Soil structure and soil organic matter of different ecosystems

Erika Tobiašová[1], Božena Dębska[2] Magdalena Banach-Szott[2]

[1]Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic,
e-mail: Erika.Tobiasova@uniag.sk,
[2]University of Technology and Life Sciences, Bernardyńska 6, 85-029 Bydgoszcz, Poland,
e-mails: debska@utp.edu.pl, mbanach@utp.edu.pl

Abstract

Tobiašová, E., Dębska, B., Banach-Szott, M. 2014. Soil structure and soil organic matter of different ecosystems. *Folia oecol*., 41: 92–99.

In this study, the soil structure of six soils of different ecosystems in Slovakia was compared. The stability of organic matter inside of aggregates was assessed through the carbon parameters – the index of carbon lability (LI_c), carbon pool index (CPI), and carbon management index (CMI). The soil structure of different ecosystems was compared through the proportion of water-resistant macro-aggregates (WMA) and the parameters of soil structure – the coefficient of vulnerability (K_v), aggregates stability index (S_w), critical soil organic matter content (S_t), and index of crusting (I_c). The quality of soil structure was decreasing in the following order: forest ecosystem (FE) > agro-ecosystem (AE) > meadow ecosystem (ME) > grassy urban ecosystem (UE). In the FE, the WMA of the 1–3 mm size fraction had the highest proportion and in case of AE the highest proportion had WMA of the 0.5–1 mm size fraction. The highest content of labile carbon was incorporated into aggregates of the FE and the highest stability of organic matter was in the aggregates of the ME. According to parameter CMI, labile components are better protected in the smaller aggregates. An important indicator for the assessing of the ecosystem impact is WMA of the 0.5–1 mm size fraction. Increased proportion of this aggregate fraction refers to the deterioration of soil structure.

Keywords

ecosystem, labile carbon, soil structure, water-resistant aggregates

Introduction

Soil quality is defined as the ability of soil to play the role within the ecosystem, so that its biological productive ability and environmental quality were preserved, and also it should support healthy growth of plants and animals (Karlen et al., 1997). Larson and Pierce (1991) propose the organic carbon, and soil structure as the indicators that are sensitive to the land use, for the monitoring of the soil quality. Soil organic matter (SOM) is important for the conservation of favourable physical, chemical, and biological properties of soils (Johnsen et al., 2013). The SOM is regarded as an essential element in the formation of aggregates (Zeytin and Baran, 2003), and the formation of aggregates contributes to the stabilisation of organic matter through the physical protection of the aggregates (Balabane and Plante, 2004; Tobiašová, 2010). Different fractions of organic matter participate in the formation and stabilization of soil aggregates by various ways (Roberson et al., 1991; Tobiašová, 2011). Stabilization through the physical-chemical protection, in hierarchical soil aggregates, is crucial for the conservation of carbon and nitrogen sources (O'Brien and Jastrow, 2013). Particularly important are labile fractions of SOM, because they are more sensitive to soil disruption and play important role in carbon and nutrient turnovers (Tian et al., 2013). Labile SOM is a sensitive indicator of changes in land use and soil management practices (Wang and Wang, 2011). Therefore the objectives of this study were as follows: (i) to compare the differences in the composition of water-resistant aggregates and in a stability of organic matter inside them, depending on the ecosystem, and (ii) to assess the suitability of the fractions of water-resistant aggregates as an indicator of the soil structure deterioration.

Material and methods

The studied areas are located in the West of Slovakia. The localities Močenok (48°13'N, 17°55'E) with Haplic Chernozem, Horná Kráľová (48°14'N, 17°54'E) with Mollic Fluvisol, and Šaľa (48°09'N, 17°52'E) with Eutric Fluvisol are situated on the northern border of the Danube lowland. Region is formed by strata of Neogene, mainly of claystones and sandstones, which are covered with younger quaternary rocks represented by different fluvial and aeolian sediments (Pristaš et al., 2000). The natural vegetation consists mostly of ash-oak-elm-alder forests, and along the river, there are willow-poplar and floodplain forests. In the elevated areas and dunes, xerophilous communities of oak-elm forests are dominant (Korec et al., 1997).

The locality Veľké Zálužie (48°18'N, 17°56'E), with Haplic Luvisol is situated in the Danubian Hills (Upland) formed by quarternary sediments – loess and loess loam. Neogene bedrock consists of lake brackish sediments (clays, gravels, and sands), Hók et al., 2001. In the lower parts of area dominate oak forests and in the higher parts, there are mixed beech forests.

