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Stability of organic mater of Haplic Chernozem and Haplic Luvisol of different ecosystems

Stabilita organickej hmoty černozeme a hnedozeme rôznych ekosystémov

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Abstract

In this study, the changes in soil organic matter (SOM) and the possibilities of their monitoring in a shorter period of time by means of carbon parameters were followed. The experiment includes four ecosystems (forest, meadow, urban, and agro-ecosystem) on Haplic Chernozem (Močenok, Horná Kráľová, Trnava) and Haplic Luvisol (Ludanice, Veľké Zálužie, Lovce) of different localities. The objectives of this study were assessment of the differences in the stability of soil organic matter in different ecosystems and in soil types using labile forms of carbon and nitrogen, and also with dependence on particle size distribution. The highest contents of total organic carbon (TOC) and labile carbon (C_L) were in a forest ecosystem, but in case of other ecosystems, the differences were determined only in the contents of C_L. After forest ecosystem, the highest content of C_L was in agro-ecosystem > meadow ecosystem > urban ecosystem. Based on parameter of lability of carbon (L_C), the most labile carbon can be evaluated also in the forest ecosystem (0.209) > agro-ecosystem (0.178) > meadow ecosystem (0.119) and urban ecosystem (0.116). In the case of nitrogen, the differences were observed between the soils. Higher contents of NT and N_L were recorded in Haplic Chernozen than in Haplic Luvisol. Contents of TOC ($P < 0.05$; r = -0.480), C_{NL} ($P < 0.05$; r = -0.480), and N_L ($P < 0.01$; r = -0.545) were in a negative correlation with the content of sand fraction. The values of studied parameters in meadow and urban ecosystems were relatively balanced, because in both cases, the vegetation cover were grass, pointing to a significant influence of vegetation on the parameters of SOM.

Key words: ecosystem, Haplic Chernozem, Haplic Luvisol, labile carbon, labile nitrogen

Abstrakt

Práca sa zaoberá štúdiom zmien v pôdnej organickej hmote (SOM) a možnosťami ich sledovania v kratšom časovom intervale prostredníctvom vybraných parametrov uhlíka. Do pokusu boli zahrnuté štyri ekosystémy (lesný, lúčny, urbánny ekosystém a agro-ekosystém) na černozemi (Močenok, Horná Kráľová, Trnava) a hnedozemi (Ludanice, Veľké Zálužie, Lovce) rôznych lokalít. Cieľom práce bolo posúdenie rozdielov v stabilite pôdnej organickej hmoty v rôznych ekosystémoch a pôdnych typoch s využitím labilných foriem uhlíka a dusíka a v závislosti od pôdnej textúry. Najvyššie obsahy TOC aj C_L boli v lesnom ekosystéme, ale medzi ostatnými ekosystémami boli stanovené rozdiely len v obsahoch C_L. Po lesnom ekosystéme bol najvyšší obsah C_L v agro-ekosystéme > lúčnom ekosystéme > urbánnom ekosystéme. Na základe parametra lability uhlíka (L_C) môžeme tiež hodnotiť za najlabilnejší uhlík v lesnom ekosystéme (0,209) > agro-ekosystéme (0,178) > lúčnom ekosystéme (0,119) a urbánnom ekosystéme (0,116). V prípade dusíka boli zaznamenané rozdiely medzi pôdnymi typmi. Vyššie obsahy NT aj N_L boli zaznamenané v černozemi ako v hnedozemi. Obsahy TOC ($P < 0.05$; r = -0.480), C_{NL} ($P < 0.05$; r = -0.483) a N_L ($P < 0.01$; r = -0.545) boli v negatívnej závislosti od obsahu frakcie piesku. Hodnoty sledovaných parametrov v lúčnom a urbánnom ekosystéme boli pomerne vyrovnané, pretože v obidvoch prípadoch boli vegetačným krytom trávy, čo poukazuje na výrazný vplyv vegetácie na parametre SOM.

