EFFECT OF CARBONATES AND BIVALENT CATIONS AND THEIR RELATIONSHIPS WITH SOIL ORGANIC MATTER FROM THE VIEW POINT OF AGGREGATE FORMATION

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ŠIMANSKÝ, V. – KOLENČÍK, M. – PUŠKELOVÁ, L.: Effects of carbonates and bivalent cations and their relationships with soil organic matter from the view point of aggregate formation. *Agriculture (Poľnohospodárstvo)*, vol. 60, 2014, no. 3, pp. 77–86.

The effect of carbonates on soil structure has not been sufficiently studied yet, despite the fact that in the literature their positive impact is mentioned mostly. Carbonates are the source of bivalent cations in soil solution and may be involved in stabilization of the aggregates, because negatively charged organic materials can be adsorbed onto the surface of clay by bivalent or polyvalent cations. We studied the effect of carbonates and bivalent cations and their relationships with soil organic matter (SOM) from the point of view of aggregate formation. The studies were carried out in several fields located on loamy Calcaric Chernozem, loamy Haplic and Mollic Fluvisols. The results showed that between exchangeable Mg^{2+} and water-stable macro-aggregates (WSA_{ma}) in size fractions >2 mm, positive correlations were found; however, the content of Mg^{2+} negative correlated with the contents of WSA_{ma} in <1 mm fractions as well as with water-stable micro-aggregates (WSA_{mi}). The threshold limit

for Mg^{2+} content for the formation of water-stable macro-aggregates was at 11.5 cmol/kg if all loamy soils were assessed together. A further increase resulted in a lower content of WSA_{ma} . If all investigated soils were assessed separately, these results did not enable us to distinguish the maximum formation of WSA_{ma} by Mg^{2+} in individual soils. We observed a positive correlation between the sum of basic exchangeable cations (SBC) as well as between cation exchange capacity (CEC) and larger size fractions of $WSA_{ma} >2$ mm; however, between SBC as well as CEC and smaller size fractions of $WSA_{ma} <1$ mm and WSA_{mi} negative correlations were observed. Statistically significant negative correlations were observed between SOM content in WSA and carbonate content, and this effect was stronger in relation to the labile carbon. There were also positive correlations between SOM in WSA and SBC and CEC found if all loamy soils were assessed together.

Key words: soil structure, aggregation, soil organic carbon, Chernozem, Fluvisol

An understanding of causes for soil structure development has a practical importance because structure has a great influence on soil physical properties and plant growth, and it is an important feature in soil diagnostic horizons being base in soil classifi-

cation as well. The process of soil aggregates formation (called aggregation) is the first step in the development of soil structure. Evidently, there must be some agents drawing the particles together to produce aggregates and also some means by which

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they are bound rather firmly, so that the structural forms may persist. There are several theories concerning the aggregation process (Tisdall & Oades 1982; Tisdall 1996; Amézketa 1999; Lal & Shukla 2004; Six *et al.* 2004; Blanco-Canqui & Lal 2007; Krol *et al.* 2013), which influences exogenous driving forces and the endogenous interactive forces. In the soil of Slovakia, the most important effect on aggregation has soil organic matter (SOM) (Šimanský 2012a; Šimanský & Bajčan 2014) because SOM is one of the most important factors responsible for binding soil mineral particles together (Six *et al.* 2004; Bronick & Lal 2005; Guggenberger *et al.* 2008; Šimanský & Bajčan 2014), and this effect can be more intensive if soils contain free cations (Chan & Heenan 1999). For example, positive effect of exchangeable Ca^{2+} and Mg^{2+} on aggregate stability in Haplic Luvisol was confirmed by the results of Šimanský (2012b). Negatively charged organic materials, such as polysaccharides, are adsorbed onto the surface of clay by Ca^{2+} or other polyvalent cations (Lal & Shukla 2004). The effect of carbonates on soil structure has not yet been sufficiently studied, despite the fact that in literature (Le Bissonnais 1996; Amézketa 1999; Boix-Fayos *et al.* 2001) mostly their positive impact is mentioned. For example, Vaezi *et al.* (2008) studied the effect of CaCO_3 on the stability of aggregates in the surface layers of soils in Italy and Iran. There was a positive correlation between calcium carbonate content and aggregates stability index. On the other hand, the results of Cerda (1996) and Lado *et al.* (2004) did not confirm this fact. Le Bissonnais (1996) stated that the effect of CaCO_3 on the stability of aggregates is likely depending on its particle size distribution and clay content. This effect is more intensive, if soils contain enough clay and CaCO_3 particle size is lesser than the size fraction of the silt. From this perspective, it would be interesting to know whether the effect of carbonates is sufficient for the formation of favourable soil structure in loamy soils. Under this context, we hypothesized that in soils such as Chernozems or Fluvisols (different soil types – based on the whole-profile soil morphology), which are the most fertile in Slovakia due to optimal chemical and physical properties (Bielek *et al.* 1998), the content of carbonates (source of bivalent cations) will be very important. In addition, several