The locality Pružina (49°00'N, 18°28'E) with Rendzic Leptosol and Eutric Cambisol is situated at the north-eastern foot of the hill Strážov, in the valley of the river Pružina. Region belongs to core mountains of the outer arc of the Central Western Carpathians. A substantial part of the Strážovské vrchy Mts is composed of the nappes with highly variable resistance of rocks. The core is formed with the crystalline slates, granites, amphibolites, and in the south and southeast, there are mesozoic dolomites, limestones and slates, which are folded and stored in the form of nappe debris (Pristaš et al., 2000). In the forests dominate beech and oak, in the higher parts with the admixture of fir and higher number of other conifers.

The experiment included four types of ecosystems, which present different land use and management (forest ecosystem, meadow ecosystem, grassy urban ecosystem, and agro-ecosystem) on six soil types (Haplic Chernozem, Mollic Fluvisol, Eutric Fluvisol, Rendzic Leptosol, Eutric Cambisol, and Haplic Luvisol). These are the soils of lowlands and uplands, which have the largest proportions in Slovakia and are intensively agriculturally used. The forest ecosystems are close to nature and managed; the meadow ecosystems were created by man 30 years ago; and the urban ecosystems are affected by human activity lawns. The studied agro-ecosystems were located in different farms under real production conditions.

The soil samples for chemical and physical properties determination were collected in three replicates from a layer of 0.0–0.3 m. Soil samples were dried at constant room temperature (25 ± 2 °C) and then divided by the sieving (dry and wet sieving) to fractions of the net aggregates. The aggregate stability index (S_w) (Henin et al., 1969), the coefficient of vulnerability (K_v) (Valla et al., 2000), the index of crusting based on textural composition and soil organic matter (I_c), Lal and Shukla, 2004, and the critical soil organic matter content (S_t) according to Pieri (1991) were also calculated. The particle size distribution, which was used for the calculation of soil structure parameters, was determined after dissolution of $CaCO_3$ with 2 mol dm^{-3} HCl and oxidation of the organic matter with 30% H_2O_2. After repeated washing, samples were dispersed using $Na_4P_2O_7.10H_2O$. Silt, sand, and clay fractions were determined according to the pipette method (Day, 1965). In the water-resistant aggregates, the TOC by wet combustion (Orlov and Grišina, 1981) and the labile carbon (C_L) by $KMnO_4$ oxidation (Loginov et al., 1987) were determined. Non-labile carbon (C_{NL}), lability of carbon (L_C), index of carbon lability (LI_C), carbon pool index (CPI), and carbon management index (CMI) were also calculated (Blair et al., 1995).

