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Original Paper

Soil crust in agricultural land

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The effects of exogenous and endogenous factors on the formation of soil crust in arable soils of Slovakia were evaluated. Soil samples for determination of selected soil organic matter parameters, physical properties – particularly soil crust, were collected from localities Dražovce, Bučany and Jacovce (different soil/climatic conditions at each site) in spring 2012. The results showed that organic fertilization decreased the formation and thickness of soil crust. According to the susceptibility to crust formation, studied soils were ranged in a decreasing order: Calcaric Chernozem > Stagni-Haplic Luvisol > Rendzic Leptosol > Mollic Fluvisol. The thickness of soil crust were significantly depended on cultivated crops. The most favourable value of index of crusting was calculated in the field with grown spring barley, following by pea < oil rape < winter wheat. We determined negative correlation between clay and index of crusting (r = -0.880, $P \leq 0.01$). Higher formation of soil crust was determined in soil with higher content of water-stable micro-aggregates (r = 0.799, $P \leq 0.05$) and smaller size fractions of water-stable macro-aggregates in size fractions 0.25–0.5 mm (r = 0.865, $P \leq 0.01$). Higher content of soil organic matter of rather stabile than labile form resulted to reduction of crust thickness as well as decreased the index of crusting.

Keywords: index of crusting, soil structure, soil organic matter, soil types, organic fertilization, crops

1. Introduction

The physical properties of a soil have much to do with its suitability for the many uses to which man puts it. The rigidity and supporting power, both wet and dry, the freedom of drainage, moisture-storage capacity, plasticity, ease of penetration by roots, aeration, and retention of plant nutrients are all intimately connected with the physical condition of the soil (Millar et al., 1962). Soil crust is a major structural feature of surface soil and one of the most important physical properties (Graef and Stahr, 2000). Formation of soil crust is mainly influenced by salts of Na^+, Ca^{2+}, soil organic matter and particle-size distribution. The soil crust is not formed in the soils with content of sand more than 60 % (Špička et al., 1964). Lal and Shukla (2004) mentioned three categories of soil crust. The physical and biological crusts are dominant especially in the semi-arid and arid regions (West, 1990; Hawkes and Flechtner, 2002). Chemical crust is formed due to salt incrustations on soil surface. Biological or micro-biotic crusts are primarily formed by algal growth. Such crusts are extremely hydrophobic, and drastically reduce the rate of water infiltration into soil. Physical crust is formed due to alternation in structural properties of the soil, and may be structural or depositional. Structural crust is formed due to the disruption of aggregates by raindrop impact and physiochemical dispersion of soil clays (McIntyre, 1958).

Nowadays, soil physical properties are more important than ever before in sustaining agricultural productivity. It was recorded great shrinking of global arable land area per capita. For example, in last years, according to the Soil Science and Conservation Research Institute, the annual average soil loss was around 1000–5000 hectares in Slovakia. Unfortunately, similar situation is currently observed in the whole European Union and world. When consider sustainable soil management, the conservation and maintenance of favourable physical properties is very important (Kotorová and Šoltýsová, 2011).

The purpose of this paper was to evaluate soil crust parameters in selected arable soils of Slovakia. We quantified (1) the effects of soil types, added farmyard manure, and crops on the formation of soil crust, and (2) the influence of selected soil properties on crust formation.

2. Material and methods

2.1 Site 1

First study area is located in south-west part of Tribeč Mountain. Soil samples were taken from a productive vineyard from an ongoing experiment with different management practices at Nitra-Dražovce (Nitra wine-growing area). The mean annual rainfall is 550 mm and the mean annual temperature is ≥10 °C. The soil was formed on limestone and dolomite. According to the

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World Reference Base for Soil Resources, soil type was classified as Rendzic Leptosol (WRB, 2006). Soil samples were collected from following treatments: 1. T – tillage – yearly medium tilth to a depth of 0.25 m with intensive cultivation between vine rows during the growing season without application of farmyard manure, and 2. T + FYM – tillage + farmyard manure – medium tilth to a depth of 0.25 m with ploughed farmyard manure at a dose of 40 t ha^{-1} and intensive cultivation between vine rows during growing season. The first application of FYM was realised in autumn 2005 and the next in autumn 2009.

