

SOIL STRUCTURE AND SOIL ORGANIC MATTER OF SELECTED SOIL TYPES IN DIFFERENT ECOSYSTEMS

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In this study, differences in soil structure in different ecosystems (forest, meadow, urban, and agro-ecosystem) and soil types (Haplic Chernozem, Haplic Luvisol, Haplic Stagnosol) with a dependence on the influence of quantity and quality of soil organic matter and the particle size distribution on fraction composition of soil aggregates were compared. Soils had different productive capacity and particle size distribution. The most favourable soil structure was in the agro-ecosystem, then in forest, meadow, and urban ecosystem. The worst soil structure was in Haplic Stagnosol. An important indicator in assessing of ecosystem influence, water-resistant macro-aggregates of the 0.5–1 mm size fraction seems to be. This fraction was the only one which was statistically significantly influenced by the ecosystem, and also the only one which was

not statistically significantly influenced by the soil type. This fraction also was not influenced either with the quantity and quality of soil organic matter, or with the particle size distribution. The quantity of soil organic matter is reflected in relation to the fractional composition of dry-sieved aggregates and its quality in relation to water-resistant aggregates. Large fractions of water-resistant macro-aggregates were in positive correlation with C : N ratio, the amount of extracted humus substances, or stability and quality of humic acids; while smaller fractions were in negative correlation just with these parameters. Clay and silt fractions had a positive influence on water-resistant macro-aggregates formation, while sand fraction had negative and *vice versa*.

Key words: soil organic matter, soil structure, ecosystem

Changes in land use had influence on the vegetation and the soil. The conversion of forest and meadow to the arable land leads primarily to a reduction in the content of soil organic carbon and changes in soil aggregate stability (Singh & Singh 1996). Analyses of dynamics in agro-ecosystems are difficult because of their complicated internal interactions between individual components (Tornquist *et al.* 2009). In agro-ecosystems, the maintenance of organic carbon amount is a major role in reducing of soil degradation (Bhattacharyya *et al.* 2009). Urban ecosystems are complicated areas composed of different ecosystems, located close to each other and

influenced by each other (Vrščaj *et al.* 2009). The soil structure in individual ecosystems is a reflection of many factors, while the particle size distribution and the quantity and quality of soil organic matter are crucial. The organic matter is considered to be an essential element in the formation of aggregates (Zeytin & Baran 2003) and on the contrary, the formation of aggregates contributes to the stabilization of soil organic matter by its physical protection in aggregates (Balabane & Plante 2004). The relationship between the soil structure and organic matter is dynamic (Bonde *et al.* 1988), while the stability of soil aggregates depends not only on the quantity

but also the quality of organic substance inputs (Tisdall & Oades 1982). The rate of soil organic matter accumulation and its fractions also depends on the particle size distribution (Amelung *et al.* 1998; Tobiašová 2011a; Tobiašová 2011b). Clay is bound with large proportion of organic substances, but also supports the formation of stabile macro-aggregates (Jastrow 1996). The objectives of this study were as follows: (i) comparison of the soil structure in different ecosystems and soil types, (ii) assessment of the quantity and quality of soil organic matter, and (iii) particle size distribution influence on fraction composition of macro-aggregates.

MATERIALS AND METHODS

Experiment includes the soil types Haplic Chernozem, Haplic Luvisol, Haplic Stagnosol (WRB 2006), which have not only different productive capacity, but also different particle size distribution (Table 1). They are the soils of lowland and hilly areas (Figure 1), which are largely cultivated and thus have the potential for carbon sequestration. The experiment includes soils of four different ecosystems (forest, meadow, urban, and agro-ecosystem).