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

Results and discussion

Proportion of water-resistant aggregates in soils of studied ecosystems

The highest amount of water-resistant macro-aggregates of the 0.5–1 mm size fraction was statistically significant in agro-ecosystem (Table 1). Emadi et al. (2009) also reported that a higher amount of the micro-aggregates and small macro-aggregates (<0.5 mm) remains in ploughed soils and according to Whalen and Chang (2002), the increased proportion of the smaller aggregates (<1.2 mm) is an important indicator of soil degradation. In the other ecosystems, the content of this aggregate fraction was relatively balanced. The values found in the meadow and grassy urban ecosystems were slightly higher than in the forest ecosystem. The richest sources of organic substances occur primarily on the soil surface in the forest ecosystem. The result of their decomposition is represented by substantially higher amounts of the mobile acids than in the arable land, in which there is a greater mixing of the organic portion with mineral portion of the soil. These acidic components later get into deeper parts of the soil profile through leaching, and support the leaching of carbonates that act as the cementing agents in aggregates, as well as acidification of soil. Iron and aluminium, which are the cement agents in the smaller aggregates, are also mobilised (Barral et al., 1998; Duiker et al., 2003). From the organic components, mainly the stabilized forms of organic matter have the function of cementing agents in smaller aggregates having the lowest proportion in the soil of forest ecosystem. The lowest proportion of the macro-aggregates of the 0.5–1 mm size fraction was in soils of the meadow and grassy urban ecosystems. In both cases there were grasses which points to the significant influence of the vegetation cover, which is higher than the impact of the anthropogenic factors, which influence the soil properties in the grassy urban ecosystem. According to Cantón et al. (2009), the type of vegetation influences the aggregates, the size of which is larger than 4–8 mm. The highest proportion of agronomically the most valuable water-resistant macro-aggregates was on average in the agro-ecosystem (56.85%), where the farmyard manure, which is a source of the stabile forms of humus substances and of the large number of micro-organisms, was added. Stabile forms of the organic matter support the formation of stabile soil aggregates and carbohydrates of microbial origin resist degradation better than carbohydrates of plant origin do (Debosz et al., 2002). The second highest proportion of these aggregates was in the forest ecosystem (47.39%). Dynamics of soil aggregates is the reflection of the chemical composition of plant residues. In the forest litter, the phenols and polyphenols, which are the precursors for the formation of humus substances, are dominant (Martens, 2000) and of the lignin, which supports the aggregate formation (Magill and Aber, 1998). The lowest contents of agronomically the most valuable aggregates were in meadow (39.72%) and in grassy urban (39.65%) ecosystems. In both cases occurred grasslands, in which the root exudates are an important source of labile fraction of soil organic matter. According to Tisdall and Oades (1982), the polysaccharides are easily mineralizable and play the role of temporary components at the formation of soil aggregates. As it can be seen, the proportion of agronomically the most valuable size fraction of 0.5–3 mm was significantly influenced not only by the quantity, but also the quality of organic substance inputs into the soil (Tobiašová, 2011). However, if we take only agronomically valuable aggregates of the 1–3 mm size fraction, it means without the size fraction 0.5–1 mm, its significantly higher proportion was in the forest ecosystem (35.45%). In the other ecosystems, their proportions were relatively balanced, with the proportion of 31.59% in the agro-ecosystem, 30.04% in urban ecosystem, and 29.64% in meadow ecosystem. Emadi et al. (2009) presented, that deforestation, and ploughing of a meadow decreased mainly the content of water-resistant macro-aggregates of the 24.75 mm size fraction (4.5-times) and the size fraction of

Table 1. Statistical evaluation of differences among contents of water-resistant aggregate fractions in different soils and ecosystems

Fraction of aggregates	2–3 mm	1–2 mm	0.5–1 mm [%]	0.25–0.5 mm	<0.25 mm
Soil					
HC[a]	11.72ab	18.65b	18.25a	11.51ab	21.52bc
MF[b]	12.87ab	18.10b	19.89a	19.00b	15.74abc
EF[c]	14.78bc	16.76ab	15.06a	8.55a	14.84ab
RL[d]	21.50c	19.68b	13.67a	8.84a	8.68a
EC[e]	18.23bc	21.27b	15.61a	9.04a	8.19a
HL[f]	6.23a	10.01a	20.95a	29.19c	25.91c
Ecosystem					
FE[g]	17.58a	17.87a	11.94a	10.07a	8.44a
ME[h]	14.87a	14.77a	10.08a	10.45a	14.71a
UE[i]	16.32a	13.72a	9.61a	7.20a	11.47a
AE[j]	12.70a	18.89a	22.26b	18.19a	19.03a

[a]HC, Haplic Chernozem; [b]MF, Mollic Fluvisol; [c]EF, Eutric Fluvisol; [d]RL, Rendzic Leptosol; [e]EC, Eutric Cambisol; [f]HL, Haplic Luvisol; [g]FE, forest ecosystem; [h]ME, meadow ecosystem; [i]UE, urban ecosystem; [j]AE, agro-ecosystem; different letters (a, b, and c) show statistically significant differences – Tukey test ($P < 0.05$).

1–2 mm (1.9-time). Both fractions are also larger, than the mentioned size fraction of 0.5–1 mm. This fact also points to the increased proportion of water-resistant macro-aggregates of the 0.5–1 mm size fraction as the negative rather than the positive state. It follows that an increase of water-resistant macro-aggregates of the 0.5–1 mm size fraction is caused mainly by the changes in soil management, which also predisposes this aggregate fraction to become an important indicator of land use impact on the soil structure.

