

Stability of soil aggregates and their ability of carbon sequestration

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Abstract

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One of the most important binding agents for forming stable aggregates is a soil organic matter (SOM), which can be retained in various size fractions of aggregates. If aggregates are water-resistant, they retain more carbon. Therefore, the aim of this study was to evaluate the stability of aggregates and their ability of carbon sequestration in different soil types and soil management systems in Slovakian vineyards. The highest content of water-stable macro-aggregates (WSA_{ma}) was determined in Cambisols, and the lowest in Fluvisols. The highest content of WSA_{ma} (size fraction 0.5–3 mm) was determined in Chernozems, decreasing within the following sequence: Fluvisols > Leptosols > Cambisols > Luvisols. The soil type had a statistically significant influence on the re-distribution of soil organic matter in size fractions of water-stable aggregates. The highest content of SOM in water-stable aggregates of the vineyards was determined in grassy strips in-between the vineyard rows in comparison to intensively cultivated rows of vineyard. The highest values of carbon sequestration capacity (CSC) in WSA_{ma} were found in Cambisols > Leptosols and the lowest values of CSC were in Fluvisols. The micro-aggregates represented a significant carbon reservoir for the intensively cultivated soils (rows of vineyard). On the other hand, increasing of macro-aggregates (size fraction 0.5–3 mm) was characteristic for grassland soils (between the rows of vineyard).

Keywords: water-stable aggregates; soil organic matter; vineyards

Soil scientists have described a very large range of soils covering the Earth's surface. Slovakia, despite its small area (4 903 380 ha), is also characterized by a wide range of soil types. On the basis of soil-forming processes, Slovak soils are divided into 10 groups and 21 soil types in total have been reported (Morphogenetic soil classification system of Slovakia, 2000). These soils represent different conditions for growth and development of plants due to their different chemical and physical properties. For example, soil structure is one of the key factors in soil quality (ROGER-ESTRADA *et al.* 2010; ŠIMANSKÝ 2011a) because it plays an important role in forming the optimal physical conditions. Similarly, soil organic matter (SOM) plays an important role in controlling soil quality and resilience through affecting buffering

capacity, microbial biodiversity, water retention, and structural stabilization (BALASHOV & BUCHKINA 2011; KADLEC *et al.* 2012; GAIDA *et al.* 2013). Soil management can be responsible for soil structure changes (BRONICK & LAL 2005; BALASHOV *et al.* 2010; ŠIMANSKÝ 2011a; SLOWINSKA-JURKIEWICZ *et al.* 2013), especially in vineyards (ŠIMANSKÝ 2012; ŠIMANSKÝ *et al.* 2013). The basic unit of the soil structure is the soil aggregate the main characteristic of which is stability. HILLEL (1982) defines aggregate stability as the amount of vulnerability of soil aggregates to destructive external forces. According to AMÉZKETA (1999), two main groups of factors affecting soil aggregate stability can be considered: (1) primary characteristics of the soil or internal factors, and (2) external factors. One

of the most important binding agents for forming stable aggregates is soil organic matter (TISDALL & OADES 1982; POLLÁKOVÁ 2012; ŠIMANSKÝ 2013b). Organic matter affects soil aggregates stability by reducing their 'wettability', and by influencing their mechanical strength (ONWEREMADU *et al.* 2007; KROL *et al.* 2013).

Information on the total organic carbon determined in different size fractions of aggregates is very important because it enables us to calculate the amount of organic matter that can potentially be lost due to the erosion process, which adversely affects the structural condition of the soil (KADLEC *et al.* 2012). Micro-aggregates are faster and more easily taken away by erosion processes than larger macro-aggregates (ŠIMANSKÝ 2011b). High water resistance of aggregates is given by high organic carbon content within aggregates and directly influences soil structure and physical properties. Overall, the soils are the largest C reservoir on Earth (LAL & SHUKLA 2004; SZOMBATHOVÁ 2010). Also, soil aggregation seems to have an important effect on C supplies, and SOM and soil aggregate are closely linked (BLANCO-CANQUI & LAL 2004). ELLIOTT and COLEMAN (1988) suggest that a major accumulator of organic matter may be various size fractions of soil aggregates.