Characteristics of the territory

The sampling places on the Haplic Chernozem are situated in Močenok, which is located on the northern edge of the Danube Basin. Its geological structure is characterized by neogene strata, consisting of claystones, sandstones, and andesites, which are covered by younger rocks of quaternary, represented by different fluvial and aeolian sediments. The relief is wavy hilly, formed by terraces of Vah and Nitra rivers. The terraces are covered with loess, loessial loams, and aeolian sands (Pristaš *et al.* 2000). The area is situated in a warm climate area with an average annual temperature of 9.8°C and with the average rainfall of 568 mm per year. Natural vegetation consists mostly of oak-ash-elm-alder forests, and along the river there are willow-poplar forests and floodplain forests. On elevated surfaces and dunes, mainly xerophilous communities with oak-elm forest exist (Korec *et al.* 1997). Dominant crops in the agro-ecosystem were: cereals (70%), root crops (20%), oil crops (5%), and the rest were other crops.

The sampling places on the Haplic Luvisol are situated in Veľké Zálužie, which is located on the Danube Lowland, on the whole Danube hilly area, on the Nitra hilly area. Its geological structure is

T a b l e 1

Chemical and physical properties of studied soils

Soil type	Ecosystem	pH/KCl	CO ₃ ²⁻	TOC ⁵	CEC ⁶	clay	silt	sand
		[%]			[mmol/kg]	[%]		
Haplic Chernozem	FE ¹	5.89	0.38	2.232	339.91	14.61	32.34	53.05
	ME ²	7.38	6.20	2.210	489.80	15.50	39.01	45.49
	UE ³	7.44	6.06	2.299	491.08	12.22	49.75	38.03
	AE ⁴	6.82	6.13	2.070	290.22	17.44	50.13	32.43
Haplic Luvisol	FE	6.61	0.40	1.395	195.08	10.77	23.00	66.23
	ME	7.63	6.20	1.577	495.51	12.96	49.47	37.57
	UE	7.84	6.20	1.400	489.81	11.44	63.53	25.03
	AE	7.33	7.24	0.889	143.29	13.05	27.36	59.60
Haplic Stagnosol	FE	4.23	0.10	0.725	125.46	16.75	58.01	25.24
	ME	5.13	0.10	0.977	175.43	25.17	36.95	37.88
	UE	4.94	0.10	0.773	191.73	29.87	26.23	43.90
	AE	5.54	0.16	1.162	204.01	25.99	43.64	30.37

¹FE – forest ecosystem, ²ME – meadow ecosystem, ³UE – urban ecosystem, ⁴AE – agro-ecosystem, ⁵TOC – total organic carbon, ⁶CEC – cation exchangeable capacity

characterized by neogene sediments – loess. Neogene bedrock consists of brackish and lake sediments (clays, gravels, and sands). The relief is formed by river terraces, which are a transition from the river floodplains to the hilly area. Wide and shallow valleys of streams divide the hilly area on the system of crests and plateaus (Hók *et al.* 2001). The area is situated in a warm climate with an average annual temperature of 9.3°C and with the average rainfall of 607 mm per year (Korec *et al.* 1997). The Nitra hilly area is highly deforested. In the lower parts oak forests exist, and in higher parts beech forests are presented. Dominant crops in the agro-ecosystem were: cereals (60%), oil crops (30%), forage (5%) and the rest were other crops.

The sampling places on the Haplic Stagnosol are situated in Hrachovo, which is located on the Juhoslovenská basin, in the catchment area of the Ipeľ river. Its geological structure is characterized by marine and brackish sediments (sandstones, sands, clays, marls, and at the edges there are gravels and limestone). The neogene sediments are covered by fluvial – alluvial deposits. The relief is formed with hilly areas and floodplains. River erosion of neogene sediments conditioned the formation of higher lying hilly areas (Šajgalík *et al.* 1986). The area is situated in a warm climate with an average annual temperature of 8.8°C and with the average rainfall of 640 mm per year (Korec *et al.* 1997). In the lower parts the forest, oak, hornbeam and acacia are presented. Dominant crops in the agro-ecosystem were: cereals (60%), forage (20%), oil crops (15%) and the rest were other crops.