From the values given in the Table 2, the soil structure of the forest ecosystem can also be considered as the best. This assessment is based on the proportion of agronomically the most valuable water-resistant macro-aggregates of the 1–3 mm fraction (the fraction of 0.5–1 mm is not taken into consideration). Soils below natural vegetation have the highest stability of soil aggregates also according to Barreto et al. (2009). Closest to the values of aggregate stability index (S_w) and coefficient of vulnerability (K_v) of forest ecosystem were the values found in agro-ecosystem. According to Borie et al. (2008), the addition of limestone or dolomite powder to the soil has a considerable impact on the formation of soil aggregates, because divalent cations Ca^{2+} and Mg^{2+} are main polyvalent cations, which not only stabilize the organic matter, but also improve the aggregation. In the agro-ecosystem, the proportion of crops can influence also the extent and frequency of wet and dry periods, which influence the stability of soil aggregates (Materechera et al., 1994). Through suitable land use, it is possible to improve the soil structure state in the agro-ecosystem and bring it near to a level that is in the forest ecosystem, in spite of the higher proportion of the size fraction of 0.5–1 mm. However, the values of the critical content of soil organic matter (S_t) and the index of crusting (I_c) clearly point at a more favourable state of soil structure in the forest ecosystem. These two parameters are significantly influenced by the amount of organic matter and particle size distribution of soil (Lal and Shukla, 2004). Given, that the statistically significant differences in particle size distribution between the ecosystems were not recorded, the positive impact can be attributed mainly to the soil organic matter. This suggests that in spite of the lower inputs of organic matter into the soil in the agro-ecosystem, one of the possibilities for improving of the soil structure can be its stabilization through the binding to polyvalent cations and mineral components of the soil.

Soil organic matter in the fractions of water-resistant aggregates

Christensen (2001) and Oades (1984) described that if the particles of labile organic matter become the core of aggregates, they can be this way physically stabilized inside the aggregates, thereby supporting the formation of stabile soil structure. In the surface soil layer of the forest ecosystem, there is a higher source of particular organic matter in the soil aggregates which was also confirmed by the results of Freixo et al. (2002). Our results (Fig. 1) show, that the highest content of labile carbon in the water-resistant macro-aggregates

Table 2. Statistical evaluation of differences among individual parameters of the soil structure of different soils and ecosystems

Parameter of soil structure	S_w [k]	K_v [l]	S_t [m] [%]	I_c [n]
Soil				
HC[a]	1.05a	1.18b	4.87ab	1.03ab
MF[b]	1.54b	0.31a	6.22b	0.82a
EF[c]	1.08a	1.47b	5.13ab	1.01ab
RL[d]	1.21a	1.04b	3.92a	1.37bc
EC[e]	1.13a	1.12b	4.27ab	1.66b
HL[f]	1.25a	1.39b	4.29ab	1.06ab
Ecosystem				
FE[g]	1.50a	0.79a	7.51b	0.75a
ME[h]	1.28a	1.10ab	5.65a	0.95ab
UE[i]	0.90a	1.62b	4.18a	1.23a
AE[j]	1.41a	0.67a	5.27a	0.99ab

[a]HC, Haplic Chernozem; [b]MF, Mollic Fluvisol; [c]EF, Eutric Fluvisol; [d]RL, Rendzic Leptosol; [e]EC, Eutric Cambisol; [f]HL, Haplic Luvisol; [g]FE, forest ecosystem; [h]ME, meadow ecosystem; [i]UE, urban ecosystem; [j]AE, agroecosystem; [k]S_w, aggregate stability index; [l]K_v, coefficient of vulnerability; [m]S_t, critical soil organic matter content; [n]I_c, index of crusting; different letters (a, b, and c) show statistically significant differences – Tukey test ($P < 0.05$) .

was recorded in the forest ecosystem, which means that the labile fractions become a part of these aggregates. In the meadow ecosystem, the source of labile forms of organic matter is also large, but only its lower amount is incorporated into the aggregates. Substances that support a richer representation of microflora are mainly root exudates. A considerable part of this labile carbon is thus decomposed before its incorporation into the aggregates, as can be seen in case of the lowest content of labile carbon in the fractions of water-resistant macro-aggregates in our study. In the case of the forest ecosystem, substantially higher amount of labile carbon is bound into the water-resistant macro-aggregates of the 0.25–3 mm size fraction, in comparison with meadow ecosystem.