2.2 Site 2

Second study area is located in the north-west part of Danube lowland. Soil samples were taken from two fields with different soil types. Climate of this area is temperate with the average annual temperature 10.1 °C and average precipitation 501 mm. In field 1, the soil was classified as Calcaric Chernozem with geological substrate – loess, and in field 2, the soil was classified as Mollic Fluvisol on fluvial sediments. Field 1: total area = 80 hectares, used as arable soil, without FYM application, sloping character with inclination max. to 5°, the sampling zone – in accumulation part of field. Field 2: total area = 250 hectares, used as arable soil, without FYM application, flat character. Both fields were bare, without any crop during sampling.

2.3 Site 3

Third area is located in north-east part of Bojnianske hills. Soil samples were taken from four different fields. Climate of this area is temperate with the average annual temperature 9.5 °C and average precipitation 650 mm. The soil on all areas was classified as Stagni-Haplic Luvisol. Farmyard manure was not applied on any of studied areas. Field 1: total area = 103 hectares with growth of spring barley. Field 2: total area = 282 hectares, winter wheat. Field 3: total area = 45 hectares, pea. Field 4: total area = 80 hectares, oil rape.

2.4 Soil sampling and analyses

In spring 2012, the soil samples were collected from above mentioned fields: locality Nitra-Dražovce (soil type Rendzic Leptosol) – from 1. intensively tilled treatment without application of farmyard manure, and 2. treatment with added farmyard manure; locality Bučany – from 1. field with soil type Calcaric Chernozem and 2. field with soil type Mollic Fluvisol; locality Jacovce (soil type Stagni-Haplic Luvisol) – from 1st field: spring barley, 2nd field: winter wheat, 3rd field: pea and 4th field: oil rape. For measurement of soil crust four zones were chosen randomly. In the area of 1 m^2 the thickness of soil crust was measured. Then from those sites, soil samples were collected to the depth of 20 cm. For undisturbed soil samples were determined parameters of soil structure: content of water-stable aggregates, coefficient of vulnerability, aggregates stability index (Zaujec and Šimanský, 2006), critical level of soil organic matter, and index of crusting (Lal and Shukla, 2004). Before determination of water stable aggregates all soil samples were pre-sieved over a series of sieves and bulked into seven size fractions (>7 mm, 7–5 mm, 5–3 mm, 3–1 mm, 1–0.5 mm, 0.5–0.25 mm and <0.25 mm). These size fractions (dry sieve) were used for the determination of water-stable aggregates (WSA) the following sizes: >5 mm, 5–3 mm, 3–2 mm, 2–1 mm, 1–0.5 mm, 0.5–0.25 mm and <0.25 mm by Baksheev method (Vadjunina and Korchagina, 1986).

The coefficient of vulnerability (K_v) was calculated according to Equation (1):

$$K_v = \frac{MWD_d}{MWD_w} \quad (1)$$

where:
MWD_d – is mean weight diameter of aggregates for dry sieving (mm)
MWD_w – mean weight diameter of water stable aggregates (mm)

The aggregates stability index (S_w) was calculated according to Equation (2):

$$S_w = \frac{WSA - 0.09 sand}{silt + clay} \quad (2)$$

where:
WSA – content of water-stable macro-aggregates (%)

The index of crusting (I_c) was calculated according to Equation (3):

$$I_c = \frac{1.5S_f + 0.75S_c}{Cl + (10.SOM)} \quad (3)$$

where:
S_f – % fine silt
S_c – % coarse silt
Cl – % clay
SOM – % soil organic matter content

Critical soil organic matter content (S_t) was calculated using Equation (4):

$$S_t = \frac{SOM}{(Clay + Silt)} \quad (4)$$

where:
SOM – % soil organic matter content

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For disturbed soil samples were determined: particle-size distribution (Fiala et al., 1999), soil organic carbon content (Hraško et al., 1962), labile carbon content (Loginow et al., 1987), hot and cold water-soluble carbon (Körschens, 2002).

The statistical processing of the data was accomplished using the Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA). A simple *t*-test was carried out to test significance between the thickness of soil crust in different soil managements, different soil types as well as in different crops cultivated on fields. The interrelations between particle-size distribution, soil structure parameters, soil organic matter and parameters of soil crust were determined through correlation matrix.