Kľúčové slová: ekosystém, černozem, labilný uhlík, labilný dusík, hnedozem

Introduction

To maintain the production capacity of the soil it is important to ensure a sufficient supply of soil organic matter (SOM), especially in intensive agricultural land use (Ding et al., 2002). Understanding of dynamics of changes in SOM is a basis for the evaluation of this source (Lal, 2004). Monitoring of changes in the total organic carbon (TOC) is very difficult, mainly because the soil is a huge source of carbon and changes in the short-term experiments are small (Hungate et al., 1996; Peterková et al., 2002). However, the monitoring of these changes is necessary in a shorter period of time, therefore more sensitive parameters such as for example labile forms of carbon and nitrogen are necessary. Labile soil organic carbon is sensitive to the changes in land use (McLauchlan and Hobbie, 2004) in a shorter period of time and is in positive correlation with TOC (Powlson et al., 1987). The quality of soil organic matter depends on its distribution between the labile and recalcitrant fractions. It is assumed that its quality decreases through the processes of decomposition (Rovira and Vallejo, 2002). Properties of labile fractions of SOM are, therefore, more suitable indicator of differences in the soil fertility than the total soil organic matter (Marriott and Wander, 2006). The objectives of this study were follows: i) to asses the differences in the stability of soil organic matter of different ecosystems and ii) soil types with the use of labile forms of carbon and nitrogen, and iii) with dependence on particle size distribution.

Materials and Methods

Experiment includes four ecosystems (forest ecosystem, meadow ecosystem, urban ecosystem, and agro-ecosystem), each located on two soil types (Haplic Chernozem, Haplic Luvisol), which are characterized by theirs specific characteristics (Table 1).

The forest ecosystems were natural forests with human control; the meadow ecosystems were created by man 30 years ago; and the urban ecosystems presented soils of urban landscape (grasses in a town influenced by human activities). The fields in agro-ecosystems were located in different farms under real production conditions

Table 1 Basic chemical and physical properties of soils

Soil type Locality	Ecosystem	pH/KCl	[5]TOC (%)	[6]CEC (mmol.kg^{-1})	Clay	Silt (%)	Sand
Haplic Chernozem Močenok	[1]FO	5.89	2.232	339.91	14.61	32.34	53.05
	[2]ME	7.38	2.210	489.80	15.50	39.01	45.49
	[3]UR	7.44	2.199	491.08	12.22	49.75	38.03
	[4]AG	5.82	2.070	390.22	17.44	50.13	32.43
Haplic Chernozem Horná Kráľová	FO	5.56	2.165	306.00	14.61	32.34	53.05
	ME	7.98	2.013	499.88	15.50	39.01	45.49
	UR	7.27	1.822	500.21	14.80	44.59	40.61
	AG	7.10	1.762	412.75	17.44	50.13	32.43
Haplic Chernozem Trnava	FO	6.97	3.604	449.96	17.43	53.76	28.81
	ME	7.06	2.357	432.88	14.62	64.33	21.05
	UR	7.21	2.108	509.95	14.39	63.61	22.00
	AG	6.23	2.229	336.10	20.19	56.15	23.66
Haplic Luvisol Veľké Zálužie	FO	6.61	1.595	295.08	10.77	23.00	66.23
	ME	7.63	1.577	495.51	12.96	49.47	37.57
	UR	7.84	1.400	489.81	11.44	63.53	25.03
	AG	6.33	0.889	243.29	13.05	27.36	59.59
Haplic Luvisol Ludanice	FO	5.44	2.662	206.78	13.84	59.46	26.70
	ME	5.91	1.806	286.52	16.02	59.23	24.75
	UR	6.98	2.026	421.39	13.09	46.86	40.05
	AG	6.00	1.592	217.93	16.03	49.69	34.28
Haplic Luvisol Veľké Lovce	FO	6.91	3.230	272.39	16.84	53.23	29.93
	ME	7.21	2.009	265.86	21.43	52.11	26.46
	UR	7.57	1.638	499.68	12.01	50.19	37.80
	AG	6.64	1.904	300.83	17.71	55.79	26.50

[1]FO – forest ecosystem, [2]ME – meadow ecosystem, [3]UR – urban ecosystem, [4]AG – agro- ecosystem, [5]TOC – total organic carbon, [6]CEC – cation exchangeable capacity

