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SOIL ORGANIC CARBON LOSS FOLLOWING LAND USE CHANGE IN A SEMIARID ENVIRONMENT

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Abstract

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Soil organic carbon is an essential part of soil and a valuable natural resource. Due to land use change SOC stocks are usually altered, which can seriously affect the environment and the ecosystem. The objective of this study was to investigate effects of different land use regimes (cropland, meadow and forest) and different soil types (Fluvisols, Chernozems, Vertisols and Solonetz) on SOC stocks. The results imply that soil type was the principal factor affecting SOC stocks. Topsoil SOC stocks (0-30 cm) decreased in the following order: Vertisols (93 t ha^{-1}) > Chernozems (68 t ha^{-1}) > Solonetz (65 t ha^{-1}) > Fluvisols (48 t ha^{-1}). The conversion of native ecosystems (forests and meadows) to croplands induced a significant SOC stock decrease and a considerable degradation of soil. Forests contain 72 t ha^{-1} of SOC, meadows 71 t ha^{-1} and cropland 62 t ha^{-1}. The highest historical loss of SOC stock due to the conversion of native ecosystems was obtained in Chernozems (16-18%), Vertisols (15-17%) and Fluvisols (13-22%), while such a loss in Solonetz was negligible (1-3%). Determining historical SOC loss based on different soil types provides useful information on potential soil degradation and sequestration potential and might thus be used as a guideline for soil protection.

Key words: soil organic carbon, soil type, land use change, carbon loss

Abbreviations: SOC – soil organic carbon, SOM – soil organic matter, BD – bulk density

Introduction

Soil organic carbon is recognized as an extremely valuable natural resource (Lal, 2004). It has a great ecological importance acting as a cementing agent between soil particles and protecting structure aggregates from depletion. The importance of SOC for carbon cycling and global climate changes is well established (Smith, 2004; Leifeld, 2006; IPCC, 2007 and Lal et al., 2007). Also, SOC improves soil water permeability, air and water capacity, decreases compaction, contibutes to cation exchange capacity and acts as a source of nutrients and is thus of great importance for agriculture. It is assumed that SOM contains approximately 58% of SOC.

The global SOC pool is estimated to be from 684 to 724 Pg (1 Pg = 1 Gt = 10^{15} g) in the upper layer (0-30 cm) of the soil (Batjes, 1996) and the regional level for Central and Eastern Europe is estimated at 48 Pg (Batjes, 2002). The concentration of SOC ranges from about 10% in humid regions to less than 0.5% in arid climates. A Lower SOC concentration in arid and semiarid regions makes SOC more valuable in such conditions. The existing equilibrium between SOC inflows and outflows is disrupted after a land use change and can be established in the new formed ecosystem (Fearnside and Barbosa, 1998). Changes in SOC concentration are most prominent in the upper layer (0-30 cm) when the native vegetation has been converted to cropland. Land use change, primarily native vegetation conversions is the main factor, which induces a SOC decrease. Soil organic carbon loss is defined as one of the eight major threats to the soil in the *EU Thematic Strategy for Soil Protection* (Blum, 2008) and contributes to atmospheric CO_2 increase and consequently to global warming. A large SOC loss in the past could mean a larger potential for SOC sequestration. Additionally, the sequestration ability for SOC in dry and warm regions appeared to be lower (0.1 to 0.3 t ha^{-1} $year^{-1}$) than in cold and humid regions (0.5 to 0.8 t ha^{-1} $year^{-1}$) (Lal, 2002). European soils have a significant potential to decrease the flux of C to the atmosphere from cropland, relative to the amount of SOC stored in cropland soils at

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present (Smith, 2004). Therefore, the need for the enrichment of datasets and knowledge of historical carbon loss becomes evident. Even though land use is a good predictor of SOC stocks, it usually masks the effect of soil type on SOC because soil type to an extent determines land use. That is why a lot of SOC variation depends on soil type (Robert, 2001 and Hagedorn et al., 2001) and all SOC estimation should be made on the basis of soil type. Bulk density has a crucial importance for SOC stock measurement. It must be measured for SOC stock assessment on an area basis (VandenBygaart et al., 2006). There are significant correlations between SOC, SOM and BD (Périé and Ouimet, 2008).