Vineyard soils are strongly influenced by anthropogenic activities. Often, prior to the vineyard foundation, the original soil type is intentionally transformed what is reflected in the structural condition and capacity of the soil to retain organic carbon.

The aim of this study was to evaluate the stability of aggregates and their ability of carbon sequestration in different soil types and soil management systems.

MATERIAL AND METHODS

During the years 2005–2011, a soil survey was conducted at three selected wine-growing sites (Južnoslovenská, Nitrianska, and Tokaj) characterized by different geological substrates and climatic conditions. The soils were classified according to the World Reference Base for Soil Resources (WRB 2006). Mean annual temperatures and mean annual precipitation as well as the classified soil types and their characteristics are presented in Table 1.

In productive vineyards, the integrated system of cultivation is performed. Before sampling, two pits were excavated at each locality: the first in the vineyard rows and the second in-between the rows (22 soil pits were dug in total). In the vineyard rows the soil was tilled each year to a medium depth of

0.25 m and intensively cultivated with hoes during the growing season, while the strips in-between the vineyard rows were grassed.

The soil pits were dug in the following order: in spring 2005 – Malá Trňa; in spring 2006 – Viničky, Dúlovce; in spring 2008 – Dvory nad Žitavou, in spring 2009 – Šoporňa; in spring 2010 – Bajč, Malá Máňa; and in spring 2011 – Dražovce (Luvisols), Dražovce (Leptosols), Oponice, and Vráble. The soil samples were taken from the 0–0.3 m depth from all 22 soil pits. The samples intended for determination of soil organic matter parameters were dried at laboratory temperature and grinded. Analyses were performed on soil samples sieved at 2 mm, using standard methods. We determined the organic carbon content (C_{org}) according to Tyurin in modification of Nikitin (DZIADOWIEC & GONET 1999), the fraction composition of humus substances according to Belchikova and Kononova (DZIADOWIEC & GONET 1999), and the optical parameters of humus substances and humic acids. The labile carbon content (C_L) (ŁOGINOW *et al.* 1987) and hot-water soluble carbon levels (C_{HWD}) (KÖRSCHENS 2002) were determined as well. For aggregate stability analysis, undisturbed soil samples were taken from the same depth of the soil pits. These soil samples were also air-dried at laboratory temperature, pre-sieved over a series of sieves, and then bulked into seven size fractions (> 7, 7–5, 5–3, 3–1, 1–0.5, 0.5–0.25, < 0.25 mm). These size fractions (dry sieve) were used for determination of water-stable aggregates (WSA). Their sizes were as follows: > 5, 5–3, 3–2, 2–1, 1–0.5, 0.5–0.25 (macro-aggregates), and < 0.25 mm (micro-aggregates). In the size fractions of WSA, we measured organic carbon (C_{org}) according to Tyurin in modification of Nikitin (DZIADOWIEC & GONET 1999) and labile carbon content (C_L) (ŁOGINOW *et al.* 1987). The soil carbon sequestration capacity in size fractions of water-stable aggregates (CSC) was calculated according to equation 1:

$$\text{CSC} = \frac{C_{\text{org}} - C_L}{C_L} \quad (1)$$

where:

C_{org} – content of organic carbon (mg/100 g) in size fraction of water-stable aggregates

C_L – content of labile carbon (mg/100 g) in the same size fraction of water-stable aggregates

SOM, WSA, SOM in WSA and CSC differences between soil types and soil management practices were determined by Multifactor Analysis of Variance (ANOVA). The LSD test was used for evaluating

