FOLIA OECOLOGICA – vol. 42, no. 1 (2015). ISSN 1336-5266

The assessment of the soil organic matter of different ecosystems according to parameters of carbon

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Abstract

Tobiašová, E., Dębska, B., Drag, M., 2015. The assessment of the soil organic matter of different ecosystems according to parameters of carbon. *Folia Oecologica*, 42: 46–53.

In this study, the differences in the assessment of the soil organic matter (SOM) of 8 soils (Eutric Fluvisol, Mollic Fluvisol, Haplic Chernozem, Haplic Luvisol, Eutric Cambisol, Rendzic Leptosol, Eutric Regosol, and Dystric Planosol) of different ecosystems (forest, meadow, urban, and agro-ecosystem) in Slovakia were compared. The quantity and quality of the SOM was assessed through the parameters of carbon in the total volume of soil and in the fractions of soil aggregates. The significant differences in the parameters of carbon between the ecosystems are more visible in the case of its assessment in the soil aggregates than in the total volume of soil and the results are influenced by the nature of SOM stabilization. The highest contents of total organic carbon (TOC) and labile carbon (C_L) in the total volume of soil were in the forest ecosystem, but more significant differences in the contents of TOC and C_L between the other ecosystems were determined only in the soil aggregates. The urban ecosystem > meadow ecosystem > agro-ecosystem followed then, and the most stabilized carbon was in the urban ecosystem. TOC and C_L had higher portions in larger fractions of aggregates (>2 mm) that had the highest proportion in the meadow ecosystems.

Key words

ecosystem, soil organic matter, water-resistant macro-aggregates

Introduction

Total organic carbon (TOC) is not sufficient parameter in a short-term dynamics of the soil organic matter (SOM) (Hungate et al., 1996), because the changes in this parameter are usually the result of plant growing or used method of its determination. Actual changes in the values of this parameter can be observed at least after two decades, but in the case of labile carbon content (C_L) and other more sensitive parameters (Blair et al., 1995), these changes are possible to be monitored in a shorter period (Tisdall and Oades, 1982). Labile fractions of SOM are important because they regulate ecosystem productivity in a short-term period and are influenced by the land use (Jandl and Sollins, 1997; McLauchlan and Hobbie, 2004; Tobiašová, 2010). Because of the positive correlation between C_L and TOC (Powlson et al., 1987), through the C_L we can also predict the other changes in SOM. They were assessed to this time in the total volume of soil. The SOM is stabilized also through the formation of soil aggregates (Six et al., 2001; Tobiašová, 2011), but the mechanisms of aggregate dynamics (Tisdall and Oades, 1982) are different. They depend not only on the soil, but also on the ecosystem, the stability of which depends mostly on the quantity and quality of SOM (Doran and Parkin, 1994). Therefore, the objectives of this study were as follows: i) to show on the differences in assessment of the quantity and quality of SOM in the total volume of soil and in the fractions of water-resistant aggregates, ii) to assess the differences in SOM of selected ecosystems, and iii) in SOM of the fractions of water-resistant macro-aggregates.

Materials and methods

The experiment includes four types of ecosystems, which present the different land use (forest, meadow, urban, and agro-ecosystem) of eight soil types (Eutric Fluvisol, Mollic Fluvisol, Haplic Chernozem, Haplic Luvisol, Eutric Cambisol, Rendzic Leptosol, Eutric Regosol, and Dystric Planosol) (WRB, 2007).

Characteristics of the territory

Šaľa (Eutric Fluvisol), Horná Kráľová (Mollic Fluvisol, Haplic Chernozem), Veľké Ripňany (Eutric Regosol), and Ludanice (Haplic Luvisol) are located in the Danube Basin with neogene formation, which are covered with younger quaternary rocks (loess and loess loamy) and brackish sediments (gravels, sands, and clays) (Pristaš et al., 2000). The original vegetation consists mostly of oak-ash-elm-alder forests and along the Vah River, willow-poplar forests are preserved. The average annual temperature of the studied area is 9.3 to 9.8 °C and the average rainfall per year is 568 to 607 mm (Korec et al., 1997). Pružina (Eutric Cambisol, Rendzic Leptosol) is located in the north-eastern foothills of the highest mountain Strážov, in the valley of Pružinka River. A substantial part of the mountain consists of nappe-folded mesozoic complexes with highly variable rock resistance (Buday et al., 1967). The original vegetation consists mostly of beech and oak forests blended with pine tree and in a higher altitude, pine forest with fir and with higher portion of conifers. The average annual temperature of studied area is 8.2 °C, and the average rainfall per year is 718 mm (Korec et al., 1997). Hrachovo (Dystric Planosol) is located in Matra – Slaná area with weathered non-carbonate rocks (crystalline volcanic rock) (Buday et al., 1967). The average annual temperature of studied area is 8.8 °C, and the average rainfall per year is 640 mm (Korec et al., 1997).