Soil samples and analytical methods used

The soil samples for determination of chemical and physical properties were collected in three replicates to a depth of 0.3 m. The soil samples were dried in a constant temperature-room and ground. The soil samples for the determination of soil structure were dried only after being homogenized

The physical analyses included particle size distribution according to pipette methods (Fiala *et al.* 1999) and soil structure by determination of dry-sieved aggregates and water-resistant aggregates according to Bakšejev method. The soil structure was assessed by the aggregate stability index (Henin *et al.* 1969), the coefficient of vulnerability (Valla

et al. 2000), the index of crusting based on particle size distribution (FAO 1979) and soil organic matter and the critical soil organic matter content (Pieri 1991). The total organic carbon was determined by wet combustion (Orlov & Grišina 1981), the total nitrogen was determined by the Kjeldahl method (Fiala *et al.* 1999), group composition of humus substances was determined by the Belčikova and Kononova method (Orlov & Grišina 1981), optical parameters of humus substances by determining of colour quotients of humus substances and humic acids measured at wavelength 425 and 650 nm (Orlov & Grišina 1981), and also the pH of the soil was potentiometrically measured and cation exchange capacity was determined (Fiala *et al.* 1999). Parameters characterizing the quality of humus, like the ratio of carbon of humic acids to carbon of fulvic acids, and C : N ratio, were also calculated.

The obtained data were analysed using Statgraph-ic Plus statistical software. A multifactor ANOVA model was used for individual treatment comparison at $P < 0.05$, with separation of the means by Tukey multiple-range test. Correlation analysis was used to determine the relationships between the quantity and quality of soil organic matter and the particle size distribution and parameters of soil structure parameters. Significant correlation coefficients were tested at $P < 0.05$ and $P < 0.01$.

RESULTS AND DISCUSSION

Formation of aggregates in soil is influenced by several factors that are specific for each soil. Aggregate dynamics is most intensively influenced by the soil organic matter and the particle size distribution. Formation of dry-sieved aggregates was mainly influenced by the amount of soil organic matter. Positive correlations were observed mainly in the range of 1–5 mm size fractions (Table 2). In the case of the largest fraction of macro-aggregates, this correlation was negative. In larger aggregates, the amount of soil organic matter is really higher, but is subject to larger changes as well, especially rapid mineralization (Six *et al.* 2001). In case of the largest fraction of dry-sieved macro-aggregates, positive correlation just with clay fraction was recorded (Table 3). Clay is able to bind a lot of water, which supports

the formation of so-called pseudo-aggregates. If this water is enriched with dissolved carbonates, by drying, links between mineral particles get created, and thus the aggregate hold together. The carbonate content (Table 1) was higher in the agro-ecosystem, because in addition to their natural presence, there was source liming of the soil as well. This shows the highest proportion of the largest fraction of dry-sieved aggregates in the agro-ecosystem only. Organic matter in the case of larger dry-sieved aggregates is quickly oxidized, because it has the lack of physical protection; so in case of its higher proportion such aggregate is disrupted. A negative correlation with the amount of organic matter was recorded in the case of micro-aggregates (Table 2). But for micro-aggregates, the lower content of organic matter is characteristic (Sohi *et al.* 2001), because on their formation mainly the mineral components of soil participate and the cement agent in them are primarily R_2O_3 (Duiker *et al.* 2003) and stabilized organic substances, especially humic acids, which shows a positive correlation between their content and dry-sieved micro-aggregates (Table 2).