Table 1. Experimental site locations with basic information

Wine-growing area	Locality	Location	Soil type (WRB 2006)	Soil management	Main characteristics of soil to the depth of 0.3 m (ŠIMANSKÝ 2013a)							
					Mean annual		C _{org}		pH	clay (%)		
					temperature (°C)	precipitation (mm)	C _{org} (%)	C _L				
Júžnoslovenská	Bajč	47°55'22.48"N	Haplic	vineyard rows	10.4	566	0.93	0.16	1.62	19.2	7.80	7.21
		18°13'6.22"E	Chernozem	grassed in-between strips	10.4	566	1.05	0.18	1.41	20.4	7.03	6.68
	Dúľovce	47°52'14.69"N	Haplic	vineyard rows	10.4	566	0.75	0.22	0.86	9.8	5.89	5.71
		18°17'38.52"E	Chernozem	grassed in-between strips	10.4	566	0.93	0.16	0.97	8.4	6.05	7.06
	Dvory nad Žitavou	47°59'0.28"N	Haplic	vineyard rows	10.4	566	1.05	0.10	1.82	45.1	8.60	7.99
		18°17'34.21"E	Chernozem	grassed in-between strips	9.7	580	1.20	0.13	0.93	49.1	8.49	
Nitrianska	Dražovce	48°21'22.50"N	Haplic	vineyard rows	9.7	580	0.98	0.14	0.74	14.0	7.98	20.7
		18°3'24.80"E	Luvisol	grassed in-between strips	9.7	580	1.43	0.20	0.93	16.4	7.90	
	Dražovce	48°20'49.21"N	Rendzic	vineyard rows	9.7	580	1.46	0.23	1.08	12.0	7.68	10.1
		18°4'36.30"E	Leptosol	grassed in-between strips	10.4	566	1.85	0.26	1.31	8.4	7.79	
	Malá Máňa	48°8'22.09"N	Luvi-Haplic	vineyard rows	9.3	607	1.31	0.19	1.66	7.6	7.86	25.7
		18°17'50.40"E	Chernozem	grassed in-between strips	9.3	607	1.64	0.26	2.11	14.0	7.59	
Oponice	48°26'38.47"N	Rendzic	vineyard rows	9.8	568	1.01	0.07	0.83	18.8	7.95	11.8	
	18°8'48.69"E	Leptosol	grassed in-between strips	9.8	568	1.27	0.14	0.82	15.6	8.12	7.6	
Šoporňa	48°15'44.36"N	Calcaric	vineyard rows	9.3	580	1.42	0.26	0.91	8.4	8.02	16.4	
	18°49'23.64"E	Fluvisol	grassed in-between strips	9.3	580	1.62	0.29	0.89	8.4	8.14		
Vráble	48°15'48.47"N	Stagni-Haplic	vineyard rows	9.3	580	0.88	0.12	0.84	21.6	7.10	7.21	
	18°16'52.52"E	Luvisol	grassed in-between strips	9.3	580	2.17	0.31	0.94	19.2	7.54	6.68	
Tokaj	Viničky	48°23'53.08"N	Eutric	vineyard rows	9.0	564	1.09	0.13	1.20	28.5	7.49	13.9
		21°43'10.69"E	Cambisol	grassed in-between strips	9.0	564	1.20	0.17	1.17	25.7	7.42	
Malá Trňa	Malá Trňa	48°26'46.77"N	Dystric	vineyard rows	9.0	564	1.44	0.28	0.53	16.8	5.99	11.8
		21°41'21.75"E	Cambisol	grassed in-between strips	9.0	564	2.71	0.45	0.68	16.1	6.19	7.57

C_{org} – organic carbon (DZIADOWIEC & GONET 1999); C_L – labile carbon (ŁOGINOW *et al.* 1987); C_{HA}:C_{FA} – carbon of humic acids and fulvic acids ratio (DZIADOWIEC & GONET 1999); CEC – cation exchange capacity (FIALA *et al.* 1999); pH – soil pH_{H₂O} (1:2.5 – soil:water); clay – content of clay determined by pipette method (FIALA *et al.* 1999)

the means in the case of significant ANOVA results (P -values < 0.05). Correlation analysis was applied to determine the relationships between SOM and water-stable aggregates and quantity of SOM in size fractions of water-stable aggregates. All statistical analyses were carried out using STATGRAPHICS Centurion XVI.I software (Statpoint Technologies, Inc., USA).