3. Results and discussion

3.1 The effect of exogenous factors

The effect of farmyard manure application on the formation of physical soil crust was evaluated on an ongoing experiment that had been running for eighth years (started in 2006) at Nitra – Dražovce. There are carrying out different soil management practices in a productive vineyard. Results obtained in this study confirmed the fact that application of farmyard manure decreased the thickness of soil crust as well as index of crusting (Figure 1A). In intensively tilled treatment (T) without application of farmyard manure, the thickness of soil crust was by 0.56 cm larger than in treatment with added farmyard manure (T + FYM). Mentioned difference was statistically significant (T vs. T + FYM; *t*-test = 8.75, *P* = 0.000). Otherwise, the difference in value of crusting index (I_c) between treatments was minimal, but in the same trend compared with thickness of soil crust. Similarly to our results, Šimanský et al. (2008a) stated that long-term incorporation of plant residues to the soil had positive effect on elimination of soil crust. Generally, organic fertilizers increase the stock of soil organic matter, through which they have positive effects on the physicochemical properties of soil, such as the formation of favourable structure (Tisdall and Oades, 1982; Šimanský et al., 2008b; Šimanský, 2011), subsequently porosity, water : air ratio (Gregory, 2006), improve sorption and buffering capacity (Stevenson, 1994; Zanini et al., 2006; Šimanský and Polláková, 2014), nutrients availability (Sandor, 2009).

Each soil type has different genesis, and hence morphological features and different soil properties (Duchafour, 1982). Therefore, we hypothesized that properties of selected soil types will be crucial for the formation of soil crust. In accordance to hypothesis, our results confirmed that soil type had significant effects on the thickness and formation of soil crust (Figure 1B). The highest thickness of soil crust was measured in Calcaric Chernozem (5.05 ±0.77 cm) and on the other hand, the lowest in Rendzic Leptosol (1.34 ±0.21). Based on the *t*-test results, statistically significant differences in the thickness of soil crust were between the following soil types: Rendzic Leptosol (RL) vs. Mollic Fluvisol (MF) (*t* = -8.14, *P* = 0.000), RL vs. Calcaric Chernozem (CCh) (*t* = -15.20, *P* = 0.000), RL vs. Stagni-Haplic Luvisol (S-HL) (*t* = -5.11, *P* = 0.000), MF vs. CCh (*t* = -3.71, *P* = 0.003) and CCh vs. S-HL (*t* = 4.85, *P* = 0.000). According to the soil's susceptibility to the crust formation, soils ranged in a decreasing order: Calcaric Chernozem > Stagni-Haplic Luvisol > Rendzic Leptosol > Mollic Fluvisol. Chernozems are characterized as one of the best and the most fertile soil type in Slovakia for their optimal chemical and physical properties (Bielek, 1998; Šimanský et al., 2007; Zaujec and Šimanský, 2008).

