

*Srđan I. ŠEREMEŠIĆ**, *Ljiljana M. NEŠIĆ¹*,
Vladimir I. ČIRIĆ¹, *Jovica R. VASIN²*,
Ivica G. ĐALOVIĆ², *Jelena B. MARINKOVIĆ²*,
Bojan Đ. VOJNOV¹

¹ University of Novi Sad, Faculty of Agriculture Novi Sad,
Trg Dositeja Obradovića 8, Novi Sad 21000, Serbia

² Institute of Field and Vegetable Crops,
Maksima Gorkog 30, Novi Sad 21000, Serbia

SOIL ORGANIC CARBON FRACTIONS IN DIFFERENT LAND USE SYSTEMS OF CHERNOZEM SOIL

ABSTRACT: The relationship between soil carbon fractions in Chernozem soils was assessed in soil samples of three different environments: arable soil, grassland and oak forest. Grassland and oak forest had higher soil organic carbon (SOC), carbon soluble in hot water (HWC), particulate organic carbon (POC) and mineral-associated carbon (MOC) than the arable soil. The POC/MOC ratio was lowest in arable soil, indicating a smaller carbon pool for microbial turnover. POC increases with higher total SOC, indicating that the preservation of organic matter depends on the renewal of labile fractions. Our results showed that fertilization had active role in soil carbon stabilization, while crop rotation had less effect on a soil carbon turnover. Our result could contribute to the better understanding of SOC fractions composition and relevance in Chernozem soil, thus could help in selection of cropping management systems for SOC preservation.

KEYWORDS: land use systems, soil organic carbon, mineral-associated carbon, particulate organic carbon

INTRODUCTION

Different qualitative fractions of SOC derived from the formation pathways could be evaluated to better understand carbon cycling of the specific cropping systems. Soil organic carbon fractions are identified according to their role in the carbon turnover and relationship with the microbiological and soil properties (Cookson et al., 2005). In recent decades, increased number of physical and chemical fractionation approaches has been proposed for separation and

* Corresponding author. E-mail: srdjan.seremesic@polj.uns.ac.rs

the identification of the different labile and stable fractions as proxies for the SOC pool and their role in soil quality (Baldock and Nelson, 2000). Each of the fractions contains specific information relevant to estimate effects of land use on SOC pool turnover and stabilization. Changes in management practices in the long-term experiment over time could induce problems in quantification of SOC pool due to the large background amounts already present and the spatial variation (Haynes, 2000). Therefore, a current perspective in SOC interpretation based on total carbon pool lacks clarity and precision in explaining the relationship between SOC content and related soil properties. Moreover, soils can vary in the potential for organic matter mineralization (Najvirt et al., 2019). The turnover of the labile SOC fraction is relatively rapid and responds quickly to the land use changes and soil management, and therefore it could be anticipated as the early and sensitive indicator of the total SOC change (Hynes and Beare, 1996). Concentration and fluxes of the SOC fractions obtained with fractionation approaches results with the similar conceptual SOC pool but with the different perception on the factor causing their occurrence in soil. Decomposition studies by Gregorich et al. (2003) provided evidence that the hot water extractable carbon (HWC) fraction of soil C is highly labile and estimated that the HWC accounted for about 70% of the total water-soluble matter. Ghani et al. (2003) found that HWC reflected the changes in SOC caused by different soil management practices compared with stable SOC pool. Particular organic carbon (POC) is considered as intermediary available SOC pool sensitive to the management practice and the grown crops (Cambardella and Elliott, 1993). Therefore, POC acts as a binding agent in soil, responsible in stabilization of the macro-aggregates and intra-aggregate structure (Six et al., 2002). Bayer et al. (2004) explained that organic matter in the POC is more sensitive to a management practices than C obtained in the total SOC pool. Martinez-Mena et al. (2012) emphasized the interaction between POC and mineral-associated carbon (MOC) to better understand the role of labile C in SOC dynamic. Due to pronounced decreasing trend in SOC, there is a need to explain how it reflects changes in the content of SOC fractions and to what extent it can affect soil productivity. The aim of this study was to determine the change in the SOC as a consequence of an interrelation of the different SOC fractions with different land use systems.