The stability of soil organic matter in water-resistant macro-aggregates is better described by the parameters of the carbon (Table 3). Lability of carbon (L_C) in the aggregates was clearly highest in the forest ecosystem. In this ecosystem, there was not only the highest amount of total organic carbon (TOC) in the aggregates, but also its labile forms. In the forest ecosystem, the values of pH are lower and according to Tobiašová (2010), at lower pH there is a higher amount of the carbon in active form. However, if we compare the stability of organic matter in aggregates of the individual ecosystems with the control variant, which is in our case forest ecosystem, the higher values of the index of carbon lability (LI_C) were in the grassy urban ecosystem and agro-ecosystem than in the meadow ecosystem, where the changes in organic matter of these aggregates, according to carbon management index (CMI), were slower.

Higher values of LI_C show a higher amount of the carbon in active form and therefore less resistance of the soil organic matter against decomposition (Blair et al., 1995). In the meadow ecosystem, the highest content of labile carbon was in the root zone, but its content in the aggregates was the lowest in comparison to other ecosystems (Table 3). Higher values of LI_C do not mean immediately a lower stability of soil aggregates. This means that the physical stabilization of soil organic matter plays an important role in the stability of soil aggregates. According to Santos et al. (1997), this is the result of protective action of the mineral particles of soil, particularly of clay, which inhibits the decomposition of organic matter within the aggregates. The values of L_C show that the lability of carbon is decreasing with reducing of the aggregate size and the values of carbon pool index (CPI) also show that the smaller aggregates in the ecosystems, the larger the amounts of TOC in them, in comparison to aggregates of the forest ecosystem. It is known that the smaller aggregates there are, the less organic matter is in them (Six et al., 2000). It follows that the labile components in smaller aggregates are better protected, especially through the physical stabilization in aggregates, which is confirmed by the values of CMI. These were the lowest in the case of larger aggregates, which indicates more rapid changes in the organic matter. The values of CPI and CMI in the micro-aggregates are a little smaller, but according to Six et al. (1998), the macro-aggregates are more influenced through the land use than the micro-aggregates. In the case of ecosystems, larger changes in the meadow ecosystem are supported by higher sources of easily decomposable substances such

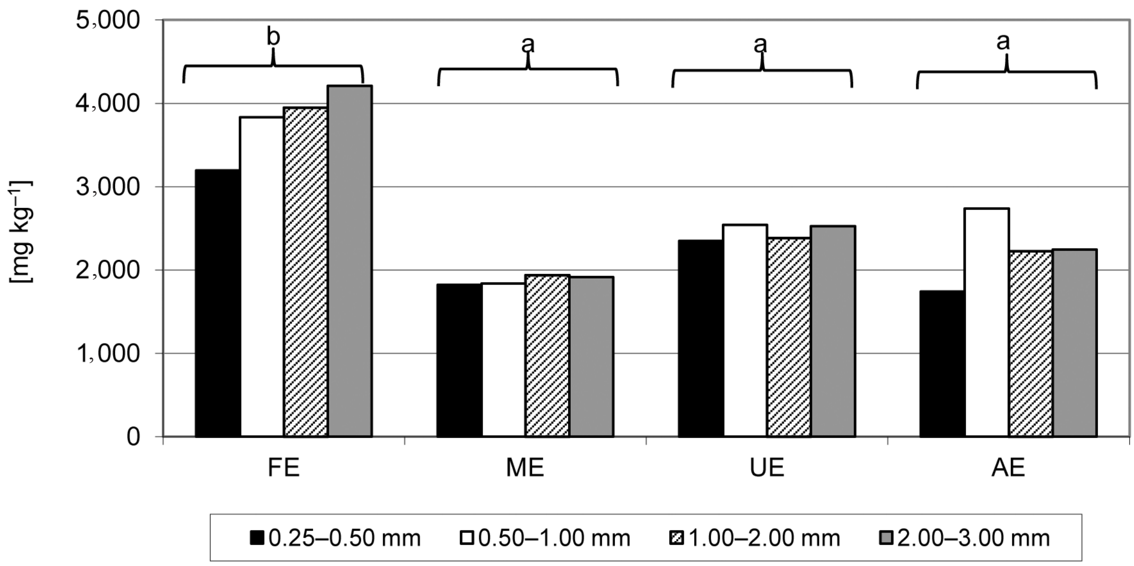

Fig. 1. Contents of labile carbon (C_L) in fractions of water-resistant macro-aggregates in soils of different ecosystems. FE, forest ecosystem; ME, meadow ecosystem; UE, urban ecosystem; AE, agro-ecosystem; different letters (a and b) between the factors show statistically significant differences – Tukey test ($P < 0.05$).