Soil samples and analytical methods used

The soil samples for determination of the physical and chemical characteristics were collected in the spring in three replicates to a depth of 0.3 m in four ecosystems of eight soil types. The basic chemical and physical properties of the soils are characterised in the Table 1. All samples for the determination of physical properties were dried in a constant-temperature room of 25 ± 2 °C. The soil samples for determination of the composition of soil aggregates were after drying divided by the wet sieve to size fractions of water-resistant aggregates. The particle size distribution was determined after dissolution of $CaCO_3$ with 2 mol dm^{-3} HCl and decomposition of the organic matter with 30% H_2O_2. After repeated washing, samples were dispersed using $Na(PO_3)_6$. Silt, sand and clay fractions were determined according to the pipette method. To determine the chemical properties, the soil samples were dried and ground. The total organic carbon (TOC) was determined by wet combustion (Orlov and Grishina, 1981) and the labile carbon (C_L) by $KMnO_4$ oxidation (Loginov et al., 1987). The non-labile carbon (C_{NL}), lability of carbon (L_C), index of carbon lability (LI_C), carbon pool index (CMI), and carbon management index (CMI) were calculated according to equations 1–5 (Blair et al., 1995).

$$C_{NL} = TOC - C_L \text{ (mg kg}^{-1}\text{)} \quad (1)$$

$$L_C = \frac{C_L}{C_{NL}} \quad (2)$$

$$LI_C = \frac{L_C \text{ in variant}}{L_C \text{in control}} \quad (3)$$

$$CPI = \frac{TOC \text{ in variant}}{TOC \text{ in control}} \quad (4)$$

$$CMI = LI_C \times CPI \times 100 \quad (5)$$

The soil pH was measured potentiometrically in a supernatant suspension of a 1 : 2.5 soil: liquid mixture. The liquid is 1 mol dm^{-3} KCl (pH/KCl). The cation exchange capacity (CEC) was determined according to Jackson (2005).

The obtained data were analysed using Statgraphic Plus statistical software. A multifactor anova model was used for individual treatment comparisons at $P < 0.05$, with separation of the means by LSD multiple-range test.

Results and discussion

The content of total organic carbon (TOC) in a total volume of soil was significantly higher in the forest ecosystem (Table 2). This is the natural forest and its soil has almost the same properties like the soil of undisturbed area, the soil of which is according to Doran and Parkin (1994) considered the soil of the highest quality. One of the reasons is the fact that in the natural ecosystems all plant residues remain, so that there is not the loss from the soil by this way. The content of the labile carbon (C_L) is more sensitive parameter than TOC. The C_L had also the highest proportion in the forest ecosystems, in which the values of soil pH are usually lower in comparison with other ecosystems, and in the case of a lower soil pH, more carbon is in an active form (Tobiašová, 2010). In the forest ecosystem, the intensity of mixing of the organic and mineral compounds is also limited, which is one of the factors of stabilization of the organic substances in the soil. This fact is confirmed by the values of the lability of carbon (L_C).