RESULTS AND DISCUSSION

Water-stable aggregates. In a productive vineyard, the content of water-stable micro- and macro-aggregates depended on the soil type and soil management practices (Table 2). In Fluvisols, contents of water-stable micro-aggregates (WSA_{mi}) were the highest, while in Cambisols they were nearly half this amount. On the other hand, the highest content of water-stable macro-aggregates (WSA_{ma}) of all the soil types was determined in Cambisols and the lowest in Fluvisols. Macro-aggregates in 0.5–3 mm size fractions (WSA_{ma} 0.5–3 mm) are important from the agronomical point of view. The highest content of WSA_{ma} 0.5–3 mm was determined in Chernozems, decreasing in the order Fluvisols $>$ Leptosols $>$ Cambisols $>$ Luvisols. In Fluvisols, the lack of $WSA_{ma} > 3$ mm size fractions reflected in the highest contents of WSA_{mi} as well as in favourable contents of WSA_{ma} 0.5–3 mm. In Cambisols, the highest content of WSA_{ma} was associated with SOM (ŠIMANSKÝ 2013a). However, the highest content of SOM was detected in Fluvisols, where the highest content of WSA_{ma} was not determined. In this case (Fluvisols), the soil structure had the highest level of vulnerability. That means the soil aggregates had very low stability due to their sweating following break down. Several authors (IGWE *et al.* 1999; LADO *et al.* 2004) found no positive correlations between

SOM and aggregate stability. It means that SOM is the only factor responsible for aggregation processes and the mechanisms of the aggregate forming can be based on other principles, for example the bonding between mineral elements and sesquioxides, or on physical and chemical properties of clay minerals (GOLDBERG & GLAUBIG 1987; KÖGEL-KNABNER *et al.* 2008). In the case of Cambisols, the highest contents of WSA_{ma} could be due to the bond between SOM and mineral elements. Of course this effect can be stronger when oxides, hydroxides, sesquioxides of iron and aluminium occur in the soils (GOLDBERG *et al.* 1988; AMÉZKETA 1999; BRONICK & LAL 2005; WISEMAN & PÜTTMANN 2006). Overall, the highest contents of WSA_{ma} were determined in grassed strips in-between the vineyard rows (Table 2). On the other hand, the contents of WSA_{mi} were statistically significantly higher in the rows of the vineyard under intensive soil cultivation. These findings are consistent with the results of ZHAO *et al.* (2008), who also recorded lower contents of WSA_{ma} as a result of nearly 100 years of conventional tillage system.

Organic matter in water-stable aggregates. Soil types had a statistically significant influence on the re-distribution of organic matter in the size fractions of WSA (Table 3). The highest average contents of organic carbon (C_{org}) and labile carbon (C_L) in WSA were determined in Fluvisols, and the lowest in Chernozems. Average contents of C_{org} and C_L in WSA_{ma} 0.5–3 mm were nearly identical in all soil types. This means that the agronomically favourable macro-aggregates in size fractions 0.5–3 mm can be significant stabilizers of SOM. NWADIALO and MBAGWU (1991) argued that the quantity of organic matter does not affect the stability of micro-aggregates if the values of C_{org} are low (below a critical level in the soil). In Fluvisols, in the size fractions of $WSA_{ma} > 1$ mm