In relation to the stability of soil aggregates, mainly the proportion of water-resistant macro-ag-

gregate fractions is important. In their formation, the quality of soil organic matter plays an important role. Sisák (1994) considers the water-resistant aggregates of the 0.5–3 mm size fraction such as agronomically the most valuable aggregate. In our case, a positive correlation between the quality of soil organic matter and water-resistant macro-aggregates of the 1–3 mm size fraction was recorded. The 0.5–1 mm size fraction of water-resistant macro-aggregates, which is still considered to be the most valuable fraction, was not influenced at all – neither through the quality of soil organic matter (Table 2), nor the particle size distribution of soil (Table 3). In case of the studied soil types, the statistically significant differences in all fractions of water-resistant macro-aggregates (0.5–1 mm) were not recorded (Table 4). On the contrary, in case of ecosystems, differences in proportion of water-resistant aggregate fractions were not recorded, in addition to just fraction of 0.5–1 mm. Therefore, this fraction of macro-aggregates seems to be the most suitable for assessing the influence of land use on soil structure. In this case, the 0.5–1 mm size fraction had the highest proportion in the agro-ecosystem, in which agronomically the most valuable macro-aggregates

T a b l e 2

Correlations between the parameters of soil organic matter and dry-sieved and water-resistant aggregates

Aggregates	TOC ¹	NT ²	C : N	C _{HS} ³	C _{HA} ⁴	C _{FA} ⁵	C _{HA} : C _{FA} ⁶	Q _{HS} ⁷	Q _{HA} ⁸
Water-resistant									
2–3 mm	–0.036	–0.214	0.456 ⁺	0.486 ⁺	0.251	0.448 ⁺	–0.205	0.526 ⁺	0.517 ⁺
1–2 mm	–0.062	–0.341	0.669 ⁺⁺	0.488 ⁺	0.480 ⁺	0.379	–0.013	0.383	0.471 ⁺
0.5–1 mm	–0.100	–0.131	–0.063	–0.186	0.116	–0.213	0.115	–0.315	–0.315
0.25–0.5 mm	–0.304	–0.159	–0.518 ⁺	–0.293	0.065	–0.347	0.269	–0.231	–0.344
< 0.25 mm	0.241	0.374	–0.372	–0.574 ⁺⁺	–0.336	–0.523 ⁺	0.331	–0.567 ⁺⁺	–0.495 ⁺
Dry-sieved									
7–10 mm	–0.387	–0.505 ⁺	0.290	0.501 ⁺	0.342	0.429	–0.193	0.501 ⁺	0.446 ⁺
5–7 mm	0.052	0.133	–0.164	–0.062	–0.479 ⁺	0.086	–0.273	0.060	0.021
3–5 mm	0.534 ⁺	0.649 ⁺⁺	–0.132	–0.360	–0.738 ⁺⁺	–0.148	–0.125	–0.291	–0.172
1–3 mm	0.559 ⁺⁺	0.504 ⁺	0.218	–0.459 ⁺	–0.259	–0.401	0.298	–0.437 ⁺	–0.366
0.5–1 mm	0.032	–0.013	0.026	–0.111	0.329	–0.221	0.286	–0.188	–0.235

⁺*P* < 0.05, ⁺⁺*P* < 0.01, ¹TOC – total organic carbon, ²NT – total nitrogen, ³C_{HS} – carbon of humus substances, ⁴C_{HA} – carbon of humic substances, ⁵C_{FA} – carbon of fulvic acids, ⁶C_{HA} : C_{FA} – ration of carbon of humic acids to carbon of fulvic acids, ⁷Q_{HS} – colour quotient of humus substances, ⁸Q_{HA} – colour quotient of humic acids

of the 0.5–3 mm size fraction had also the highest proportion (52.30%). Emadi *et al.* (2009) also reported that ploughed soils have higher proportion of the micro-aggregates and small macro-aggregates (< 0.5 mm). According to Whalen and Chang (2002), the increased proportion of small aggregates (< 1.2 mm) is an important indicator of soil degradation. Relatively balanced content of the 0.5–1 mm size fraction was in the meadow and urban ecosystem, because in both cases it was grassland, indicating a higher influence of vegetation cover than anthropogenic factors influencing the soil properties in urban ecosystem. The lowest content of the 0.5–1 mm size fraction was in the forest ecosystem, but the lowest total content of agronomically the most valuable macro-aggregates was not recorded in this ecosystem. The 0.5–3 mm size fraction of water-resistant aggregates had nearly the same proportion in the forest ecosystem (45.85%) as in meadow (43.31%) and urban ecosystems (41.25%). Agronomically the most valuable aggregates, however, do not necessarily mean the best stability of soil structure, or higher sequestration of carbon in soil.