studies (Zhang & Norton 2002; Lal & Shukla 2004; Bronick & Lal 2005) and as is mentioned above, the soil aggregates can be formed by SOM and mineral particles through cationic bridging. In general, carbonates are the source of Ca^{2+} and Mg^{2+} , which can leach into the soil solution and may be involved in the stabilization of aggregates (Bronick & Lal 2005).

Therefore, in this work the following were assessed: (1) the effect of carbonates and bivalent cations on the formation of individual size fractions of water-stable aggregates (WSA) and (2) testing the relationships between the content of SOM in WSA and the content of carbonates and bivalent cations if all investigated soils were assessed separately as well as together.

MATERIAL AND METHODS

Studied areas are located in the north-west part of Danube lowland (Figure 1). Geological substrates of the mentioned region are neogene clays, sands and gravels, in most such areas they are covered with loess and loess loam. Fluvial sediments are found along the Váh and Dudváh rivers. Soil samples were collected from the 0–0.2 m of A-horizons of Calcic Chernozem, Haplic and Mollic Fluvisols (soil types classified according to the WRB 2006) at the fields in Bučany, Šulekovo and Trakovice, respectively. The sites have a temperate climate. The aver-

Figure 1. Selected sites in Slovakia

age monthly precipitation and temperatures in 2011 were as follows: the average annual temperature is 10.1°C and average precipitation 501 mm. The soils are deep, with weakly alkaline pH. Soils are loamy, with average content of sand, silt and clay – 43%, 42% and 15%, respectively. Other soil characteristics in the top layer (0–0.2 m) are shown in Table 1.

All soils are used as arable land, with intensive cultivation of crops. In 2011, the sugar beet (*Beta vulgaris* L. var. *altissima*) was grown in all fields. The crop previous to sugar beet was spring barley (*Hordeum sativum* L.) in all cases. In autumn 2010, the soils were ploughed to the depth of 0.25 m, and in case of Haplic Fluvisol the farmyard manure in dose of 40 t/ha was applied. Within the first decade of May, the sugar beet was sown in all fields.

Four different places were chosen on each field and the soil samples were always taken from these areas. Soil samples were taken from the depth of 0–0.2 m during the growing season of sugar beet in 2011 (May, 25; June, 18; July, 15; August, 14; September, 15 and October, 16). In laboratory, the large clods of soil were gently broken up along the natural fracture lines, and soil samples for the determination of individual size fractions of aggregates (undisturbed soil samples) were obtained. Part of the soil samples was grinded before analysis and we obtained soil samples for the determination of chemical characteristics. We determined soil pH – potentiometrically in the supernatant suspension of a 1:2.5 soil/distilled water (Fiala *et al.* 1999). Soil colloidal complex was characterized by the sum of