Table 2. Statistical evaluation of water-stable micro- and macro-aggregates

Size fractions of water-stable aggregates (mm)	Soil type					Soil management	
	Chernozems	Luvisols	Leptosols	Cambisols	Fluvisols	vineyard rows	grassed strips in-between rows
< 0.25	20.99 ^a	20.13 ^a	28.96 ^b	19.40 ^a	34.28 ^b	29.97 ^b	19.53 ^a
0.25–0.5	23.57 ^b	19.04 ^{ab}	9.97 ^a	10.56 ^a	21.1 ^{ab}	21.28 ^b	12.41 ^a
0.5–1	26.57 ^b	15.11 ^{ab}	11.51 ^a	11.68 ^a	33.22 ^b	18.39 ^a	20.85 ^a
1–2	13.58 ^{ab}	13.06 ^{ab}	16.54 ^b	14.24 ^{ab}	6.22 ^a	12.65 ^a	12.81 ^a
2–3	7.05 ^a	10.73 ^{ab}	16.42 ^b	15.11 ^b	5.18 ^a	9.35 ^a	12.44 ^a
3–5	4.43 ^{ab}	8.18 ^b	16.60 ^c	17.58 ^c	0.10 ^a	6.11 ^a	12.65 ^b
> 5	2.77 ^{ab}	13.83 ^b	0.10 ^a	11.43 ^b	0.10 ^a	1.90 ^a	9.39 ^b

^{a-c}treatment means are significantly different at $P < 0.05$ according to LSD multiple range test

Table 3. Statistical evaluation of organic and labile carbon contents in size fractions of water-stable aggregates

Parameters (%)	Size fractions of water-stable aggregates (mm)	Soil type					Soil management	
		Chernozems	Luvisols	Leptosols	Cambisols	Fluvisols	vineyard rows	grassed strips in-between rows
C_{org}	< 0.25	0.93 ^a	1.11 ^a	1.13 ^a	1.35 ^{ab}	1.47 ^b	1.14 ^a	1.24 ^a
	0.25–0.5	0.97 ^a	1.35 ^b	1.32 ^{ab}	1.45 ^b	1.38 ^b	1.24 ^a	1.35 ^a
	0.5–1	1.05 ^a	1.35 ^{ab}	1.44 ^{ab}	1.60 ^b	1.51 ^b	1.32 ^a	1.46 ^a
	1–2	1.11 ^a	1.44 ^{ab}	1.43 ^{ab}	1.54 ^b	1.57 ^b	1.34 ^a	1.49 ^a
	2–3	1.15 ^a	1.46 ^{ab}	1.38 ^a	1.46 ^{ab}	1.56 ^b	1.33 ^a	1.49 ^a
	3–5	1.19 ^a	1.59 ^{ab}	1.43 ^a	1.55 ^{ab}	1.69 ^b	1.48 ^a	1.50 ^a
	> 5	1.17 ^a	1.42 ^a	1.50 ^{ab}	1.55 ^{ab}	1.61 ^b	1.29 ^a	1.49 ^a
C_{L}	< 0.25	0.13 ^a	0.17 ^{ab}	0.16 ^{ab}	0.13 ^a	0.18 ^b	0.14 ^a	0.16 ^b
	0.25–0.5	0.14 ^a	0.24 ^b	0.18 ^{ab}	0.15 ^a	0.24 ^b	0.18 ^a	0.20 ^b
	0.5–1	0.15 ^a	0.24 ^{ab}	0.17 ^{ab}	0.17 ^{ab}	0.30 ^b	0.19 ^a	0.22 ^b
	1–2	0.16 ^a	0.23 ^b	0.18 ^a	0.20 ^{ab}	0.29 ^c	0.21 ^a	0.22 ^a
	2–3	0.16 ^a	0.25 ^b	0.18 ^a	0.18 ^a	0.29 ^c	0.20 ^a	0.23 ^a
	3–5	0.16 ^a	0.26 ^{bc}	0.17 ^{ab}	0.20 ^{abc}	0.31 ^c	0.20 ^a	0.24 ^a
	> 5	0.17 ^a	0.21 ^{ab}	0.17 ^a	0.19 ^a	0.34 ^b	0.21 ^a	0.22 ^a

C_{org} – organic carbon, C_{L} – labile carbon; ^{a–c}treatment means significantly different at $P < 0.05$ according to LSD multiple range test