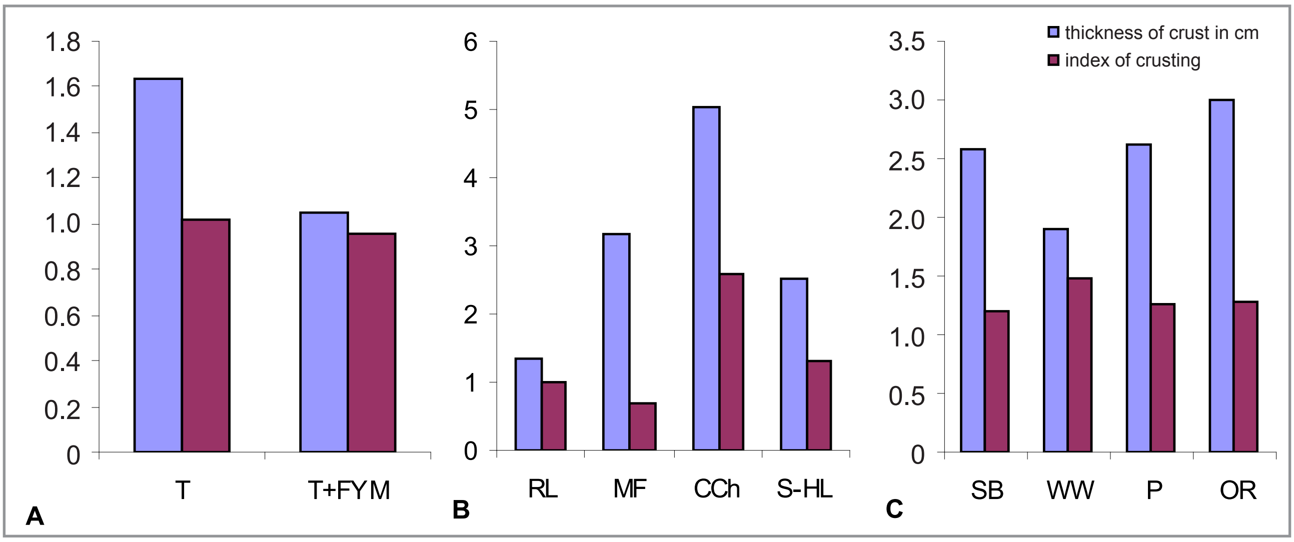

Figure 1 Parameters of soil crust in dependence on A) application of organic fertilizer, B) soil type and, C) cultivated crops
T – tillage, T+FYM – tillage + farmyard manure, RL – Rendzic Leptosol, MF – Mollic Fluvisol, CCh – Calcaric Chernozem, S-HL – Stagni-Haplic Luvisol, SB – Spring barley, WW – Winter wheat, P – Pea, OR – Oil Rape

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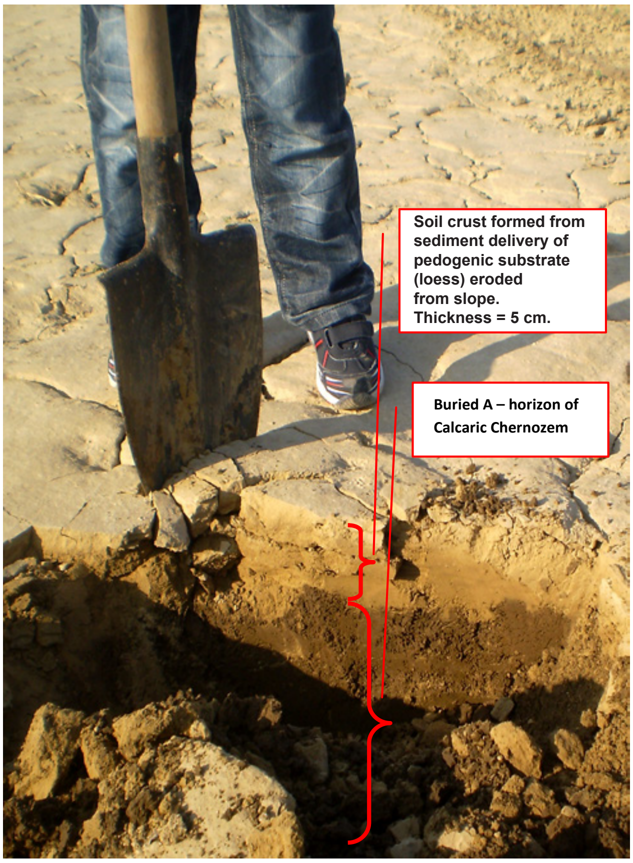

Figure 2 Formed physical (depositional) soil crust on the surface A-horizon of Calcaric Chernozem (Bučany)

If consider above mentioned fact, results obtained in this study are not in accordance with generally good quality of Chernozem. Our explanation of this phenomenon is as follows. In studied Calcaric Chernozem, the thickness of soil crust was measured in the accumulation part of field. Due to intense soil (including carbonate loess) erosion on the slope, sediment delivery and subsequent deposition in the accumulation part of field there was created rather thick (5.05 cm) depositional physical soil crust. The crust, consisting mostly of carbonate loess, covered and buried good A-horizon of Chernozem, and moreover, after drying it created rather impermeable layer, cemented by carbonates (Figure 2). Chen et al. (1980) characterized depositional crust as one formed by transport and deposition of fine particles by surface flow.

Soil crust has a negative effect on emergence and growth plants; therefore we evaluated the effect of different crops on formation of soil crust at the same soil type (Stagni-Haplic Luvisol). As is showed in Figure 1C, the largest thickness of soil crust was measured in the field with cultivated oil rape, on the contrary, the lowest in the field with winter wheat. Statistically significant differences in the thickness of soil crust were between the following crops: spring barley vs. winter wheat ($t = 5.17$, $P = 0.002$) and winter wheat vs. oil rape ($t = -2.64$, $P = 0.033$). In opposite, diametrically different results were observed for I_c values. The most favourable value of I_c was calculated for the field with cultivated spring barley and then follows pea < oil rape < winter wheat.