basic exchangeable cations (SBC) and cation exchange capacity (CEC), which were determined. We also determined the contents of exchangeable cations such as Ca^{2+} and Mg^{2+} by Kappen method (Fiala *et al.* 1999). Carbonates were determined by volumetric method using a Jankov calcimeter, based on the CO_2 evolution after reacting with HCl (diluted with water in a 1:3 ratio). Soil organic carbon content (C_{org}) was measured using the wet combustion method (oxidation of SOM by a mixture of 0.07 mol/dm³ H_2SO_4 and $\text{K}_2\text{Cr}_2\text{O}_7$ with titration using Mohr's salt), according to Tyurin (Dziadowiec & Gonet 1999). In the grinded soil samples, particle-size distribution was determined by pipette method (Fiala *et al.* 1999). On the other hand, in undisturbed soil samples, individual size fractions of aggregates were determined by sieving 250 g of soil through sieves with diameter >7, 7–5, 5–3.15, 3.15–1, 1–0.5, 0.5–0.25 and <0.25 mm with amplitude 1.2 for 10 min in the AS 200 (dry sieving) device. These size fractions of air-dried aggregates were used for the determination of WSA distribution by Baksheev method (Vadjunina & Korchagina 1986). Following size fractions of WSA >5, 5–3, 3–2, 2–1, 1–0.5, 0.5–0.25 (macro-aggregates) and <0.25 mm (micro-aggregates) were determined. In size fractions of WSA, the soil organic carbon content (C_{org}) was also determined (above-mentioned) according to Tyurin (Dziadowiec & Gonet 1999), and labile carbon content (C_L) was determined using 0.005 mol/dm³ KMnO_4 (Loginow *et al.* 1987). Hence, soils that have difference between the Ca^{2+}

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Soil characteristics in the top layer (0–0.2 m)

Soil types	pH	CEC	Ca^{2+}	Mg^{2+}	CO_3^-	C_{org}	sand	silt	clay
		[cmol/kg]			[%]	[g/kg]	[%]		
Calcaric Chernozem	7.8±0.04	18.7±0.12	9.3±1.5	7.6±2.1	9.28±1.04	11.9±0.08	43±3.95	47±3.17	10±1.48
Haplic Fluvisol	7.6±0.06	17.8±0.16	10.3±1.1	10.5±2.1	2.12±0.27	21.2±0.11	38±6.13	40±2.85	17±3.94
Mollic Fluvisol	7.8±0.03	17.2±0.20	8.6±1.4	12.4±3.5	11.6±0.94	19.2±0.12	47±3.69	38±4.29	14±1.83

pH – soil $\text{pH}_{\text{H}_2\text{O}}$, CEC – cation exchange capacity, CO_3^- – content of carbonates, C_{org} – soil organic carbon content

and Mg^{2+} contents were carried out using X-ray diffraction analysis (XRD) for further examination of mineral composition. This method was directly oriented to the identification of primary and secondary crystalline phases (including clay minerals) from a typical soil aggregates (alluvial sediments) obtained from Trakovice and Šulekovo. Crystalline symmetry and structure parameters of solid phase were studied by X-ray powder diffraction (XRD) analysis, using the diffractometer PW1710 (Philips, The Netherlands) under the following conditions: Bragg-Brentano geometry (Theta-2Theta), Cu anti-cathode ($\lambda\alpha_1 = 1.54060 \text{ \AA}$), accelerating voltage 40 kV, beam current 40 mA. The step size was $0.01^\circ 2\theta$, the step time was 1 s per one step and the range of the measurement was $4\text{--}65^\circ 2\theta$.

The interrelations between SOM in WSA, chemical properties and individual size fractions of the WSA were determined through correlation matrix using the Statgraphics Centurion XVI (Statpoint Technologies, Inc., USA). For the expression of dynamics of individual size fractions of WSA as well as for SOM in WSA, the quadratic polynomial regression models were used.

RESULTS AND DISCUSSION

As mentioned in Table 1, despite the fact that the soil had different genesis they had weakly alkaline pH, good CEC and their texture was classified as loamy. In Haplic and Mollic Fluvisols, a higher

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Dynamics of water-stable aggregates and soil organic matter content in water-stable aggregates