Table 1. Chemical and physical properties of the soils in different ecosystems

Soil type	Ecosystem	pH/KCl	TOC	CEC	Sand	Silt	Clay
			(%)	(mmol kg^{-1})		(%)	
EF	FO	7.28	2.955	392.73	46.25	42.46	11.29
	ME	7.28	2.113	303.43	41.20	43.28	15.52
	UR	6.92	1.936	347.18	32.00	43.33	24.67
	AG	7.28	1.546	401.56	30.26	51.59	18.15
MF	FO	6.14	1.496	321.83	54.43	35.13	10.44
	ME	7.39	1.144	400.17	44.64	31.20	24.16
	UR	7.50	1.766	401.23	27.11	52.33	20.56
	AG	6.77	2.095	378.34	46.69	37.08	16.23
HC	FO	6.56	2.165	324.80	53.05	32.34	14.61
	ME	7.98	2.013	399.90	45.49	39.01	15.50
	UR	7.27	1.822	400.17	38.03	49.75	12.22
	AG	7.10	1.762	330.20	32.43	50.13	17.44
HL	FO	5.44	2.662	165.42	26.70	59.46	13.84
	ME	5.91	1.806	229.22	24.75	59.23	16.02
	UR	6.98	2.026	257.11	40.05	46.86	13.09
	AG	6.00	1.592	174.34	18.57	52.55	18.88
EC	FO	6.16	3.076	319.24	28.97	53.49	17.54
	ME	7.01	2.040	326.96	59.83	28.38	11.79
	UR	6.94	2.370	321.64	35.58	48.14	16.28
	AG	6.36	1.222	312.61	30.24	50.88	10.65
RL	FO	7.25	3.168	403.57	43.58	41.11	15.31
	ME	7.36	1.765	403.23	43.41	37.18	19.41
	UR	7.26	1.158	402.57	41.42	40.08	18.50
	AG	7.04	1.312	384.06	33.99	50.48	15.53
ER	FO	4.87	1.136	278.40	28.72	61.63	9.65
	ME	6.06	1.003	244.80	36.84	50.92	12.24
	UR	5.97	1.208	254.00	34.28	54.78	10.94
	AG	6.05	1.141	300.80	43.60	41.22	15.18
DP	FO	4.23	1.725	100.37	25.24	58.01	16.75
	ME	5.13	0.977	140.43	47.88	36.95	15.17
	UR	4.34	0.773	153.38	43.90	26.23	29.87
	AG	4.54	1.162	163.21	30.37	43.64	25.99

EF, Eutric Fluvisol; MF, Mollic Fluvisol; HC, Haplic Chernozem; HL, Haplic Luvisols; EC, Eutric Cambisol; RL, Rendzic Leptosol; ER, Eutric Regosol; DP, Dystric Planosol; FO, forest ecosystem; ME, meadow ecosystem; UR, urban ecosystem; AG, agro-ecosystem; TOC, total organic carbon; CEC, cation exchange capacity.

However, more significant differences in these parameters between the ecosystems take effect in the case, if we consider only the organic matter bound in the soil aggregates, because the losses of soil organic carbon are determined primarily by the destruction of macro-aggregates (Elliott, 1986). In the case of incorporated carbon in the aggregates (Table 3), the significant differences were observed also between the other ecosystems. In the case of evaluation of the TOC and C_L in a total volume of the soil, the values in the meadow and urban ecosystems are nearly the same, but if we evaluate their contents only in the fractions of water-resistant macro-aggregates, the differences are statistically significant. Second highest contents of the TOC and C_L, after forest ecosystem, were in the urban ecosystem. In the case of both ecosystems, meadow and urban, the vegetation cover were grasses, therefore the differences in their contents in a total volume of the soil were not more significant. The source of organic matter in the meadow ecosystem, compared to the for-

Table 2. Statistical evaluation of carbon parameters in soil to a depth of 0.3 m

Factor	TOC (mg kg^{-1})	C_L (mg kg^{-1})	C_{NL} (mg kg^{-1})	L_C	LI_C	CPI	CMI
Ecosystem							
FO	25,267b	3,549b	21,719b	0.181b	–	–	–
ME	17,086a	1,923a	15,163a	0.127a	77.48a	0.686a	51.67a
AG	14,918a	1,939a	12,979a	0.153ab	96.49a	0.655a	60.30a
UR	16,695a	1,869a	14,801a	0.134a	87.22a	0.691a	56.00a
Soil type							
EF	18,648b	2,247b	16,401b	0.137abc	90.45bcd	0.631ab	57.12ab
MF	16,683b	1,862ab	14,821b	0.121ab	61.03ab	1.115c	73.54b
HC	18,658b	1,944ab	16,713b	0.117ab	37.82a	0.862bc	32.50a
HL	18,078b	2,428b	15,651b	0.155bc	117.97de	0.679ab	80.38b
EC	18,772b	1,899ab	16,806b	0.121ab	81.53bc	0.610ab	48.28ab
RL	14,115ab	1,173a	12,943ab	0.094a	68.50ab	0.446a	29.18a
ER	15,201ab	2,312b	12,889ab	0.181c	110.99cde	0.512a	56.56ab
DP	9,707a	1,418ab	8,288a	0.177c	128.20e	0.563a	70.34b