MATERIALS AND METHODS

The arable plots were selected from a long-term stationary experimental rotation-crop field “Plodoredi” (Šeremešić et al., 2011) of the Institute of Field and Vegetable Crops (N 45° 32' 51"; W 19° 84' 77"; 84 m above sea) in Novi Sad, Serbia and adjacent grassland and forest. The trial was set up on Calcic Chernozem (Aric, Loamic, Pachic) (abbreviated CH-cc-ai.lo.ph) (IUSS Working Group WRB, 2014) in 1946/1947, and the fertilized crop rotation systems were redesigned in 1969/70, while the unfertilized systems remained unchanged.

Experiment performance involved applications of organic and mineral fertilizers and plowing of the crop residue according to the following layout:

1. Maize monoculture (MO): mineral N – 120 kg/ha, P and K according to soil analyses, established in 1969/70.
2. Unfertilized 2-year rotation (maize-winter wheat) (N2): established in 1946/47 without any fertilizers and with plowing the crop residue since 1987.
3. Fertilized 2-year rotation (maize-winter wheat) (D2): mineral N – 120 kg ha⁻¹, P and K according to soil analyses, established in 1969/70.
4. Fertilized 3-year rotation (maize-soybean-winter wheat) (S3): mineral N – 120 kg ha⁻¹, 25 t ha⁻¹ farmyard manure after winter wheat. P and K according to soil analyses, established 1969/70.
5. Grassland (UG): 45° 20,549', (E) 19° 51,492', at 81 m elevation
6. Oak forest (OF): 45° 20,591', (E) 19° 51,374', at 83 m elevation

Soil samples were taken at the beginning of maize growing period (5th of May, 2012) and after maize harvest (5th of October, 2012) with auger corer. The average soil sample consisted of 5 drillings. The disturbed soil samples (approximately 1 kg) were transferred to carton boxes and stored as air-dry samples at room temperature subsequent to analyses. The samples were ground in a mill and sieved (2 mm diameter). Soil organic carbon in the soil samples was determined with the Tyrin's titrimetric wet combustion method using dichromate (K₂Cr₂O₇) with external heating, followed by titration with ferrous ammonium sulphate (Mohr's salt). In our study the 0–30 cm layer of soil was analyzed divided into 3 sub-layers (0–10 cm, 10–20 cm and 20–30 cm). Hot-water extractable C (HWC) was determined by adapting the procedures of Ghani et al. (2003). A previously published protocol (Cambardella and Elliott, 1993; Martinez-Mena et al., 2012) was used to obtain particulate organic matter (POC). The data on the SOC, HWC, POC and MOC were statistically assessed using the ANOVA on a significance level of $\alpha = 0.05$, and the LSD test was used for individual comparisons of the treatments' means. The data were statistically processed by using the program STATISTICA series 12.6.

RESULTS AND DISCUSSION

Comparison of different land use systems reveals that the highest content of SOC was in the grassland and the lowest in the unfertilized 2-year rotation. Significantly higher SOC content was obtained in samples taken in May (Table 1). Lowest SOC values obtained in the arable soils could be related to mineralization, which is faster on arable soils, whereas non-agricultural soil favors the accumulation of OM (McLauchan et al., 2006). Molnar et al. (2003) presented analyses from 1991 where 12.12 g kg⁻¹ of SOC was found in N2, which suggests that continuous SOC decline, as a lack of the external inputs, is not sufficient to provide biomass for C stabilization. With the increasing soil depth, SOC decrease was more pronounced in grassland and oak forest where C accumulated in the top soil. The opposite distribution of SOC in the soil profile was found at the S3 where manure was applied. Many studies confirmed that the

amount of crop residues and farmyard manure are responsible for SOC content change (Van Wesemael et al., 2010).