Content of water-stable aggregates in %									
Soil type	Water-stable aggregates	Date of sampling						Polynomial model	
		May, 25	June, 18	July, 15	August, 14	September, 15	October, 16	R ²	<i>P</i>
Calcaric Chernozem	WSA _{ma}	82	64	62	56	61	84	0.928	0.01
	WSA _{mi}	18	36	38	44	39	16		
Haplic Fluvisol	WSA _{ma}	73	88	86	92	88	94	0.768	0.05
	WSA _{mi}	27	12	14	8	12	6		
Mollic Fluvisol	WSA _{ma}	91	90	93	96	91	88	0.591	n.s.
	WSA _{mi}	9	10	7	4	9	12		
C _{org} in WSA [g/kg]									
Calcaric Chernozem	WSA _{ma}	11.10	12.00	11.70	15.90	12.90	11.80	0.445	n.s.
	WSA _{mi}	9.20	8.90	9.10	9.80	9.60	9.20	0.294	n.s.
Haplic Fluvisol	WSA _{ma}	21.80	21.40	21.10	21.90	20.40	20.80	0.442	n.s.
	WSA _{mi}	17.80	18.20	18.30	16.50	14.70	19.60	0.193	n.s.
Mollic Fluvisol	WSA _{ma}	18.10	19.20	19.80	19.10	19.50	19.10	0.730	0.05
	WSA _{mi}	14.60	14.80	14.30	14.90	16.10	12.50	0.334	n.s.
C _L in WSA [g/kg]									
Calcaric Chernozem	WSA _{ma}	0.06	0.06	0.08	0.13	0.12	0.14	0.875	0.01
	WSA _{mi}	0.07	0.05	0.05	0.06	0.07	0.09	0.955	0.001
Haplic Fluvisol	WSA _{ma}	0.23	0.22	0.22	0.23	0.22	0.22	0.180	n.s.
	WSA _{mi}	0.13	0.14	0.13	0.12	0.12	0.17	0.530	n.s.
Mollic Fluvisol	WSA _{ma}	0.12	0.15	0.16	0.13	0.13	0.14	0.217	n.s.
	WSA _{mi}	0.12	0.13	0.12	0.12	0.05	0.07	0.704	0.05

WSA_{ma} – content of water-stable macro-aggregates, WSA_{mi} – content of water-stable micro-aggregates, C_{org} in WSA – soil organic carbon in water-stable aggregates, C_L in WSA – labile carbon in water-stable aggregates
n.s. – non-significant

contents of exchangeable Mg^{2+} rather as Ca^{2+} were determined; however, opposite trend (more Ca^{2+} than Mg^{2+}) was observed in Calcaric Chernozem. The C_{org} content was lowest in Calcaric Chernozem in comparison to other soil types. These differences are mainly not only due to different soil-forming processes (Duchaufour 1982) but also can be affected by soil management (Balashov & Buchkina

2010; Slowinska-Jurkiewicz *et al.* 2013). For example, in studied Calcaric Chernozem, the content of C_{org} in A-horizon was influenced by inappropriate soil management practices (ploughing the soil on the slope and overall, which is a unsuitable choice of field for growing sugar beet). Due to intense soil (including carbonate loess) erosion on the slope down, sediment delivery was created there rather

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Correlation coefficients between chemical properties and size fractions content of water-stable aggregates and soil organic matter in size fractions of water-stable aggregates