Characteristics of the territory

Močenok (Haplic Chernozem), Horná Kráľová (Haplic Chernozem), Trnava (Haplic Chernozem), Ludanice (Haplic Luvisol), Veľké Zálužie (Haplic Luvisol), and Veľké Zálužie are located in the Danube basin with neogene strata, covered with younger Quaternary rocks (loess, loess loam) and brackish sediments (gravels, sands, clays) (Pristaš et al., 2000). Natural vegetation consists mostly of oak-ash-elm-alder forests, along the river there are willow-poplar forests. In dry areas of uplands, the dominant forests are oak and oak-hornbeam with the species of steppe vegetation. The vegetation in the agro-ecosystems is given by the crop rotations. The average annual temperatures of the studied areas are 9.3-9.9^{o}C and the average rainfalls per year are 568-607 mm (Korec et al., 1997).

Soil samples and analytical methods used

The soil samples for determination of physical and chemical properties were collected in three replicates to a depth of 0.30 m in spring. The soil samples were dried in a constant-temperature room of 25±2^{o}C and ground. From the physical properties, the particle size distribution was determined according to the pipette method (Fiala et al., 1999). From the chemical properties, the total organic carbon

(TOC) was determined by wet combustion (Orlov and Grišina, 1981), the total nitrogen (NT) was determined by the Kjeldahl method (Bremner, 1960), the labile carbon (C_L) by $KMnO_4$ oxidation (Loginov et al., 1987), and potentially mineralisable nitrogen (N_L) (Standford and Smith, 1978). The parameters of non-labile carbon and nitrogen, and lability of carbon and nitrogen were also calculated (Blair et al., 1995).

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 Tukey multiple-range test. Correlation analysis was used to determine the relationships between the parameters of carbon and nitrogen and particle size distribution. Significant correlation coefficients were tested at $P < 0.05$ and $P < 0.01$.

Results and discussion

The differences in the content of total organic carbon (TOC) were recorded between ecosystems (Table 2). The highest content of TOC was in the forest ecosystem, where the forest litter is dominant. Then there were meadow and urban ecosystems, where the vegetation covers of both ecosystems were grass. In addition to the amount of root biomass, a huge amount of root exudates contribute to its higher content. According to Arshad et al. (2004), meadow ecosystems have high content of carbon and are the potential sink of carbon. Overall in the natural ecosystems, all sources of organic matter remain, but in the agro-ecosystem, part of them is removed by the yield and it is necessary to replace it by the secondary sources, which are the organic fertilizers. In the agro-ecosystem, the lowest content of TOC was recorded. The reasons are more intensive removing of yield biomass, replacement of permanent vegetation to the short-term vegetation, or more intensive tillage. Balesdent et al. (2000) or Six et al. (2002) consider these losses mainly for the losses of physically protected of soil organic carbon. TOC values in agro-ecosystem are moreover the reflection of crops that are cultivated in the studied year; therefore it is not possible to evaluate the changes in the carbon content of less than after 15-20 years. During this time, the crop rotation in the field turns 2-3 times and a part of the organic matter is stabilized and became a part of the soil supply. On the other hand, we have to respond to the changes occurring in the soil in a shorter period; therefore the labile forms of organic matter seem to be more suitable parameters for monitoring of these changes. The highest content of labile carbon (C_L) was also determined in the forest ecosystem (Table 2). In the organic matter of this ecosystem, a large number of labile components are, because it accumulates especially in the upper parts of the soil profile as well as its mixing with the mineral particles is deficient (Arevalo et al., 2009), and thus their concentrations increase, while their stabilization is limited. The second the highest content of C_L, unlike TOC, was in the agro-ecosystem. In this ecosystem, the organic fertilizers are secondary source of organic matter. In this case, it was farmyard manure, which is not only the source of stabile forms of organic matter, but also a huge amount of labile components. Riffaldi et al. (1998) reported, that after the farmyard manure application, labile components were dominant, especially carbohydrates and fatty acids. The lowest contents of C_L were determined in the meadow and urban ecosystems. The main source of labile components of organic matter in the soils, the root exudates are. These are substances of polysaccharide origin, which are immediate source of the energy for heterotrophic microorganisms (Högberg and Read, 2006). According to Cheng et al. (2003), the intensity of decomposition of SOM was about 380% higher compared to soils without plants, what could be the reason of the lowest C_L content in these ecosystems. Only a few of these labile components, therefore, are incorporated into the soil aggregates in such short time. In the contrary, the microbial biomass, also a source of labile carbon, increases, but after the depletion of easy available sources, its amount decreases. Released cytoplasmic substances react with the mineral parts of soil, thus they are stabilized or incorporated into more complex structures of organic compounds, such as for example humus substances. The final components are further stabilized through the alkali cations, which have in the both cases of these soils significant proportion. On the basis of the parameter of lability of carbon (L_C), we can also consider as the most labile the organic matter of forest ecosystem and vice versa, as the most stabilized the organic matter of the meadow and urban ecosystems.