Understanding the effects of native vegetation conversion on different soils is essential for predicting and modelling future SOC stocks and sequestration potential. In the Serbian province of Vojvodina, main conversions of natural vegetation to cropland occurred about 200 years ago. Since then Vojvodinian soils have lost most of their original SOC stocks. Nešić et al. (2008) noted a 0.68% decrease of SOC concentration in Vojvodinian soils of Srem recorded in the 1992-2006 monitoring period. The seriousness of SOC loss is not fully recognized in Serbia and there is a lack of polices that support soil protection and restoration of natural vegetation, with a view of enhancing soil fertility and reducing its susceptibility to erosion as well as establishing ecosystem stability.

The objective of this comparative study was to estimate SOC stocks in four different soil types (Fluvisols, Chernozems, Vertisols and Solonetz) under three different land use regimes (cropland, meadow and forest). In order to investigate the effects of native vegetation conversions we calculated historical carbon loss for different soil types.

Materials and Methods

Site description

The study was carried out in the Serbian Province of Vojvodina, which occupies the southernmost part of the Pannonian Basin (46º11'- 46º37'N, 18º51'- 21º33'E) and is its warmest and driest part. Vojvodina covers an area of 2,150,600 ha of which 1,648,000 ha is arable land. The climate is semiarid with the average annual precipitation of 602 mm and the mean annual temperature of 11.0ºC. The dominant relief in Vojvodina consists of loess terraces (70-90 m altitude), loess and sand plateaus (90-120-200 m altitude) and river plains (Danube, Tisza and Sava rivers). Steppe-forest vegetation and the dominance of loess as parent material were a prerequisite for the genesis of very fertile soils.

The investigated croplands have been tilled >100 years with the most frequent crop rotation consisting of corn, wheat and soybean. Vojvodinian natural meadows consist mainly of mezophytes (*Poa pratensis, Dactylis glomerata, Bromus mollis, Festuca pratensis, Cirsium arvense*) and grasses (*Poa* sp., *Stipa* sp., *Festuca* sp., *Cynodon* sp., *Panicum* sp.). In the areas of alkaline and saline soils halophytes prevail (*Agropyrum repens, Matricaria chamomilla, Roripa kerneri, Chenopodium rubrum, Rumex crispus*). The areas under natural forests are mostly represented by *Fagus* sp., *Quercus* sp., *Populus* sp. and *Salix* sp.

Sampling design and analysis

Our investigation was performed on five most common soil types in the Province of Vojvodina: Arenosols, Fluvisols, Chernozems, Vertisols and Solonetz (WRB, 2006). Every soil type was observed at three different sites in Vojvodina and at each site under three different land uses (cropland, meadow and forest). Every cropland, meadow and forest within a single site was sampled at 0-30 cm with three replicates approximately 10 m apart and with sampling distances between different land uses smaller than 200 m to ensure soil similarity. The samples were air-dried and sieved through a 0.2 mm sieve prior to the SOC concentration analysis. A core method with cylinders (V=100 cm^3) was applied to take undisturbed soil samples for BD determination in nine repetitions. Soil organic carbon concentration was determined by titrimetric wet combustion method, after organic matter oxidation by potassium dichromate ($K_2Cr_2O_7$) solution with sulphuric acid (Rowell, 1997).

Soil organic carbon stock (t ha^{-1}) was calculated by the following equation:

$$SOC_{stock} = BD \times SOC \times D, \quad (1)$$

where BD is the bulk density of soil (g cm^{-3}), SOC is the SOC concentration (%), D is the depth of soil layer (30 cm).

Historical loss of SOC (t ha^{-1}) was calculated as follows:

$$SOC_{historical\ loss}\ (t\ ha^{-1}) = SOC_{na}\ (t\ ha^{-1}) - SOC_{cr}\ (t\ ha^{-1}), \quad (2)$$

where SOC_{na} is organic carbon stock in soil under natural vegetation (forest or meadow) (t ha^{-1}), SOC_{cr} is organic carbon stock in soil under cropland (t ha^{-1}).

For determining the significance of treatments and separating means at $p < 0.05$ level of significance ANOVA and Fisher's LSD test were applied. Statistica 10.0 software system was used for all calculations.