Table 3. Statistical evaluation of differences among individual carbon parameters in soils, ecosystems and water-resistant aggregate fractions

Parameter of carbon	[k]TOC	[l]C_L	[m]C_{NL}	[n]L_C	[o]LI_C	[p]CPI	[r]CMI
	[mg kg^{-1}]						
Soil							
HC[a]	20,827b	3,026b	17,801b	0.170c	72.95ab	0.813c	58.90b
MF[b]	18,958ab	1,709a	17,249ab	0.096a	83.03abc	1.162d	102.20c
EF[c]	19,323ab	2,681ab	16,642ab	0.157bc	85.03abc	0.899c	81.87bc
RL[d]	22,330b	2,064ab	20,266b	0.092a	60.09a	0.262a	15.26a
EC[e]	24,199b	2,996b	21,202b	0.136b	86.35bc	0.532b	46.11ab
HL[f]	12,891a	2,223ab	10,668a	0.209d	101.42c	1.170d	110.99c
Ecosystem							
FE[g]	27,380b	3,647b	23,733b	0.168c	–	–	–
ME[h]	17,092a	1,791a	15,301a	0.117a	69.26a	0.799a	55.26a
UE[i]	18,536a	2,369a	16,167a	0.144b	88.28b	0.873a	85.14b
AE[j]	16,010a	1,992a	14,018a	0.144b	86.89b	0.743a	67.27ab
Aggregate fraction							
3–2 mm	20,599a	2,725a	17,874a	0.151a	71.58a	0.760a	57.57a
2–1 mm	20,896a	2,624a	18,271a	0.144a	78.18a	0.784a	59.51a
1–0,5 mm	20,332a	2,529a	17,803a	0.147a	82.24a	0.798a	66.05a
0.5–0.25 mm	18,881a	2,208a	16,674a	0.140a	85.64a	0.886a	84.38a
<0.25 mm	18,066a	2,164a	15,902a	0.135a	89.76a	0.795a	78.60a

[a]HC, Haplic Chernozem; [b]MF, Mollic Fluvisol; [c]EF, Eutric Fluvisol; [d]RL, Rendzic Leptosol; [e]EC, Eutric Cambisol; [f]HL, Haplic Luvisol; [g]FE, forest ecosystem; [h]ME, meadow ecosystem; [i]UE, urban ecosystem; [j]AE, agro-ecosystem; [k]TOC, soil organic carbon; [l]C_L, labile carbon; [m]C_{NL}, non-labile carbon; [n]L_C, lability of carbon; [o]LI_C, index of carbon lability; [p]CPI, carbon pool index; [r]CMI, carbon management index; different letters (a, b, c and d) show statistically significant differences – Tukey test ($P < 0.05$).

as polysaccharides derivable from the root exudates and microorganisms. In the case of agro-ecosystem, larger changes are supported by an application of the farmyard manure.

It follows that the quality of soil structure was decreasing in the following order: forest ecosystem > agro-ecosystem > meadow ecosystem > grassy urban ecosystem.

The water-resistant macro-aggregates of the 1–3 mm size fraction had the highest proportion in the forest soil, whereas of 0.5–1 mm fraction in the soil of agro-ecosystem.

The highest content of the labile carbon is incorporated into the aggregates of the forest ecosystem and the highest stability of the organic matter was in the aggregates of the meadow ecosystem. The carbon management index shows, that the labile components are better protected in the smaller aggregates.

An important indicator, for assessing of the ecosystem influence, seems to be the water-resistant macro-aggregates of the 0.5–1 mm size fraction. This is only one size fraction, at which statistically significant differences between the ecosystems were recorded, and at which differences between the soil types were not recorded. Increased proportion of this aggregate fraction refers to the deterioration of soil structure.

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).

References

Balabane, M., Plante, A.F. 2004. Aggregation and carbon storage in silty soil using physical fractionation techniques. *Eur. J. Soil Sci.*, 55: 415–427.

Barral, M.T., Arias, M., Guérif, J. 1998. Effects of iron and organic matter on the soil porosity and structural stability of soil aggregates. *Soil Till. Res.*, 46: 261–272.