FO, forest ecosystem; ME, meadow ecosystem; AG, agro-ecosystem; UR, urban ecosystem; EF, Eutric Fluvisol; MF, Mollic Fluvisol; HC, Haplic Chernozem; HL, Haplic Luvisols; EC, Eutric Cambisol; RL, Rendzic Leptosol; ER, Eutric Regosol; DP, Dystric Planosol; TOC, total organic carbon; C_L, labile carbon; C_{NL}, non-labile carbon; L_C, lability of carbon; LI_C, index of carbon lability; CPI, carbon pool index; CMI, carbon management index; different letters (a, b, c, d, and e) between the factors show statistically significant differences ($P < 0.05$) – LSD test.

est ecosystem, comes mainly from the underground biomass. This is not only visible rich root system, but the plants during their life produced a huge amount of root exudates. These substances are mainly polysaccharide nature, it means they represent the labile fraction of organic matter, which is an immediate source of the carbon and energy for soil microflora (Huang and Schoenau, 1996) and the secondary can support the growth of microbial population. In these ecosystems, larger aggregates (>3 mm) had significantly higher proportion. The formation of these size fractions is supported mainly by the roots of plants, which have the largest proportion in the grass ecosystems (Table 4). Soils of urban ecosystems are more compact (Puskás and Farsang, 2009), and this causes the inhibition of microbial activity. The root exudates, which are the main source of labile forms of carbon in the grass ecosystems (Hütsch et al., 2002) are therefore in the soil of urban ecosystem less exploited by the microorganisms. This organic matter is stabilized mainly physically through its incorporation into the soil aggregates, in which is protected by inhibiting against carbon oxidation (Six et al., 1998; Hernanz et al., 2002).

The lowest carbon contents in a total volume of the soil as well as in the soil aggregates were in the agro-ecosystem, in which the inputs of organic matter into the soil are the lowest (Tobiašová, 2010; Tobiašová, 2014) and also the intensity of oxidation of the organic matter is the highest. The reason is mainly mechanical destruction of aggregates (Šimanský et al., 2008), because the carbon inside of these aggregates is physically protected (Elliot, 1986; Tobiašová, 2011). The part of the year is a soil in the agro-ecosystem without a vegetation cover, which is a next reason of the low content of carbon (Cheng et al., 2003).

In the larger fractions of water-resistant macro-aggregates (>3 mm), higher amounts of TOC and C_L were included, but the organic matter in them subjected more intensive oxidation (Sohi et al., 2001). These larger macro-aggregates had significantly higher proportion in the grass ecosystems. On the other hand, the content of carbon in smaller aggregates was lower, but better stabilized; however the increased proportion of smaller size fractions of aggregates is characteristic for degraded soils (Whalen and Chang, 2002). Smaller fractions of macro-aggregates had higher proportion in the agro-ecosystem.

However, if we compare the quantity and stability of SOM of the individual ecosystems with the forest ecosystem, we can observe the changes that occur in the studied ecosystems. Suitable parameters for tracking of these changes are parameters such as lability of carbon (LI_C), carbon pool index (CPI), and carbon management index (CMI) that were described by Blair et al. (1995). In the case of these parameters, more significant differences were recorded in the soil aggregates than in a total volume of the soil. The CPI values indicate the highest contents of organic matter in the aggregates of urban ecosystem while the values of LI_C indicate the highest lability of this organic matter. Parameter of