To assess the overall condition of the soil structure, we can use several parameters, which reflect

not only the main factors involved in the formation of stable soil structure, but also take into account the internal mechanisms operating in aggregate dynamics. In relation to the soil type, statistically significant differences in the case of aggregate stability index (S_w) and critical soil organic matter content (S_c) were recorded (Table 4). In relation to the ecosystem, the highest S_w was recorded in the forest ecosystem. Aggregate dynamics is a reflection of the chemical composition of plant residues. In forest litter, phenols and polyphenols, which are precursors of humus substances (Martens 2000) and lignin are dominated, and support the aggregate formation (Magill & Aber 1998). Second the most stable aggregates were in the agro-ecosystem, with the application of farmyard manure, which is a source of stable humus substances and the number of microorganisms. According to Debosz *et al.* (2002), the carbohydrates of microbial origin resist the degradation better than do the carbohydrates of plant origin. In the meadow ecosystem, an important source of organic matter is mainly root exudates, which belong to the labile fraction of soil organic matter. According to Tisdal and Oades (1982), polysaccharides are easily mineralizable and act rather as temporary



Figure 1. Localities of the soil: 1 – Haplic Chernozem, 2 – Haplic Luvisol, 3 – Haplic Satgnosol

T a b l e 3

Correlations between the particle size distribution and dry-sieved and water-resistant aggregates

Aggregates	0.25–2	0.05–0.25	0.01–0.05	0.001–0.01	< 0.001	< 0.01
	[mm]					
Water-resistant						
2–3 mm	0.023	–0.679 ⁺⁺	0.117	0.540 ⁺	0.655 ⁺⁺	0.824 ⁺⁺
1–2 mm	0.152	–0.709 ⁺⁺	0.039	0.560 ⁺⁺	0.620 ⁺⁺	0.680 ⁺⁺
0.5–1 mm	0.086	0.323	–0.178	–0.281	–0.263	–0.426
0.25–0.5 mm	–0.136	0.822 ⁺⁺	–0.261	–0.642 ⁺⁺	–0.477 ⁺	–0.590 ⁺⁺
< 0.25 mm	–0.279	0.467 ⁺	0.245	–0.351	–0.544 ⁺	–0.653 ⁺⁺
Dry-sieved						
7–10 mm	–0.275	–0.400	0.078	0.584 ⁺⁺	0.631 ⁺⁺	0.718 ⁺⁺
5–7 mm	–0.457 ⁺	0.163	0.110	0.156	0.128	0.113
3–5 mm	–0.272	–0.205	0.510 ⁺	0.182	–0.082	–0.057
1–3 mm	–0.030	–0.318	0.511 ⁺	0.010	–0.135	–0.103
0.5–1 mm	0.443 ⁺	0.206	–0.297	–0.425	–0.323	–0.371
0.25–0.5 mm	0.393	0.477 ⁺	–0.509 ⁺	–0.517 ⁺	–0.365	–0.427
< 0.25 mm	0.416	0.253	–0.541 ⁺	–0.261	–0.117	–0.177

T a b l e 4

Statistical evaluation of dry-sieved and water-resistant aggregates in soil types and ecosystems