(statistically significant), the highest contents of C_{org} were determined. However, organic matter was not sufficiently protected against microbial decomposition, as evidenced by the high values of C_{L} in WSA. It points to the probable presence of a particular organic matter derived from partially decomposed plant and root residues (CAMBARDELLA & ELIOT 1992; ŠIMANSKÝ 2013b), possibly the grasses growing in and between the vineyard rows, which were the subject of intense degradation by micro-organisms due to the high content of sand fraction in the soils (sand content 70%, silt content 14%, clay content 16%). As mentioned above, Fluvisols contained 70% of sand which influenced the aggregation processes and the largest size of WSA_{ma} (> 3 mm) was not formed at that location. As reported in ŠIMANSKÝ (2012), the higher the contents of organic matter in active forms (not physically protected) in the soil, the less the aggregation and soil structure stability. At the same time, increasing of C_{org} and C_{L} in WSA resulted in the increase of the size fractions of WSA. This trend had a statistically significant linear character in Chernozems (C_{org} : $r = 0.960$; $P < 0.001$; C_{L} : $r = 0.929$; $P < 0.01$) > and in Fluvisols (C_{org} : $r = 0.840$; $P < 0.05$; C_{L} : $r = 0.904$; $P < 0.01$). Overall, the highest content of C_{org} and C_{L} in WSA was determined in the grassy strips in-between the vineyard

rows, rather than in the intensively cultivated rows themselves. This can be seen as a result of tillage and the intensive cultivation of soil (BEARE *et al.* 1994; ŠIMANSKÝ *et al.* 2008; BALASHOV & BUCHKINA 2011; GAIDA *et al.* 2013).

Carbon sequestration capacity in water-stable aggregates. Of the soil types, the highest values of carbon sequestration capacity (CSC) in WSA_{ma} were in Cambisols > Leptosols and the lowest in Fluvisols. As for the size fractions of water-stable aggregates, the highest values of CSC in WSA_{mi} (8.42) but also in WSA_{ma} (9.66) were detected in Cambisols, due to the high resistance of the soil structure, and: (i) association of SOM with clay minerals and Fe and Al oxides, (ii) sequestration into macro- and micro-pores of soil aggregates; and (iii) biochemical stabilization (CHENU & PLANTE 2006; VON LÜTZOV *et al.* 2008). Relatively high values of CSC in WSA_{mi} (7.24) were also in Fluvisols but, on the other hand, this soil type had the lowest CSC in WSA_{ma} (4.39). This fact was a reflection of the high vulnerability of larger aggregates in Fluvisols. The CSC depends not only on the return of organic matter into the soil, but also on the capacity of soil to accumulate SOC, which has certain limits. In some cases, the long-term application of high rates of organic fertilizers is accompanied by a continuous rise in the soil SOC

concentration. In other cases, the soil saturation with organic carbon takes place relatively quickly, so that the additional inputs of organic matter are subjected to rapid mineralization (Six *et al.* 2002). Soil management practices had a statistically significant influence on the carbon sequestration capacities in the size fractions of WSA (ŠIMANSKÝ 2013b). SEMENOV *et al.* (2008) showed that the CSC values in arable soil are higher than in the soils of natural ecosystems. Therefore, from the point of view of carbon sequestration, such methods of management (for example the application of organic fertilizers and crop residues, minimal tillage or no-tillage, etc.) increase the carbon content in the soil. Grass growing on the strips between the vineyard rows had a positive effect on CSC in WSA_{ma}. The values of CSC were higher here by 12% in WSA_{ma} and by 23% in WSA_{ma} 0.5–3 mm compared to those detected in the soil in vineyard rows which was under intensive cultivation. In intensively cultivated rows, the values of CSC in WSA_{mi} were higher (by 15%) in comparison to those from the grassy strips in-between the vineyard rows. TISDALL and OADES (1980) reported that higher carbon content is in the macro- rather than in the micro-aggregates and also its content is influenced by the land use or soil management practices used (BALASHOV & BUCHKINA 2011; ŠIMANSKÝ 2012; GAIDA *et al.* 2013). For example, TISDALL and OADES (1980) also reported that due to a greater biomass (plant roots, microscopic fungal hyphae), in soils from meadows or native grasslands the carbon content in macro-aggregates is higher. From the presented results (Table 4) we concluded that in intensively cultivated soil the micro-aggregates are a significant reservoir for carbon sequestration; however, in grassed soils the macro-aggregates are

very important, especially size fractions WSA_{ma} 0.5–3 mm.