Table 1. Soil organic carbon content in different land use systems (g kg⁻¹)

Sam- pling time	Depth (cm) (De)	Land use (Lu)						Average De	Average St
		MO	N2	D2	S3	UG	OF		
May	0–10	15.34±0.1	11.10±0.1	14.30±0.0	15.94±0.1	30.34±0.43	28.37±0.3	19.23	17.09 ^a
	10–20	14.48±0.2	11.06±0.0	14.01±0.1	17.38±0.2	25.75±0.53	19.88±0.1	17.04	
	20–30	14.08±0.2	11.06±0.0	13.83±0.0	17.79±0.2	21.33±0.58	19.30±0.6	16.23	
Average Lu/St		14.63	11.07	14.04	17.03	25.80	22.51		
October	0–10	14.42±0.1	8.84±0.0	13.37±0.0	15.05±0.1	29.36±0.32	25.99±0.4	17.83	15.92 ^b
	10–20	11.92±0.1	8.78±0.1	13.35±0.0	14.76±0.2	22.15±0.36	21.45±0.4	15.40	
	20–30	12.62±0.3	8.37±0.1	12.62±0.0	14.47±0.0	22.42±0.12	16.74±0.3	14.54	
Average Lu/St		12.98	8.66	13.18	14.76	24.64	21.39		
Average Lu/De		14.88	9.97	13.83	15.49	29.85	27.18	18.55 ^a	
Average Lu/De		13.20	9.92	13.68	16.07	23.95	20.66	16.27 ^b	
Average Lu		13.35	9.71	13.22	21.87	21.87	18.02	15.34 ^c	
Average Lu		13.80^D	9.86^E	13.57^D	17.81^C	25.22^A	21.95^B		

Lu – land use; De – Depth (cm); St – Sampling time; ^{ABC} Data followed by the same capital letter within a row do not differ significantly at the $P \leq 0.05$ level; ^{abc} Data followed by the same capital letter within a column do not differ significantly at the $P \leq 0.05$ level.

The average HWC content for different land use systems ranged from 180 mg kg⁻¹ to 1,454 mg kg⁻¹ (Table 2). With the increased depth the content of HWC in all land use systems slightly decreased. Leinweber et al. (1995) found 430–650 mg kg⁻¹ HWC in Bad Lauchstädt, while Sparling et al. (1998) determined HWC content which is comparative with our results. Chen et al. (2009) reported mean values of HWC in Cambisol, at a depth of 0–15 cm was 375 mg kg⁻¹, and at a depth of 15–30 cm it amounted to 243 mg kg⁻¹. The highest average content of HWC was found in samples taken from forest (860 mg kg⁻¹), while the lowest content was measured in N2 (231 mg kg⁻¹). We assumed that in the unfertilized maize rotation with lowest SOC small amount of labile organic SOC is produced and simultaneously stabilized with clay and CaCO₃ that prevent from further decline of SOC. Bouajila and Gallai (2008) also found less HWC content in soils with a higher content of CaCO₃. Significant variability was found among cropping systems and depth compared to sampling time. Leinweber et al. (1995) reported larger amounts HWC measured at the end of the growing season due to easily decomposable mucilage created by microorganisms living in the rhizosphere. The increase of labile HWC fractions in maize monoculture compared with the arable land use systems is associated with more efficient utilization of nutrients from fertilizers and transformation of plant residues. Janzen et al. (1992) also found high content of labile SOC in continuous

monoculture on Chernozem in Canada. Manure application has influenced the HWC content compared to maize fertilized and unfertilized 2-year rotation and by increased microbial activity. According to Šimon (2008) single organic manuring did not increase the HWC significantly as compared to the single NPK variant but increased the HWC content significantly in comparison with the control. These findings also support the fact that the manure application is more efficient with addition of NPK fertilizers (Blair et al., 2006). The highest distribution of HWC in total SOC was measured in the maize monoculture and it is attributed to the long-term production of large amounts of crop residues and presence of a large number of weeds (e.g. *Sorghum halepense*). Accordingly, increase or decrease in total biomass of the specific cropping systems, could contribute to soil carbon allocation through the soil profile.

Table 2. Hot water extractable carbon (HWC) in land use systems (mg kg⁻¹)

Sampling time	Depth (cm) (De)	Land use (Lu)						Average De	Average St
		MO	N2	D2	S3	UG	OF		
May	0–10	528	289	406	497	1121	1454	716	598 ^A
	10–20	441	325	392	582	859	881	580	
	20–30	459	282	410	509	707	622	498	
Average Lu/St		476^{bc}	299^c	402^{bc}	529^b	895^a	986^a		
October	0–10	1256	180	360	451	968	1181	733	599 ^A
	10–20	1160	192	530	447	645	641	602	
	20–30	992	115	424	371	489	383	462	
Average Lu/St		1136^a	162^d	438^c	423^c	701^b	735^b		
Average Lu/De		892	234	383	474	1045	1317	724	
		800	258	461	515	752	761	591	
		725	199	417	440	598	503	481	
Average Lu		806^A	231^C	420^B	477^B	800^A	860^A		

Lu – land use; De – Depth (cm); St – Sampling time; ^{ABC/abc} Data followed by the same letter within a row or a column do not differ significantly at the P ≤ 0.05.