Results and Discussion

Bulk density

Soil organic carbon concentrations and BD are considered the two prerequisites for estimating SOC stocks (Xu et al., 2011). A higher BD implies higher SOC stocks at the same

SOC concentrations in the soil. Bulk density is related to natural soil properties (Chen et al., 1998). It is often in a strong relationship with soil texture. Heavily textured soils are usually more compacted, but the type of clay can significantly decrease BD values. In this paper we obtained significantly different BD between different soil types (Figure 1). The lowest BD was obtained in Vertisols (1.20 g cm^{-3}) due its high porosity and swelling of montmorilonite clay. Chernozems and Solonetz showed the highest BD values (1.41 g cm^{-3} and 1.37 g cm^{-3}, respectively), as a consequence of high content of non-swelling illite clays in these soils. As is the case with coarse textured soils, Fluvisols showed significantly lower BD (1.32 g cm^{-3}) than Chernozems and Solonetz.

Land use significantly affected the BD of the soil (Figure 2). The values of BD decreased in this order: cropland (1.43 g cm^{-3}) > meadow (1.35 g cm^{-3}) > forest (1.24 g cm^{-3}). Long-term tillage in croplands induces breaking of soil aggregates and soil compaction. This is the cause of significantly higher BD established in croplands. Meadows are occasionally exposed to grazing and mowing so BD is significantly higher than in the forests where a good structure provides a lower BD. Land use had a significant impact on BD, which was higher under grassland and arable land than forest (Manojlović et al., 2011).

SOC stocks

The statistical analysis showed that SOC stocks differ significantly between soil types in the topsoil (Figure 3). Largest SOC stocks were observed in Vertisols (93 t ha^{-1}). These soils in Vojvodina are heavily textured and under a frequent influence of groundwater (Gleyic Vertisols), which contributes to creating and maintaining high SOC stocks. Chernozems and Solonetz showed very similar SOC stocks (68 and 65 t ha^{-1} respectively). These two soils are predominantly formed on a silty parent material (loess) which is a prerequisite for the creation of considerable high SOC stocks. Texture has a strong impact on SOC stocks. Increasing silt and clay contents have been associated with higher SOC storage (Paul et al., 2008). Chernozems of Central and Eastern Europe contain 76-97 t ha^{-1} SOC in the 0-30 cm layer (Batjes, 2002). Vojvodinian Solozetz has SOC stocks between 55 and 89 t ha^{-1} (Belić et al., 2004). Fluvisols had the lowest SOC stocks in the topsoil (48 t ha^{-1}) due to a continuous influence of flooding water, which maintains the surface layer in its initial stage. Soil type has an important effect on SOC stocks as well as on the dynamics of SOC decline through land use change. Thus soil type can be used as a universal predictor of SOC stocks in the topsoil.

The type of land use is a principal factor influencing SOC. Soils under meadow and forest contain significantly higher levels of SOC stocks (71 and 72 t ha^{-1}) than the same soils under cropland (62 t ha^{-1}) (Figure 4). This indicates a negative impact of continuous tillage on SOC stocks. Six et al. (1998) reported significantly lower total SOC in the 0-20 cm layer of a native grassland soil compared to a conventionally tilled soil. Wang et al. (2008) recorded a slight loss of SOC after conversion of grasslands to croplands over about a 35-year period. Significantly higher total SOC was found in the 0-25 cm layer of a native forest than in same depth of agricultural soils (DeGryze et al., 2004). Intensive agriculture leads to more intensive and more rapid SOC decomposition. Crushing forces of agricultural machinery in the long term expose SOM to oxidation and thus cause degradation processes, which in turn leads to releasing CO_2 to the atmosphere and raising the levels of greenhouse gases. Long-term cultivation decreases aggregate stability, which is paralleled with a reduction of SOC concentration (Elliott, 1986).