BARRETO, R. C., MADARI, B. E., MADDOCK, J. E. L., PEDRO, J. F., MACHADO, L. O. A., TORRES, E., FRANCHINI, J., COSTA, A. R. 2009. The impact of soil management on aggregation, carbon stabilization and carbon loss as CO_2 in the surface layer of a RhodicFerrasol in Southern Brazil. *Agric. Ecosyst. Envir.*, 132: 243–251.

BLAIR, G. J., LEFROY, R. D. B., LISLE, L. 1995. Soil carbon fractions, based on their degree of oxidation, and the development of a Carbon Management Index for agricultural systems. *Austr. J. Agric. Res.*, 46: 1459–1466.

BORIE, F., RUBIO, R., MORALES, A. 2008. Arbuscular mycorrhizal fungi and soil aggregation. *J. Soil. Sc. Pl. Nutr.*, 8: 9–18.

DAY, P.R. 1965. Particle fractionation and particle-size analysis. In BLACK, C.A., American Society of Agronomy et al. (eds). *Methods of soil analysis. Part 1.* Agronomy, no. 9. Madison, Wis.: American Society of Agronomy, p. 552–562.

DEBOSZ, K., PETERSON, S. O., KURE, L. K., AMBUS, P. 2002. Evaluating effects on sewage sludge and household compost on soil physical, chemical and microbiological properties. *Appl. Soil Ecol.*, 19: 237–248.

DUIKER, S. W., RHOTON, F. E., TORRENT, J., SMECK, N. E., LAL, R. 2003. Iron (hydr)oxide crystallinity effects on soil aggregation. *Soil Sci. Soc. Amer. J.*, 67: 606–611.

CANTÓN, Y., SOLÉ-BENET, A., ASENSIO, C., CHAMIZO, S., PUIGDEFÁBREGAS, J. 2009. Aggregate stability in range sandy loam soils – Relationships with runoff and erosion. *Catena*, 77: 192–199.

CHRISTENSEN, B. T. 2001. Physical fractionation of soil and structural and functional complexity in organic matter turnover. *Eur. J. Soil Sci.,* 52: 345–353.

EMADI, M., BAGHERNEJAD, M., MEMARIAN, H.R. 2009. Effect of land-use change on soil fertility characteristics within water-stable aggregates of two cultivated soils in northern Iran. *Land Use Policy*, 26: 452–457.

FREIXO, A. A., MACHADO, P. L. O. A., SANTOS, H. P., SILVA, C. A., FADIGAS, F.S. 2002. Soil organic carbon and fractions of a Rhodic Ferrasol under the influence of tillage and crop rotation systems in Southern Brazil. *Soil Till. Res.,* 64: 221–230.

HENIN, S., GRAS, R., JUNGERIUS, P.D. 1969. *Le profil cultural: I´état physique du sol et ses consequences agronomiques* [The cultural profile: The condition of soil physics and agronomic consequences]. Paris: Masson. 332 p.

HÓK, J., KAHAN, Š., AUBRECHT, R. 2001. *Geológia Slovenska* [Geology of Slovakia]. Bratislava: Univerzita Komenského. 43 p.

JOHNSEN, K. H., SAMUELSON, L. J., SANCHEZ, F. G., EATON, R. J. 2013. Soil carbon and nitrogen content and stabilization in mid-rotation, intensively managed sweetgum and loblolly pine stands. *Forest Ecol. Mgmt*, 302: 144–153.

KARLEN, D. L., MAUSBACH, M. J., DORAN, J. W., CLINE, R.G., HARRIS, R.F., SCHUMAN, G.E. 1997. Soil quality: a concept, definition, and framework for evaluation (guest editorial). *Soil Sci. Soc. Am. J*, 61: 4–10.

KOREC, P., LAUKO, V., TOLMÁČI, L., ZUBRICKÝ, G., MIČIETOVÁ, E. 1997. *Kraje a okresy Slovenska. Nové administratívne členenie* [Counties and districts of Slovak Republic. New administrative structure]. Bratislava: Q111. 391 p.

LAL, R., SHUKLA, M. K. 2004. *Principles of soil physics*. New York: Marcel Dekker. 340 p.

LARSON, W. E., PIERCE, F. J. 1991. Conservation and enhancement of soil quality. In *Evaluation for sustainable land management in the seveloping world. Vol. 2.* IBSRAM proceedings, no. 12, Technical Papers. Bangkok, Thailand: International Board for Soil Research and Management, p. 175–203.