3.2 The effect of pedological factors

Correlation coefficient between selected physical properties, soil organic matter and parameters of soil crust are summarized in Table 1. In literature (Špička et al., 1964; Lal and Shukla, 2004; Šimanský et al., 2008a) is stated that the particle-size distribution is one of the most important factor influencing soil crust formation. We determined positive correlations between fine sand and crust thickness and also index of crusting, as well as between fine and medium silt and index of crusting (Table 1). In contrast with literature, where prevail studies describing positive effect of clay on formation of soil crust (Špička et al., 1964; Lal and Shukla, 2004), we determined negative correlation between clay and index of crusting. The most probable reason of such effect was breakage of soil aggregates with following degradation of soil structure, what was confirmed by our results – positive correlation between vulnerability coefficient and index of crusting and also negative correlation between critical level of soil organic matter and index of crusting. Larger formation of soil crust was caused by higher content of water-stable micro-aggregates ($r = 0.799$, $P \leq 0.05$) and smaller size fractions of water-stable macro-aggregates in size fractions 0.25–0.5 mm ($r = 0.865$, $P \leq 0.01$). The soils contained predominantly medium content of soil organic matter (*SOM*) what resulted to slight formation of stable bonds between the clay and *SOM*, thus the newly formed aggregates were unstable. Such weak aggregates were easily disintegrated to elementary particles due to action of water, which moreover caused particles transportation, their distribution according to grain size and creation the visible layers (Figure 3). As shown in the Figure 3, the thickness of soil crust was approx. 5 cm. In first layer (approx. 2 cm) was accumulated fine sand, followed by thin layer (0.2–0.3 cm) composed of fine silt and clay. Above mentioned layers, the medium and coarse sand was accumulated in thickness of 1 cm and on the top were gradually accumulated fine sand, silt and clay. Clay particles caused cementation of sand grains to soil crust. This cementation (obvious from picture) can partially explain the positive correlation between index of crusting and fine sand content and opposite, highly negative correlation between index of crusting and clay content. Moreover, the negative effect of clay on index of crusting we can explain by statistically significant correlation between soil organic carbon content and clay ($r = 0.919$, $P \leq 0.01$). Higher content of clay resulted to higher sorptive ability – arising from type of crystalline (D´Acqui et al., 1998) and thus higher content of soil

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Table 1 Correlation coefficients between selected physical properties, soil organic matter and parameters of soil crust

	Particle size distribution						Soil organic matter			
	>0.25	0.25–0.05	0.05–0.01	0.01–0.001	<0.001	<0.01	C_{org}	C_L	C_{HWD}	C_{CWD}
Thickness of soil crust	n. s.	0.790*	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.
Index of crusting	n. s.	0.790*	n. s.	0.780*	-0.881**	-0.851**	-0.895**	n. s.	n. s.	n. s.

	Structure parameters			Water-stable macro-aggregates			Water-stable micro-aggregates
	K_v	S_t	S_w	>5	5–0.5	0.5–0.25	
Thickness of soil crust	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.	n. s.
Index of crusting	0.781*	-0.911**	n. s.	n. s.	n. s.	0.865**	0.799*

C_{org} – soil organic carbon, C_L – labile carbon, C_{HWD} – hot water soluble carbon, C_{CWD} – cold water soluble carbon, K_v – vulnerability coefficient, S_t – critical level of soil organic matter, S_w – stability index of aggregates
n. s. – non-significant = P >0.05; *P ≤0.05; ** P ≤0.01; *** P ≤0.001

Figure 3 Layers of grain size in soil crust

organic matter (Šimanský et al., 2009). Since stock of soil organic carbon negatively correlated with index of crusting (r = -0.895, P ≤0.01) we can conclude, that higher content of soil organic carbon prevents soil crusting. From the results in Table 1 we also conclude, that labile soil organic matter fractions did not have any effects on soil crust parameters.

4. Conclusions

All in all, we can conclude that fertilization with organic fertilizers decreased the formation and thickness of soil crust. According to the soil's susceptibility to the crust formation, soils ranged in a decreasing order: Calcaric Chernozem > Stagni-Haplic Luvisol > Rendzic Leptosol > Mollic Fluvisol. The thickness of soil crust depended on cultivated crops. The most favourable value of index of crusting was calculated in the field with cultivated spring barley, following by pea < oil rape < winter wheat. Our results did not confirm the positive effect of higher content of clay on formation soil crust, but larger crust formation was determined due to higher content of water-stable micro-aggregates and smaller size fractions of water-stable macro-aggregates (0.25–0.5 mm). Higher content of soil organic matter of rather stabile than labile form resulted to reduction of crust thickness as well as decreased the index of crusting.

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