When land uses were observed separately within a single soil type (Table 1), we obtained higher SOC stocks in Vertisols under meadows (97 t ha^{-1}) and forests (100 t ha^{-1}) than

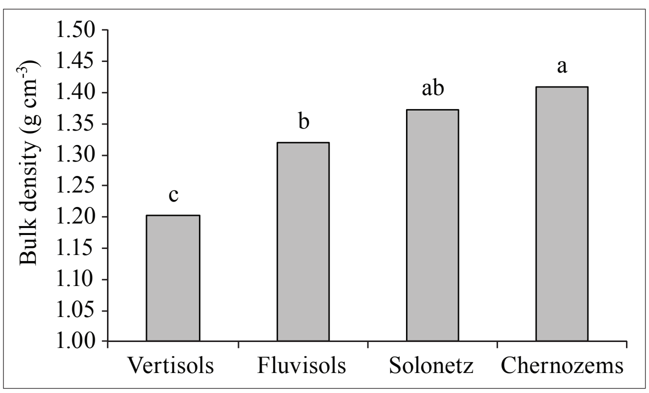

Fig. 1. Bulk density of soil in different soil types (0-30 cm). Columns followed by a different letter are significantly different at $p < 0.05$ using Fisher's LSD test

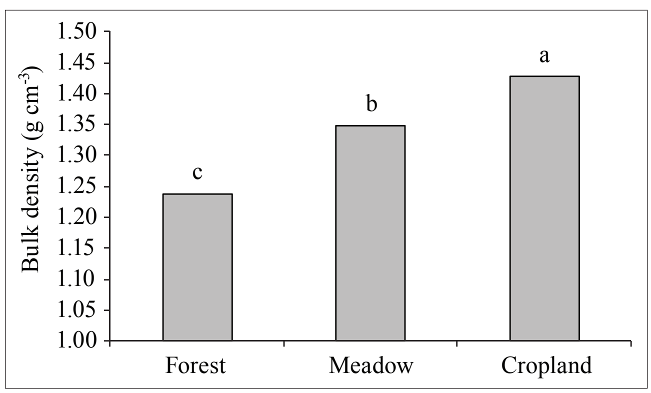

Fig. 2. Bulk density of soil (0-30 cm) under different land uses. Columns followed by a different letter are significantly different at $p < 0.05$ using Fisher's LSD test

under croplands (82 t ha^{-1}). A similar case was found in Chernozems where meadows and forests had higher SOC stocks (71 and 72 t ha^{-1}, respectively) than croplands (59 t ha^{-1}). Ćirić (2008) determined that the average SOC stock of 65 t ha^{-1} in the plow layer (0-30 cm) ranges from 58 to 76 t ha^{-1} in Vojvodinian Chernozem on a loess terrace. Fluvisols also showed higher SOC stocks under native vegetation (forests 54 t ha^{-1} and meadows 48 t ha^{-1}) than under croplands (42 t ha^{-1}). Only Solonetz had slightly different SOC stocks under forest, meadow and cropland. Chernozems, Vertisols and Fluvisols in Vojvodina are much more exposed to intensive agriculture due to a high degree of their fertility in contrast to Solonetz. Intensive agriculture leads to more intensive and more rapid SOC decomposition. Long-term continuous tillage leads to a SOC decrease and reduced crop yields and soil biological activity. Therefore, if tillage is deeper, the decrease of SOC is higher (Mando, 2003). This is the reason why the differences in SOC stocks are considerably higher in Chernozems, Vertisols and Fluvisols under native vegetations than in croplands while in Solonetz these differences are not substantial.

Historical SOC loss

Historical loss of SOC stocks following conversions of meadows and forests to croplands was different in different soil types (Table 2). The absolute loss of SOC stocks was highest in Vertisols (15-17 t ha^{-1}). In Chernozems such a loss

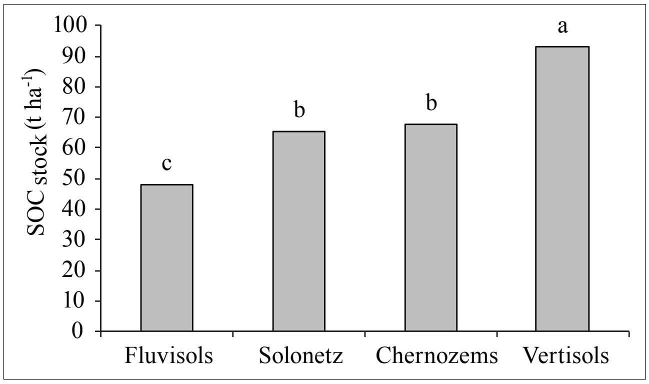

Fig. 3. Soil organic carbon stocks (0-30 cm) in different soil types. Columns followed by a different letter are significantly different at $p < 0.05$ using Fisher's LSD test