Table 2. Statistical evaluation of carbon and nitrogen parameters

Factor	TOC	C_L	C_{NL}	L_C	NT	N_L	N_{NL}	L_N
		(mg.kg^{-1})				(mg.kg^{-1})		
Soil								
HC	22392a	3164a	19228a	0.168a	2058b	114b	1944b	0.060a
HL	18440a	2377a	16063a	0.144a	1664a	88a	1577a	0.057a
Ecosystem								
AG	17410a	2646ab	14764a	0.178ab	1644a	99a	1545a	0.062a
FO	25480b	4330b	21150a	0.209b	2011a	101a	1910a	0.055a
ME	19953ab	2114a	17839a	0.119a	1999a	94a	1906a	0.049a
UR	18821ab	1992a	16829a	0.116a	1790a	110a	1681a	0.068a

HC - Haplic Chernozem, HL - Haplic Luvisol, AG - agro-ecosystem, FO - forest ecosystem, ME - meadow ecosystem, UR - urban ecosystem, TOC - total organic carbon, C_L - labile carbon, C_{NL} - non-labile carbon, L_C - lability of carbon, NT - total nitrogen, N_L - labile nitrogen, N_{NL} - non-labile nitrogen, L_N - lability of nitrogen. Different letters (a, b) between the factors show statistically significant differences ($P < 0.05$).

The differences in nitrogen contents were recorded between the soil types (Table 2). The contents of total nitrogen (NT) and labile nitrogen (N_L) were higher in Haplic Chernozem than in Haplic Luvisol. Parameters of nitrogen are rather a result of the production capacity of soil. In Haplic Luvisol, the stability of organic substances is lower, therefore, the nitrogen will release faster. Subsequently, the nitrogen can be adsorbed by the roots, or quickly lost through the processes of denitrification, volatilization (Triberti et al., 2008), and nitrification (Stevenson, 1986).

The rate of accumulation of SOM and its fractions depends on the particle size distribution and more authors recorded a positive correlation between TOC and clay contents (Bosatta and Ågren, 1997; Amelung et al., 1998; Tobiašová et al., 1999), or conversely, a negative correlation between TOC and sand contents (Tobiašová, 2010). In this case, the higher the content of fine sand fraction was, the lower were the contents of TOC and C_{NL} (Fig. 1, 2), so mainly more stabile forms of carbonaceous organic material. In the case of nitrogen, this size fraction (0.05-0.25 mm) influenced mainly labile forms of nitrogenous organic substances (Fig. 3, 4).

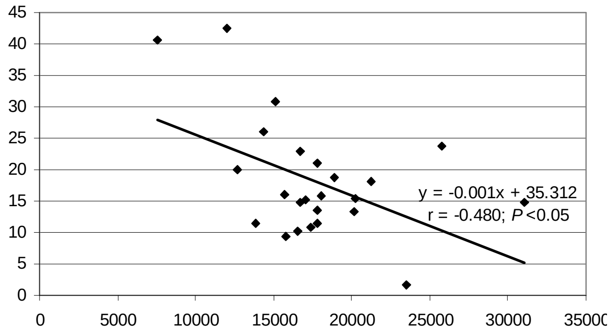

Fig. 1 Dependence between total organic carbon (TOC) and sand fraction (0.05-0.25 mm)