Size fractions of water-stable aggregates	$CaCO_3$	Ca^{2+}	Mg^{2+}	SBC	CEC
> 5	n.s.	n.s.	0.551 ⁺	0.668 ⁺⁺	0.662 ⁺⁺
3–5	n.s.	n.s.	0.538 ⁺	0.785 ⁺⁺⁺	0.783 ⁺⁺⁺
2–3	n.s.	n.s.	0.626 ⁺⁺	0.788 ⁺⁺⁺	0.787 ⁺⁺⁺
1–2	n.s.	n.s.	n.s.	n.s.	n.s.
0.5–1	n.s.	n.s.	-0.512 ⁺	-0.591 ⁺⁺	-0.584 ⁺
0.25–0.5	n.s.	n.s.	n.s.	-0.478 ⁺	-0.476 ⁺
< 0.25	n.s.	n.s.	-0.475 ⁺	-0.684 ⁺⁺	-0.685 ⁺⁺
Soil organic carbon in size fractions of water-stable aggregates					
> 5	-0.490 ⁺	n.s.	0.475 ⁺	0.758 ⁺⁺⁺	0.759 ⁺⁺⁺
3–5	n.s.	n.s.	0.473 ⁺	0.844 ⁺⁺⁺	0.844 ⁺⁺⁺
2–3	-0.515 ⁺	n.s.	0.477 ⁺	0.799 ⁺⁺⁺	0.800 ⁺⁺⁺
1–2	n.s.	n.s.	0.469 ⁺	0.806 ⁺⁺⁺	0.806 ⁺⁺⁺
0.5–1	n.s.	n.s.	n.s.	0.838 ⁺⁺⁺	0.838 ⁺⁺⁺
0.25–0.5	-0.606 ⁺⁺	n.s.	n.s.	0.773 ⁺⁺⁺	0.774 ⁺⁺⁺
< 0.25	-0.574 ⁺	n.s.	n.s.	0.743 ⁺⁺⁺	0.744 ⁺⁺⁺
Labile carbon in size fractions of water-stable aggregates					
> 5	-0.658 ⁺⁺	n.s.	n.s.	0.477 ⁺	0.484 ⁺
3–5	-0.864 ⁺⁺⁺	n.s.	n.s.	0.499 ⁺	0.503 ⁺
2–3	-0.798 ⁺⁺⁺	n.s.	n.s.	0.669 ⁺⁺	0.673 ⁺⁺
1–2	-0.636 ⁺⁺	n.s.	n.s.	0.670 ⁺⁺	0.672 ⁺⁺
0.5–1	-0.741 ⁺⁺⁺	0.472 ⁺	n.s.	0.651 ⁺⁺	0.653 ⁺⁺
0.25–0.5	-0.755 ⁺⁺⁺	n.s.	n.s.	0.604 ⁺⁺	0.611 ⁺⁺
< 0.25	n.s.	n.s.	n.s.	0.560 ⁺	0.562 ⁺

SBC – sum of basic cations, CEC – cation exchange capacity
n.s. – non-significant; ⁺ $P \leq 0.05$; ⁺⁺ $P \leq 0.01$; ⁺⁺⁺ $P \leq 0.001$

thick depositional physical soil crust. The crust, consisting mostly of carbonate loess, covered and buried good A-horizon of Chernozem.

Changes in water-stable macro (WSA_{ma}) and micro-aggregates (WSA_{mi}) contents in different soil types during the vegetation season of sugar beet are given in Table 2. The content of WSA_{ma} decreased mostly from May through August in the Calcaric Chernozem by 68%, whereas during the same period an increase in WSA_{mi} was observed. These trends had a statistically significant polynomial character. In Haplic Fluvisol, the highest content of WSA_{ma} (94%) and the lowest content of WSA_{mi} (6%) were determined in the end of the period (on October). In Mollic Fluvisol, the changes in WSA contents were minimal (without statistical significance) during the vegetation season of sugar beet.

The differences in the contents of C_{org} in WSA depended on the soil type (Table 2); however, they were almost identical during growing season of sugar beet in individual soil types. In Calcaric Chernozem, in WSA_{ma} and in WSA_{mi} , C_{org} contents ranged from 11.1 to 15.9 g/kg and from 9.1 to 9.8 g/kg, respectively. Almost double values of C_{org} in WSA were determined in Haplic and Mollic Fluvisols. A major part of the C_{org} is formed of the stable fraction of organic matter, and it has been turned-over thousands of times over the years (Hungate *et al.* 1996; Haynes 2005), but on the other hand, the labile fractions have a much shorter turnover time (Janzen *et al.* 1997) as it confirmed our results of C_L in WSA (Table 2); therefore, the dynamics of labile carbon in WSA can be, due to its relatively wide range, considered as an important and sensitive indicator of the quality of soil environment under different soil management practices (Šimanský 2013).

Aggregation is further enhanced by biological and chemical processes such as flocculation and cementation by organo-mineral bonding (Dexter *et al.* 1988) while the aggregation process can be more intensive due to higher carbonates or bivalent cations content in the soil (Bronick & Lal 2005). Therefore, one of the most important objectives in this study was to test the effect of carbonates and bivalent cations on the formation of individual size fractions of WSA in two ways: (1)

if all investigated (classified as loamy) soils were assessed separately as well as and (2) together.