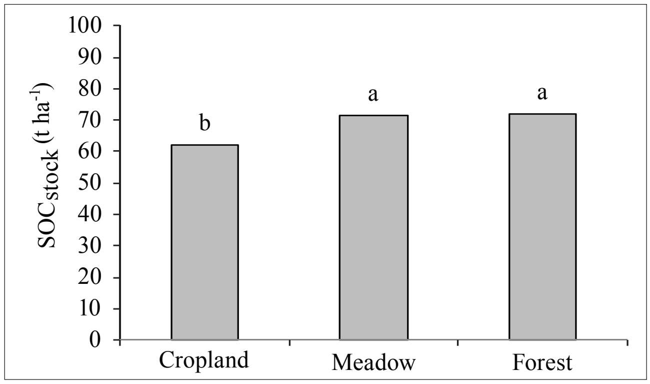

Fig. 4. Soil organic carbon stocks (0-30 cm) under different land uses. Columns followed by a different letter are significantly different at $p < 0.05$ using Fisher's LSD test

Table 1
Present SOC stocks (0-30 cm) in different soil types under croplands, meadows and forests

Land uses \ Soil types	SOC stocks (t ha^{-1})			
	Fluvisols	Chernozems	Vertisols	Solonetz
Croplands	42	59	82	64
Meadows	48	71	97	65
Forests	54	72	100	66

Table 2
Absolute and relative historical loss of SOC stocks (0-30 cm) from different soil types after conversion of meadows and forests to croplands

Land use conversion \ Soil types	Fluvisols	Chernozems	Vertisols	Solonetz
	Absolute historic SOC stocks loss (t ha^{-1})			
From meadows to croplands	6	12	15	1
From forests to croplands	12	13	17	2
	Relative historic SOC stocks loss (%)			
From meadows to croplands	13	16	15	1
From forests to croplands	22	18	17	3

was 12-13 t ha^{-1}, while in Fluvisols it was 6-12 t ha^{-1}. Solonetz showed a substantially lower SOC stock loss (1-2 t ha^{-1}).

The highest relative loss of SOC stock after long-term tillage of soils under native vegetation was observed in Chernozems and Vertisols (16-18% and 15-17%, respectively). A similar relative SOC loss was registered in Fluvisols (13-22%) but Solonetz shows the lowest negligible loss (1-3%). After conversion from native forest to crop and from pasture to crop, Guo and Gifford (2002) reported a 42% and 59% average decline of SOC stocks. Poeplau et al. (2011) noticed a carbon loss after deforestation (32 ± 20%) and after conversion of grassland to cropland (36 ± 5%). A relatively low loss of SOC stocks has appeared because of significant differences in BD of different land uses. Thus, a higher BD contributed to higher SOC stocks obtained for cropland, which decreases real SOC stocks loss, but the SOC concentration loss was notably higher.

The calculation of historical SOC loss for different soil types helps us determine the degree of soil degradation and provides us with insight into a sequestration potential of these soils. The sequestration potential for SOC is most often induced by a previous SOC loss from its decomposition and erosion and varies substantially with soil type, location and land use (Tan and Lal, 2005). Large losses of SOC in the past imply a higher potential of agricultural soils for SOC increases (Manojlović et al., 2010).

Conclusions

Soil type might be used as a principal predictor of SOC stocks. Soil organic carbon stocks in the topsoil (0-30 cm) decrease in the following order: Vertisols (93 t ha^{-1}) > Chernozems (68 t ha^{-1}) > Solonetz (65 t ha^{-1}) > Fluvisol (48 t ha^{-1}). Land uses affect SOC stocks. The conversion of forests and meadows to croplands leads to a reduction of SOC stocks, which decreased in this order: forests (72 t ha^{-1}) > meadows (71 t ha^{-1}) > croplands (62 t ha^{-1}).

Negative effects of native vegetation conversions are most pronounced in Chernozems, Vertisols and Fluvisols, which showed high absolute loss of SOC stock after native vegetation conversions to croplands. Solonetz showed a negligible SOC stock loss following native vegetation conversion. A relative loss of SOC stock was also highest in the soil types exposed to most intensive tillage. Chernozems have lost 16-18% of their ancient SOC stocks, Vertisols 15-17%, Fluvisols 13-22% and Solonetz 1-3%.

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