Mineral-associated organic carbon (MOC) is considered an organic material difficult for microbial decomposition and represents the part of SOC which is commonly related to particle dimension composition (Table 3). Due to this, highest SOC in samples resulted with the highest MOC. Content of MOC is more stable C fraction than POC and positively correlated with clay content as clay minerals have a certain capacity to make complex with SOC (Mikutta et al., 2006). Comparing the different land use systems, non-agricultural soil samples were significantly higher in MOC content compared to arable land use (Table 3). Accordingly, changes in SOC contents induced by the land use are primarily caused by changes in the mineral associated SOC pool (John et al., 2005). Samples taken in May had a lower content of MOC compared to soil

samples from October. This increase derived from non agricultural samples and can be attributed to soil organic matter chemical composition and straight of connection with the clay (Leifeld and Kögel-Knabner, 2005). Content of MOC had no clear pattern of change with the increasing soil depth. The differences are related to soil bulk density and content of the total SOC and tillage. The application of manure in S3 was significantly higher in MOC content than in 2-year rotations but not higher than MO, indicating that C from manure was mineralized and enriched POC fraction.

Table 3. Content of mineral-associated organic carbon (MOC) and particulate organic carbon (POC) in the soil of different land use systems (g kg⁻¹)

C-fractions	Sam-pling time	Depth (cm) De	Land use systems (Lu)					Ave- rage De	Ave- rage St	
			MO	N2	D2	S3	UG			OF
MOC	May	0–10	16.70±0.3	15.81±0.3	13.71±0.1	20.21±0.8	24.31±0.1	25.41±0.2	19.36	18.69 ^B
		10–20	18.48±0.2	16.54±0.3	15.83±0.3	17.88±0.5	22.37±0.1	14.99±0.1	17.68	
		20–30	19.00±0.3	16.67±0.2	14.47±0.2	21.62±0.4	20.87±0.7	21.56±0.5	19.03	
		St/De	18.06	16.34	14.67	19.91	22.51	20.65		
	October	0–10	23.32±0.4	12.65±0.1	17.30±0.2	18.32±0.5	29.48±0.2	35.87±0.1	22.82	21.49 ^A
		10–20	17.46±0.3	15.45±0.2	16.46±0.2	19.74±0.2	33.48±0.1	26.91±0.3	21.58	
		20–30	19.26±0.2	14.67±0.2	15.21±0.4	18.33±0.3	27.94±0.1	24.89±0.3	20.05	
		St/De	20.01	14.26	16.32	18.80	30.30	29.22		
	MOC (Average) Lu			19.03^b	15.30^c	15.49^c	19.35^b	26.40^a	24.93^a	
POC	May	0–10	2.55±0.7	1.29±0.1	2.37±0.2	2.47±0.5	9.82±1.4	8.91±0.7	4.57	3.77 ^A
		10–20	2.58±0.2	1.17±0.3	2.20±0.3	3.37±0.6	5.82±2.8	7.27±2.5	3.74	
		20–30	3.16±0.6	1.17±0.2	1.95±0.3	3.13±0.7	5.93±3.7	2.62±0.3	2.99	
		St/De	2.76	1.21	2.17	2.99	7.19	6.27		
	October	0–10	3.39±0.8	1.21±0.2	2.40±0.8	3.32±1.0	9.44±1.2	11.84±0.0	5.27	3.93 ^A
		10–20	2.40±0.6	1.23±0.1	2.49±0.6	2.54±0.1	6.73±0.8	7.76±1.1	3.86	
		20–30	2.36±0.1	1.31±0.2	2.37±0.3	2.83±0.2	3.50±0.1	3.51±0.3	2.65	
		St/De	2.72	1.25	2.42	2.89	2.90	6.56		
	POC (Average) Lu			2.74^b	2.23^c	2.29^b	2.94^b	5.04^a	6.41^a	

