the context of climate change: a case study from Ohio. Environmental Modelling and Software,* 16, 4, 361–375.

**Filcheva, E., Rousseva, S.V., Kulikov, A., Nedyalkov, S. & Chernogorova, T.Z.**, 2002. *Organic Carbon Stocks in Soils of Bulgaria. In: Lal R, Kimble JM, Follett RF (eds) Agriculture Practices and Policies for Carbon Sequestration in Soil*, CRC Press, 471-476.

**Hiederer, R.**, 2009. *Distribution of Organic Carbon in Soil Profile Data. EUR 23980 EN. Luxembourg.* Office for Official Publications of the European Communities, 126.

**IUSS Working Group WRB.**, 2007. *World Reference Base for Soil Resources 2006,* first update 2007. World Soil Resources Reports No. 103. FAO, Rome.

**Kadović R., Belanović S., Knežević M., Danilović M., Košanin O. & Beloica J.**, 2012. *Organic carbon stock in some forest soils in Serbia.* Bulletin of the Faculty of Forestry 105, 81-98.

**Lal, R.**, 2004. *Soil Carbon Sequestration Impacts on Global Climate Change and Food Security.* Science 304, 1623-1627.

**Mikhailova, E.A. & Post, C.J.**, 2006. *Organic carbon stocks in the Russian Chernozem.* European Journal of Soil Science, Volume 57, Issue 3: 330-336.

**Milne, E., Easter, M., Cerri, C., E., Paustian, K. & Williams, S.**, 2006. *Technical Report of The Global Environment Facility* Co-financed Project No. GFL-2740-02-4381. Assessment of Soil Organic Carbon Stocks and Change at National Scale, 1.

**Post, W. M., Emanuel, W. R., Zinke, P. J. & Stangenberger, A. G.**, 1982. *Soil carbon pools and world life zones.* Nature, 298, 156–159.

**Sleutel, S., De Neve, S. & Hofman, G.**, 2003. *Estimates of carbon stock changes in Belgian cropland.* Soil Use and Management, 19, 166-171.

**State of Soil in the Republic of Serbia for 2012,** 2013. *Environmental Protection Agency, Republic of Serbia Belgrade*, ISSN 2334-9913: 37.

**Statistical Yearbook of the Republic of Serbia 2010,** 2010. Statistical Office of the Republic of Serbia, , *2010.* Belgrade, ISSN 0354-4206, 18.

**Škorić, A., Filipovski, G. & Ćirić, M.,** 1985. Classification of Yugoslav Soils. Academy of sciences and arts of Bosnia and Herzegovina. Special publications. Sarajevo, Tome LXXVIII, 13, 29-69.

**Thun, R., Herrmann, R. & Knickmann, F.,** 1955. *Die Untersuchung von Boden. 3. Aufl., Neuman Verlag, Radebeul und Berlin: 271.* (The International system soil mechanical elements proposed by Atterberg)

**USDA - NRCS, NSSC,** 1996. *Chemical analyses of organic carbon (6A). Soil Survey Laboratory Methods Manual. Soil Survey Investigation Report No. 42, Version 3.0,* US Government Printing Office. 217.

**Van Meirvenne, M., Pannier, J., Hofman, G. & Louwagie, G.,** 1996. *Regional characterisation of the long-term change in soil organic carbon under intensive agriculture. Soil Use and Management,* 12, 86-94.

**Van Ranst, E., Thomasson, A.J., Daroussin, J., Hollis, J.M., Jones, R.J.A., Jamagne, M., King, D. & Vanmechelen, L.,** 1995. *Elaboration of an extended knowledge database to interpret the 1:1,000,000 EU Soil Map for environmental purposes. In: European Land Information Systems for Agro-environmental Monitoring.* D. King, R.J.A. Jones and A.J. Thomasson (eds). European Soil Bureau Research Report No.1, EUR 16232 EN, Office for Official Publications of the European Communities, Luxembourg, 71-84.

**Verheye, W. & Ameryckx, J.,** 1984. *Mineral fractions and classification of soil texture. Pedologie* 1984-2, 215-225.

**Vidojević, D. & Manojlović, M.,** 2007., *Overview of the soil information and policies in Serbia. In: Status and prospect of soil information in south-eastern Europe: soil databases, projects and applications. Hengl T., Panagos P., Jones A. and Toth G. (eds.)* Office for Official Publications of the European Communities, EUR 22646EN, Scientific and Technical Research series, ISSN 1018-5593, 87-98.

**Vidojević, D. & Manojlović M.,** 2010. *Estimation of soil organic matter content in Serbia, Proceedings of XXIV meeting of agronomists, veterinarians and technologists,* Belgrade, 16, 1-2, 231-244 (in Serbian).

**Vidojević, D., Manojlović M., Đorđević, A. & Dimić, B.,** 2014. *Estimation of soil organic carbon stocks in agricultural soils in the Republic of Serbia, Proceedings of XXVIII meeting of agronomists, veterinarians, technologists and agroeconomists, ,* 20, 1-4, 139-146 (in Serbian).

**Vidojević, D., Manojlović, M., Đorđević, A. & Nešić, Lj.,** 2012. *Assessment of Soil Organic Carbon Stocks in Serbia Soil science for the benefit of mankind and environment.* 4th International Congress of the European confederation of soil science societies (ECSSS). 2-6 July 2012, Bari – Italy: 1808.

**Yang, Y., Mohammat, A., Feng, J., Zhou, R. & Fang, J.,** 2007. *Storage, patterns and environmental controls of soil organic carbon in China.* Biogeochemistry, 84, 131–141.