In Calcaric Chernozem, between carbonates, Ca^{2+} , Mg^{2+} , SBC, CEC and individual size fractions of WSA no correlation was recorded. The content of CO_3^{2-} negatively (-0.819 , $P \leq 0.05$, $n = 6$) and positively (-0.882 , $P \leq 0.05$, $n = 6$) correlated with WSA_{ma} 3–5 mm in Haplic and Mollic Fluvisols, respectively. At the same time, we determined negative correlation (-0.919 , $P \leq 0.01$, $n = 6$) between CO_3^{2-} and WSA_{ma} 2–3 mm in Haplic Fluvisol. Between carbonates, bivalent cations and individual size fractions of WSA, no significant correlations were observed if all loamy soils were assessed separately. The content of carbonates, as well as exchangeable Ca^{2+} , did not correlate with the content of individual size fractions of WSA; but on the other hand, significant correlations between exchangeable Mg^{2+} and WSA (Table 3) were surprising if all loamy soils were assessed together. In contrast to our results, Zhang and Norton (2002) reported that Ca^{2+} is more effective than Mg^{2+} in improving soil structure, because Mg^{2+} may have deleterious effect on aggregate stability by increasing clay dispersion. The extent of negative effect of Mg^{2+} compared with Ca^{2+} may depend on clay type (Amézketa 1999) and electrolyte concentration in the soil (Tisdall 1996). The higher content of Mg^{2+} in comparison to Ca^{2+} (in our cases in Haplic and Mollic Fluvisols), we can observe the unfavourable technological properties of the soil such as soil hardness (Zaujec *et al.* 2009). This was also confirmed by the mineralogical composition of aggregates at Šulekovo (Haplic Fluvisol)

Figure 2. X-ray – diffraction (XRD) patterns of minerals from soil aggregates

and at Trakovice (Mollic Fluvisol). Mineralogical composition of soil aggregates was determined for XRD analysis (Figure 2). Dolomite $\text{CaMg}(\text{CO}_3)_2$ and quartz SiO_2 were identified as the most dominant minerals in soil samples. However, significant content of albite and muscovite-vermiculite type of structure was confirmed. Generally, with the exception of clay minerals, various concentrations of Ca^{2+} and Mg^{2+} also still exist in carbonates. Our results indicate widely isomorphic substituting ability of Mg^{2+} versus Ca^{2+} with predominant dolomite phase compared with calcite content. Typical mineralogical association (dolomite, quartz, feldspar-albite and muscovite-vermiculite structure) was obtained from Haplic Fluvisol and Mollic Fluvisol at Trakovice and at Šulekovo, respectively. According to González *et al.* (2007), comparison of our mineralogical composition was almost similar in all cases; the differences were found with more calcite than dolomite. González *et al.* (2007) examined the Calcaric Fluvisols collected from abundant river terraces with intensive agricultural production. Pedogeochemical genesis and stability of detecting minerals in soil system were influenced on the transporting mechanisms and polygenetic alteration of rocks (Pozzuoli *et al.* 1992; Righi *et al.* 1993). Formation of characteristic Calcaric Chernozem from Central European region poses relative monotone mineralogical composition. Many studies elaborated the concentration of primary and secondary carbonate

minerals from this type of soils as well as containing quartz and clay minerals with higher Ca^{2+} values (for instance, polysilicate montmorillonite) (Eckmier *et al.* 2007). A similar result was achieved by the considerably higher values of Ca^{2+} in soil aggregates from the Bučany district.

The relationship between Mg^{2+} and the content of WSA_{ma} had significant polynomial character, this means that maximal formation of WSA_{ma} was at the level of Mg^{2+} equal to 11.5 cmol/kg and the next increasing content of Mg^{2+} resulted in lower content of WSA_{ma} (Figure 3a) if all loamy soils were assessed together. If all investigated soils were assessed separately, these results did not enable us to distinguish the maximum formation of WSA_{ma} by Mg^{2+} in individual soils. Therefore, we did not give any threshold limit for Mg^{2+} for Calcaric Chernozem, Haplic and Mollic Fluvisols separately.