CMI also shows on the highest changes. The lower is the value of CPI, the higher is the loss of organic matter from the soil (Blair et al., 1995; Conteh et al., 1998). This fact also shows on a great importance of the physical stabilization of carbon as the prevention from its loss from the soil. It follows that a higher proportion of labile forms of organic matter does not mean its more rapid loss from the soil. The increase of CMI values is not the result of formation of the organic compounds as a result of the increased annual input of carbon, but as a result of the changes in a quality of SOM, especially C:N ratio, contents of lignin, cellulose, hemicellulose, proteins, and carbohydrates that affect the lability of carbon to oxidation of $KMnO_4$ (Tirol-Padre and Ladha, 2004). The LI_C were significantly higher in the agro-ecosystem than in the meadow ecosystem, but the values of CMI were fairly balanced. In the agro-ecosystem, besides of the primary source of organic matter of the plant residues, the secondary source was farmyard manure. It increased the lability of organic matter (Kalbitz et al., 2003); therefore the values of LI_C were higher in the agro-ecosystem than in the meadow ecosystem. Farmyard manure also stimulates biological fixation of N_2 in the soil (Ladha et al., 1989), which can cause the increase of the values of CMI. The reasons of increased values of CMI in the agro-ecosystem are moreover leguminous plants (Vieira et al., 2007).

In the case of soil type, the highest content of TOC was in the Eutric Cambisol and the lowest in the Dystric Planosol in a total volume of the soil (Table 2) as well as in the soil aggregates (Table 3). The tendency was nearly the same also in the case of other soil types. However, if we compare the other parameters of carbon the values are different in the case of a total volume of the soil, but higher differences are in the case of soil aggregates. More significant differences are observed, if we make the comparisons to the control, it means against to the soil of the forest ecosystem. The LI_C was the lowest in Haplic Chernozem in a total volume of the soil as well as in the soil aggregates. In this soil the labile components of organic matter are chemically and also physically stabilized. On the other hand, the highest values of LI_C were in Dystric Planosol and Haplic Luvisol in a total volume of the soil as well as in the soil

Table 3. Statistical evaluation of carbon parameters in water-resistant aggregates

Factor	TOC (mg kg^{-1})	C_L (mg kg^{-1})	C_{NL} (mg kg^{-1})	L_C	LI_C	CPI	CMI
Ecosystem							
FO	27,889c	3,775c	24,114c	0.159c	–	–	–
ME	18,125ab	2,070a	16,056ab	0.123a	81.14a	0.779a	65.93a
AG	16,956a	2,066a	14,889a	0.142b	91.83ab	0.797a	75.68a
UR	20,607b	2,782b	17,826b	0.152bc	99.45b	1.023b	123.18b
Soil type							
EF	19,435ab	2,596abc	16,839b	0.152bcd	80.47ab	0.790c	64.49ab
MF	20,109b	1,959a	18,151bc	0.105a	83.43b	1.145d	101.08bc
HC	24,967b	3,277c	21,690cd	0.147bc	63.56a	0.689bc	43.28a
HL	19,726b	2,834bc	16,891b	0.163cde	121.81d	1.052d	129.48c
EC	25,636b	3,203bc	22,433d	0.138b	86.57bc	0.504ab	44.32a
RL	21,481ab	2,038a	19,443bcd	0.096a	67.16ab	0.324a	19.99a
ER	20,405b	2,961bc	17,444b	0.173de	105.65cd	0.480ab	49.98a
DP	15,395a	2,516ab	12,880a	0.178e	117.80d	1.946e	253.50d
Fraction of water-resistant macro-aggregates (mm)							
> 5	18,762b	2,462b	16,300b	0.145a	93.24a	0.774a	82.26a
5–3	19,077b	2,454b	16,623b	0.144a	89.18a	0.843a	86.84a
3–2	19,133b	2,374ab	16,759b	0.139a	79.76a	0.871a	83.09a
2-1	19,555b	2,446b	17,108b	0.141a	94.16a	0.910a	102.84a
1–0,5	18,483ab	2,200ab	16,283ab	0.135a	92.19a	0.904a	84.92a
0.5–0.25	16,367a	1,898a	14,469a	0.130a	96.32a	0.895a	89.64a

FO, forest ecosystem; ME, meadow ecosystem; AG, agro-ecosystem; UR, urban ecosystem; EF, Eutric Fluvisol; MF, Mollic Fluvisol; HC, Haplic Chernozem; HL, Haplic Luvisols; EC, Eutric Cambisol; RL, Rendzic Leptosol; ER, Eutric Regosol; DP, Dystric Planosol; TOC, total organic carbon; C_L, labile carbon; C_{NL}, non-labile carbon; L_C, lability of carbon; LI_C, index of carbon lability; CPI, carbon pool index; CMI, carbon management index; different letters (a, b, c, d, and e) between the factors show statistically significant differences ($P < 0.05$) – LSD test.