Factors	2–3 mm	1–2 mm	0.5–1 mm	0.25–0.5 mm	< 0.25 mm	S _w ⁸	K _v ⁹	S _t ¹⁰	I _c ¹¹
	[%]								[%]
Soil type									
HC ¹	11.72 ^a	18.65 ^b	18.25 ^a	11.51 ^a	21.52 ^b	1.54 ^a	0.30 ^a	6.15 ^c	0.87 ^a
HL ²	6.24 ^a	10.01 ^a	20.95 ^a	29.07 ^b	25.91 ^b	2.03 ^b	0.26 ^a	4.29 ^b	1.06 ^a
HS ³	20.36 ^b	25.31 ^c	14.04 ^a	7.11 ^a	7.21 ^a	1.36 ^a	0.37 ^a	2.61 ^a	1.15 ^a
Ecosystem									
FE ⁴	15.92 ^a	19.28 ^a	10.65 ^a	12.67 ^a	13.24 ^a	2.10 ^b	0.25 ^a	5.77 ^{bc}	0.88 ^a
ME ⁵	14.11 ^a	15.85 ^a	13.35 ^{ab}	9.25 ^a	17.28 ^a	1.37 ^a	0.32 ^a	3.48 ^{ab}	1.28 ^a
UE ⁶	14.01 ^a	14.32 ^a	12.92 ^{ab}	10.87 ^a	20.95 ^a	1.41 ^a	0.38 ^a	2.25 ^a	1.22 ^a
AE ⁷	11.34 ^a	19.12 ^a	21.83 ^b	19.70 ^a	19.00 ^a	1.66 ^a	0.39 ^a	6.82 ^c	0.77 ^a

¹HC – Haplic Chernozem, ²HL – Haplic Luvisol, ³HS – Haplic Stagnosol, ⁴FE – forest ecosystem, ⁵ME – meadow ecosystem, ⁶UE – urban ecosystem, ⁷AE – agro-ecosystem, ⁸S_w – aggregate stability index, ⁹K_v – coefficient of vulnerability, ¹⁰S_t – critical soil organic matter content, ¹¹I_c – index of crusting. Different letters (a, b, and c), between the factors, show statistically significant difference $P < 0.05$ – Tukey test

components for the formation of aggregates. In individual ecosystems, the influence of vegetation cover on the stability of soil aggregates was shown. The highest Sw was in Haplic Luvisol, although the sand fraction had the highest proportion in it. Fine sand fraction was in negative correlation with larger fractions of water-resistant macro-aggregates (1–3 mm) and in positive correlation with smaller macro-aggregates (0.25–0.5 mm) and micro-aggregates. In Haplic Luvisol, the content of these fractions was the highest (Table 3). On the contrary, clay and fine silt fractions were in positive correlation with larger macro-aggregates (1–3 mm) and with small fractions of macro-aggregates (0.25–0.5 mm), and in negative correlation with micro-aggregates. Haplic Luvisol had the highest content of carbonates and the highest value of pH/KCl.

According to the parameter of St, the best soil structure was in Haplic Chernozem; in spite of that, it was evaluated as an unstable structure with a risk of soil degradation. In the case of Haplic Luvisol and Haplic Stagnosol, there is loss of soil structure with high susceptibility to erosion. In relation to the ecosystem, the soil structure in the agro-ecosystem and forest ecosystem can be evaluated as the best soil structure, although it is also an unstable structure with a risk of soil degradation.

CONCLUSION

The most favourable soil structure was in the agro-ecosystem, then in forest, meadow, and urban ecosystem. The soil structure of the Haplic Stagnosol was the worst. Water-resistant macro-aggregates of the 0.5–1 mm size fraction seem to be an important indicator for assessing the ecosystem influence on soil. This fraction was the only one, which was statistically significantly influenced by the ecosystem and the only one, which was not statistically significantly influenced by the soil type. This fraction was not influenced either with the quantity and quality of soil organic matter, or with the particle size distribution.

The quantity of soil organic matter is reflected mainly in relation to the fractional composition of dry-sieved aggregates and its quality in relation to water-resistant aggregates. Larger fractions

(> 1 mm) of water-resistant macro-aggregates were in positive correlation with C : N ratio, the amount of extracted humus substances, and the stability and quality of humic acids; while smaller fractions (< 0.5 mm) were in negative correlation just with these parameters.

Clay and silt fractions influenced the formation of larger water-resistant macro-aggregates positively, while sand fraction negatively, and vice versa.

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