As reported by Dimoyiannis *et al.* (1998) and Greene *et al.* (2002), the CEC is related to stable aggregates. We observed a positive correlation between SBC as well as CEC and higher size fractions of $\text{WSA}_{\text{ma}} > 2$ mm; however, between SBC as well as CEC and smaller size fractions of $\text{WSA}_{\text{ma}} < 1$ mm and WSA_{mi} , the negative correlations were observed if all loamy soils were assessed together (Table 3). It means that if the content of bivalent cations in the soil is high, the soil structure is better. If all loamy soils were assessed separately, no significant correlation between SBC, CEC and individual size frac-

Figure 3. Relationship between A) exchangeable magnesium (Mg^{2+}) and water-stable macro-aggregates (WSA_{ma}) B) cation exchange capacity (CEC) and water-stable macro-aggregates

tions of WSA was recorded. The maximal formation of WSA_{ma} was at the level of CEC equal to 15.5 cmol/kg, and the next increasing content of CEC resulted in lower content of WSA_{ma} (Figure 3b). If all investigated soils were assessed separately, a significant polynomial relationship between CEC and WSA_{ma} was determined in Calcaric Chernozem. In this case, the maximal formation of WSA_{ma} was at the level of CEC equal to 8.0 cmol/kg. In Haplic and Mollic Fluvisols (assessed separately), we did not detect any significant polynomial relationships.

Aggregation process is connected with the interactions of mineral particles, cations and SOM (Bronick & Lal 2005; Alagöz & Yilmaz 2009; Šimanský 2011) and, therefore, the second objective was to test the relationships between the content of C_{org} and C_L in individual size fractions of WSA and the content of carbonates and bivalent cations in loamy soils. Correlation coefficients are shown in Table 3, if all loamy soils were assessed together. Statistically significant negative correlations were observed between SOM in WSA and carbonate content, and this effect was stronger in relation to labile carbon. C_L in water-stable micro-aggregates did not correlate with CO_3^{2-} . Carbonates decreased the stability of micro-aggregates (Boix-Fayos *et al.* 2001). High carbonate concentration in the silt fraction decreases aggregation, suggesting that particle size may also influence the role of carbonates in aggregation (Dimoyiannis *et al.* 1998). In general, alkaline pH supports the accumulation of carbonates and, as presented by Haynes and Naidu (1998), large aggregates are formed in the soils of high pH. In our case, the average pH of investigated loamy soils was 7.73 ± 0.11 , but if soil moisture is increasing at high C_{org} content in the soil, the microbial respiration increases and carbonates are dissolved, and then we can observe the effect of bivalent cations (Boix-Fayos *et al.* 2001). Statistically significant positive correlations were observed between C_{org} in $WSA_{ma} > 1$ mm and Mg^{2+} , but on the other hand, in case of C_L in WSA, this effect was not observed. Positive correlations between SOM in WSA and SBC and CEC were found if all loamy soils were assessed together (Table 3). If all loamy soils were assessed separately, we detected negative significant correlation between C_{org} in WSA_{mi} and SBC, CEC in Calcaric Chernozem ($r = -0.900$ and $r = -0.907$,

$P \leq 0.05$, $n = 6$) as well as in Mollic Fluvisol ($r = -0.906$ and $r = -0.903$, $P \leq 0.05$, $n = 6$). On the other hand, in Haplic Fluvisol, we detected positive significant correlation between C_{org} in $WSA_{ma} > 5$ mm and size fraction 3–5 mm and SBC, CEC. Significant correlation between C_L in WSA, SBC and CEC were detected if all soils were assessed separately.

CONCLUSION

Even though the soils are different from pedogenesis view point, they had the same particle-size distribution and so we tried to generalize our results on the basis of this factor. Our results show the fact that more intensive aggregation process in loamy soils is connected with high content of basic exchangeable cations, and high value of CEC and stabile organic matter content in WSA. The higher content of exchangeable Mg^{2+} rather than Ca^{2+} was significantly related to the formation of larger size fractions of water-stable macro-aggregates (> 2 mm), and these effects were more intensive when in WSA, the content of soil organic carbon was higher. The threshold limits for Mg^{2+} for the formation of water-stable macro-aggregates were equal to 11.5 cmol/kg, respectively. A further increase resulted in lower content of WSA_{ma} . To confirm the findings, more research is required in the future.

Acknowledgement. Partial support was provided by project CZ.1.05/1.1.00/02.0070 (IT4Innovations) and the PostDoc project “Opportunity for young researchers” No. CZ.1.07/2.3.00/30.0016.

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Received: July 10, 2014