LOGINOV, W., WISNIEWSKI, W., GONET, S. S., CIESCINSKA, B. 1987. Fractionation of organic carbon based on susceptibility to oxidation. *Pol. J. Soil Sci.*, 20: 47–52.

MAGILL, A. H., ABER, J. D. 1998. Long-term effects of experimental nitrogen additions on foliar decay and humus formation in forest ecosystems. *Pl. and Soil*, 203: 301–311.

MARTENS, A. D. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. *Soil Biol. Biochem.*, 32: 361–369.

MATERECHERA, S. A., KIRBY, J. M., ALSTON, A. M., DEXTER, A. R.1994. Modification of soil aggregation by watering regime and roots growing through beds of large aggregates. *Pl. and Soil*, 160: 57–66.

OADES, J. M. 1984. Soil organic matter and structural stability: mechanisms and implications for management. *Pl. and Soil*, 76: 319–337.

O'BRIEN, S. L., JASTROW, J. D. 2013. Physical and chemical protection in hierarchical soil aggregates regulates soil carbon and nitrogen recovery in restored perennial grasslands. *Soil Biol. Biochem.*, 61: 1–13.

ORLOV, D. S., GRIŠINA, L.A. 1981. *Praktikum po chimiji gumusa* [Analyses of humus chemistry]. Moskva: IMU. 272 p.

PIERI, C. 1991. *Fertility of soils: A future for farming in the West African savannah*. Berlin: Springer-Verlag. 348 p.

PRISTAŠ, J., ELEČKO, M., MAGLAY, J., FORDINÁL, K., ŠIMON, L., GROSS, P., POLÁK, M., HAVRILA, M., IVANIČKA, J., HATÁR, J., VOZÁR, J., MELLO, J., NAGY, A. 2000. *Geologická mapa Podunajskej nížiny Nitrianska pahorkatina 1:50 000* [Geological map of the Danube Lowland Nitra Upland 1:50 000]. Bratislava: Štátny geologický ústav Dionýza Štúra.

Roberson, E.B., Sarig, S., Firestone, K. 1991. Crop cover management of polysaccharide-mediated aggregation in an orchard soil. *Soil Sci. Soc. Am. J.,* 55: 734–739.

Santos, D., Murphy, S.L.S., Taubner, H., Smucker, A.J.M., Horn, R. 1997. Uniform separation of concentric surface layers from soil aggregates. *Soil Sci. Soc. Am. J.*, 61: 720–724.

Six, J., Elliot, E.T., Paustian, K., Doran, J.W. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Sci. Soc. Am. J.,* 62: 1367–1377.

Six, J., Paustian, K., Elliott, E.T., Combrink, C. 2000. Soil structure and organic matter. I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Sci. Soc. Am. J.*, 64: 681–689.

Tian, J., Lu, S., Fan, M., Li, X., Kuzyakov, Y. 2013. Labile soil organic matter fractions as influenced by non-flooded mulching cultivation and cropping season in rice-wheat rotation. *Eur. J. Soil Biol.*, 56: 19–25.

Tisdall, J.M., Oades, J.M. 1982. Organic matter and water stable aggregates in soils. *J. Soil Sci*., 33: 141–163.

Tobiašová, E. 2010. *Pôdna organická hmota ako indikátor kvality ekosystémov* [Soil organic matter as an indicator of ecosystem quality]. Nitra: Slovenská poľnohospodárska univerzita. 107 p.

Tobiašová, E. 2011. The effect of organic matter on the structure of soils of different land use. *Soil Till. Res*., 114: 183–192.

Valla, M., Kozák, J., Ondráček, V. 2000. Vulnerability of aggregates separated from selected anthorsols developed on reclaimed dumpsites. *Pl. Soil Envir.*, 46: 563–568.

Wang, Q., Wang, S. 2011. Response of labile soil organic matter to changes in forest vegetation in subtropical regions. *Appl. Soil Ecol.*, 47: 210–216.

Whalen, J.K., Chang, C. 2002. Macroaggregate characteristics in cultivated soils after 25 annual manure applications. *Soil Sci. Soc. Am. J.*, 66: 1637–1647.

Zeytin, S., Baran, A. 2003. Influences of composted hazelnut husk on some physical properties of soils. *Bioresour. Technol.*, 88: 241–244.

Received January 29, 2014
Accepted February 21, 2014