Lu – land use; De – Depth (cm); St – Sampling time; ^{ABC/abc} Data followed by the same letter within a row or a column do not differ significantly at the P ≤ 0.05

The highest content of POC was found in the non-agricultural land use systems, while the lowest contents were measured in N2 soil samples (Table 3). In our study statistical differences of the soil POC among two sampling periods were not observed. Crop rotation had no effect on POC, however fertilization significantly affected the content of POC. The plot where mineral N was omitted had the lowest content of POC which indicates a positive role of N addition to the formation of POC. The surface layer in grassland and oak

forest were highest in POC due to the presence of fresh OM associated with soil particles and slower decomposition. According to Šeremešić et al. (2013) non-agricultural soils are composed of >30% macroaggregates compared to the <5% macroaggregates in arable soils. Given that the content of POC is related to the macroaggregates, we attributed highest POC content in forest and grassland samples to the better structural properties and better conditions for the soil aggregation. Likewise, the presence of hydrophobic substances in the non-agricultural soils coats the aggregates and slows the entry of water into solum and prevents their impairment (Blair et al., 2006). Changes in organic C by land use occurred mainly in the fraction of POM, however differences in MOC could be SOC background coupled with long-term soil tillage (De Figueiredo et al., 2010). The non-agricultural soil showed highest ratio of POC in SOC >20%, followed with the fertilized plots, and lower ratio was observed at unfertilized plots (6.58–7.66%). Besides, POC concentration was lower in arable soil compared with forest and grassland, reflecting the tillage activities that resulted with fast decomposition of easily available organic matter (Sandén et al., 2017).

CONCLUSION

The present study illustrates differences in SOC fractions concentration of the investigated land use systems. The highest values of carbon soluble in hot water were obtained on samples from non-agricultural soil and lowest level was found in the unfertilized soil. Arable soils had lower POC/MOC ration than grassland and forest indicating lower amount of labile carbon and potential for significant loss of OM in arable soils. This demonstrated substantial inflow and stabilization of the fresh OM in non-agricultural soils. Accordingly, management practices have a significant role in carbon transformation and fertilization has a significant role in maintenance and preservation of soil organic carbon.

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ФРАКЦИЈЕ ОРГАНСКОГ УГЉЕНИКА У РАЗЛИЧИТИМ НАЧИНИМА КОРИШЋЕЊА ЗЕМЉИШТА НА ЧЕРНОЗЕМУ

Срђан И. ШЕРЕМЕШИЋ¹, Љиљана М. НЕШИЋ¹,
Владимир И. ЋИРИЋ¹, Јовица Р. ВАСИН², Ивица Г. ЂАЛОВИЋ²,
Јелена Б. МАРИНКОВИЋ², Бојан Ђ. ВОЈНОВ¹

¹ Универзитет у Новом Саду, Пољопривредни факултет,
Трг Д. Обрадовића 8, Нови Сад 21000, Србија
² Институт за ратарство и повртарство,
Максима Горког 30, Нови Сад 21000, Србија

РЕЗИМЕ: Однос између фракција угљеника у земљишту испитиван је у узорцима земљишта пореклом са различитих начина коришћења: обрадиво земљиште, травњак и храстова шума. Травњак и храстова шума имали су већи садржај органског угљеника (SOC), угљеника растворљивог у топлој води (HWC), честичног органског угљеника (POC) у односу на ораницу. Однос POC/MOC је био најмањи у обрадивом земљишту, што указује на мању количину лабилног угљеника услед интензивнијих процеса разградње. Вредности POC расту са већим укупним SOC, што указује да очување органске материје зависи од обнављања лабилних фракција. Наши резултати су показали да је ђубрење имало значајну улогу у стабилизацији угљеника у земљишту, док је плодоред имао мањи утицај. Добијени резултати могу допринети бољем разумевању улоге лабилне органске материје у чернозему, те на тај начин помоћи у одабиру система ратарења за управљање и очување SOC.

КЉУЧНЕ РЕЧИ: системи коришћења земљишта, органски угљеник у земљишту, угљеник везан у минералима, честични органски угљеник