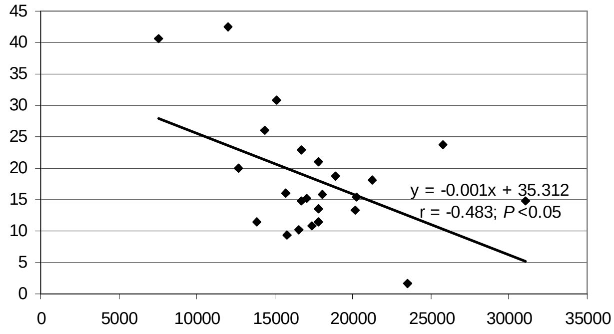

Fig. 2 Dependence between non-labile carbon (C_{NL}) and sand fraction (0.05-0.25 mm)

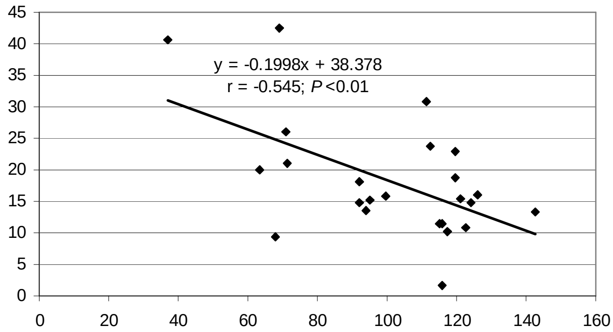

Fig. 3 Dependence between labile nitrogen (N_L) and sand fraction (0.05-0.25 mm)

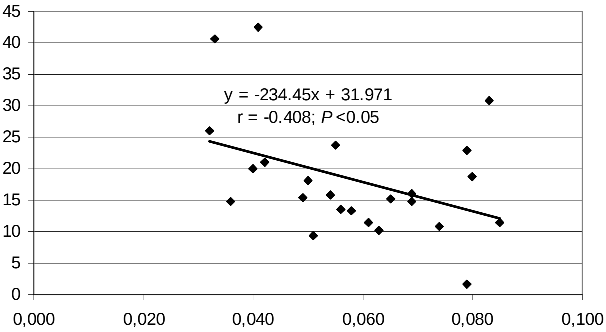

Fig. 4 Dependence between lability of carbon (L_N) and sand fraction (0.05-0.25 mm)

Negative correlation was recorded between the contents of fine sand and labile nitrogen (N_L) and lability of nitrogen (L_C). Higher content of sand fraction contributes to a higher oxidation of organic matter, which will show not only in the decreasing of the carbon content, but also in the increasing of the chemically more stabilized fractions; therefore, the negative correlation between the sand fraction and labile fractions of carbon was determined. In the case of nitrogen, a higher content of sand fraction has negative influence, mainly to the labile components, because the probability of their binding to the mineral portion of the soil is lower, resulting in lower their physical stabilization. The less stabilized organic matter is, the faster is nitrogen released (Triberti et al., 2008). The result will be also a lower content of labile nitrogen. Important is also the fact that the soil samples were taken in spring and according to Tedla et al. (2009), the content of labile carbon is lower in summer, but the content of labile nitrogen in spring. It depends on the intensity of rainfall, uptake of nitrogen by plants, volatilization of nitrogen, or nitrification, which are the processes, the intensity of which is increasing with increasing of the content of sand fraction and decreasing with the content of clay fraction, which stabilizes particularly these labile components. In the case of carbon, the data of different authors about the influence of rainfall vary. In some localities, the dependence of carbon content on the clay content was higher than on the amount of rainfall (Nichols, 1984), but in other localities, the higher influence of rainfall was recorded (Sims and Nielsen, 1986). In this case, more significant differences in the amount of rainfall in studied localities were not observed, so that the carbon and nitrogen contents are the results of influence of particle size distribution.

Conclusion

The highest contents of TOC and C_L were in a forest ecosystem, but in case of other ecosystems, the differences were determined only in the contents of C_L. After forest ecosystem, the highest content of C_L was in agro-ecosystem > meadow ecosystem > urban ecosystem.

In the case of nitrogen, the differences were observed between the soils. Higher contents of NT and N_L were recorded in Haplic Chernozen than in Haplic Luvisol.

Contents of TOC, C_{NL}, and N_L were in negative correlation with the content of sand fraction.

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