Table 4. Statistical evaluation of % proportion of size fractions of water-resistant macro-aggregates in soil to a depth of 0.3 m

Factor	>5 mm	3–5 mm	2–3 mm	1–2 mm	0.5–1 mm	0.25–0.5 mm
				(%)		
Ecosystem						
FO	11.01ab	14.43ab	18.13a	18.06a	13.57a	9.49a
ME	16.92b	17.72b	17.92a	17.37a	10.69a	8.81a
AG	3.65a	9.02a	15.13a	19.48a	20.06b	15.37a
UR	14.61b	17.35b	18.47a	19.05a	11.70a	9.33a
Soil type						
EF	29.01b	17.88bc	14.86a	14.29ab	10.90ab	5.55a
MF	5.83a	10.60ab	13.04a	17.35abc	17.33b	18.62c
HC	5.75a	13.36abc	22.26b	21.75c	16.03ab	13.24abc
HL	11.67a	12.02abc	11.32a	12.15a	17.14ab	15.84bc
EC	14.08a	18.45bc	20.61b	20.10bc	10.68a	5.38a
RL	12.45a	18.90c	22.82b	19.21abc	10.82ab	6.52ab
ER	4.34a	8.86a	13.74a	18.54abc	16.18ab	14.28abc
DP	9.26a	16.96abc	20.64b	24.52c	12.94ab	6.56ab

FO, forest ecosystem; ME, meadow ecosystem; AG, agro-ecosystem; UR, urban ecosystem; EF, Eutric Fluvisol; MF, Mollic Fluvisol; HC, Haplic Chernozem; HL, Haplic Luvisols; EC, Eutric Cambisol; RL, Rendzic Leptosol; ER, Eutric Regosol; DP, Dystric Planosol; different letters (a, b, c, d, and e) between the factors show statistically significant differences ($P < 0.05$) – LSD test.

aggregates, and not in the Mollic Fluvisol and Rendzic Leptosol as we would expect, because the contents of C_L in these soils were low. The lowest contents of C_L in a total volume of the soil were in the Rendzic Leptosol, which assumes mainly the chemical stabilization by the effect of carbonates while the lowest contents of C_L were in the soil aggregates of Mollic Fluvisol, which assumes mainly the physical stabilization inside of soil aggregates and the dominance of stabilized humus substances. This fact is confirmed with the highest values of CMI in a total volume of the soil in the case of soils (Dystric Planosol, Haplic Luvisols, Mollic Fluvisol), that are characterized by an alternating of the dry and wet periods, which have positive influence on the formation of soil aggregates (Bravo-Garza et al., 2009; Šimanský et al., 2008) and also the stabilization of humus substances and the formation of stronger links with the mineral proportion of soil (Denef et al., 2002). The next proof can be the lowest CPI values of District Planosol in a total volume of the soil and vice versa the highest values of this parameter in the soil aggregates. It is known that in this soil the majority of organic matter is physically stabilized.

Conclusion

More significant differences in the parameters of carbon between the ecosystems are visible in the case of assessment of the organic matter in soil aggregates than in a total volume of the soil and the results are influenced by the nature of stabilization of the organic matter.

The highest contents of TOC and C_L in a total volume of the soil were in the forest ecosystem, but more significant differences between the other ecosystems were recorded only in their contents in water-resistant macro-aggregates. After the forest ecosystem, the urban > meadow > agro-ecosystem followed, and the most stabilized carbon was in the urban ecosystem.

The TOC and C_L had higher proportions in larger fractions of the macro-aggregates (>2 mm), which had the highest proportion in the meadow ecosystems.

Acknowledgements

This project was supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (No. 1/0124/13 Physical stabilization of organic matter in soils of different ecosystems).

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Received March 24, 2015
Accepted May 21, 2015