Relationships between SOM and water-stable aggregates. Aggregates are formed mostly by the action of humic substances on mineral particles. The higher the content of hot-water soluble carbon in the soil was, the higher was the size fraction of WSA_{ma} > 5 mm ($r = 0.428$, $P < 0.05$). It means that root exudates and metabolic products of microorganisms were participated in the formation and stabilization of WSA >5 mm. The results published by GIJSMAN and THOMAS (1995) confirmed this fact. On the other hand, the higher the ratio of C_{HA}:C_{FA} (indicator of humus quality) in the soil was, the lesser was the size fraction of WSA_{ma} 2–3 mm. Overall, the humus quality negatively affected the increase of fractions of larger macro-aggregates, while smaller macro- and micro-aggregates acted positively on their stability, but without statistical significance (except WSA_{ma} 2–3 mm). Humus stability was correlated with the size fraction of WSA_{ma} 0.25–0.5 mm, however, this effect was not observed in larger size fractions of WSA_{ma}. The negative effect of the stability of humic substances on the larger water-stable macro-aggregates was also confirmed.

Relationships between SOM and organic matter in size fractions of water-stable aggregates. As mentioned above, the SOM is a very important factor for aggregation processes (BALASHOV *et al.* 2010; SLOWINSKA-JURKIEWICZ *et al.* 2013). Therefore, we calculated the correlations between SOM and organic carbon and labile carbon in size fractions of WSA. High positive correlations between SOM and organic carbon and the labile carbon in WSA were ascertained. In addition, increasing of organic carbon in the soil caused elevation of its content in size fractions of WSA.

Table 4. Statistical evaluation of carbon sequestration capacity in size fractions of water-stable aggregates

Size fractions of water-stable aggregates (in mm)	Soil type					Soil management	
	Chernozems	Luvissols	Leptosols	Cambisols	Fluvisols	vineyard rows	grassed strips in-between rows
< 0.25	6.30 ^{ab}	5.88 ^a	7.96 ^b	8.42 ^b	7.24 ^a	7.67 ^b	6.66 ^a
0.25–0.5	6.11 ^{ab}	4.93 ^a	7.75 ^{ab}	9.12 ^b	4.98 ^a	6.34 ^a	6.82 ^a
0.5–1	5.97 ^a	4.93 ^a	8.94 ^b	12.88 ^c	4.09 ^a	6.91 ^a	7.81 ^a
1–2	5.62 ^{ab}	5.32 ^{ab}	7.91 ^c	9.92 ^d	4.45 ^a	5.46 ^a	7.82 ^b
2–3	6.05 ^b	5.40 ^{ab}	7.51 ^c	9.40 ^d	4.46 ^a	6.09 ^a	7.04 ^b
3–5	6.50 ^{ab}	5.27 ^{ab}	8.11 ^b	7.77 ^{ab}	4.46 ^a	6.91 ^b	5.93 ^a
> 5	6.02 ^b	5.77 ^b	8.65 ^c	8.87 ^c	3.90 ^a	6.33 ^a	6.95 ^a

^{a–d}treatment means significantly different at $P < 0.05$ according to LSD multiple range test

CONCLUSION

According to the content of macro-aggregates in 0.5–3 mm size fractions (important from the agronomical viewpoint), the soils ranged in a decreasing order: Chernozems > Fluvisols > Leptosols > Cambisols > Luvisols.

We concluded that in intensively cultivated soil the micro-aggregates are a significant reservoir for carbon sequestration; however, in grassed soils the macro-aggregates are very important, especially the size fractions WSA_{ma} 0.5–3 mm.

All in all, the results point out the substantial role of SOM as one of the most significant soil factors positively affecting formation of a favourable soil structure in intensively exploited soils of Slovakian vineyards; therefore, it is very important to pay attention to the quantity and quality of organic matter in relation to soil structure, especially under productive vineyards.

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