

Soil wetting effects on fallow and cropland in three different soil types of the Czech Republic

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ABSTRACT

This paper brings the comparison of characteristic changes of cropland and of land that has been left fallow for ten years. The disruption of soil structure (MWD) was tested and correlated with basic soil parameters (soil texture, soil hydraulic properties (K_{sat}), soil organic matter content (C_{ox}), gentle acidification (pH_{KCl})). Sub-wetting processes of MWDs for three soil types (Chernozems, Cambisols, Luvisols) were tested and confronted with the results of a small-rainfall simulator in laboratory conditions. Statistically provable changes occurred on the plots of fallow land, i.e.: (i) decreased risk of water erosion and crustability (MWD), improvement of K_{sat} , a slight increase in C_{ox} and the outset of pH_{KCl} . The MWDs were poorly correlated (0.23–0.37%) with soil texture and highly (59%) with saturated hydraulic conductivity. The results of this paper confirmed that fallow lands/grass cover lands better infiltrated rainfall and almost eliminated water erosion risk. The results of the detailed evaluation of MWDs and rain simulator for specific soil types presented an extremely high water erosion risk (and high slaking effect) for cropland Luvisol. We have estimated that the soil loss of cropland Luvisol can reach up to 9 t/ha when there is 8-min torrential rain (on dry lands).

Keywords: land use; soil aggregate stability; mean weight diameter; soil crustability; small rainfall simulator

The soil structure (expressed by mean weight diameter (MWD)) is a key parameter that affects a wide range of soil properties and defines soil porous system (Amezketta 1999, An et al. 2010). Thus, the soil structure and its stability of aggregates determine soil hydraulic properties (K_{sat}), retention capacity and resistance to water erosion and overland flow (Bronic and Lal 2005). The MWD and K_{sat} are interrelated and they are strongly influenced by processes such as tillage, cropping systems, climate (Guérif et al. 2001), rainfall compaction (Legout et al. 2005); and affected by pedogenic processes, such as soil texture (Lado et al. 2004), soil type, weathering and mineral

composition (Kodešová et al. 2009). Soil erosion processes considerably affect soil stability within the morphologically diverse areas (Morgan 2005, Cantón et al. 2009, Zádorová et al. 2011, Jakšík et al. 2015). The virgin sites and sites that were under long-term grassing/left as fallow display greater aggregate stability than the cultivated ones (Golchin et al. 1995). This effect is linked to different organic compounds (Spaccini et al. 2002), nutrient reserves (Zhang and Norton 2002), crop roots, fungal influences, plant exudates, microbial products (Chatigny et al. 1997, Kodešová et al. 2006). Most works dealing with this issue focus on the soil structure formation (Golchin et al. 1995,

doi: 10.17221/357/2015-PSE

Kodešová et al. 2006) or erosion process (Morgan 2005, Cantón et al. 2009, Zádorová et al. 2011, Kadlec et al. 2012, Jakšík et al. 2015); some of them bring comparison of different soil types (Kodešová et al. 2009, 2011, Jirků et al. 2013). However, there are few studies which would evaluate the soil structure stability compared to the simulated rainfall measurement (Le Bissonnais et al. 1989, Legout et al. 2005) on fallow land sites.

The objectives of this study are: (i) to prove if there are statistically provable differences between the use of cropland and fallow land (ii) to analyse how the soil properties, such as soil texture, soil hydraulic properties (K_{sat}), soil organic matter content (C_{ox}), pH_{KCl} have influenced the MWD value; (iii) evaluate the statistical difference of disruptive processes (MWDs) for three soil types and two land uses; (iv) verify results through experiments with small rain simulator and (v) discuss the risk of surface crust formation by slaking.

MATERIAL AND METHODS

Site descriptions. Six localities (Figure 1) were selected (Table 1) in the Czech Republic representing the three important soil types, i.e. Chernozems (loam/sandy loam) – CH, Luvisols (silt loam) – LV and Cambisols (loam/silt loam) – CM (FAO 2014) (Table 1). The site selection represents a wide range of soil properties. However, these are typical soil properties in the Czech Republic (localisation described in Figure 1). The parent material for all evaluated haplic Cambisols was very similar – paragneiss (Table 1). Slight differences of the climatic conditions for the Haplic Cambisol were disregarded as well as the time variability of the soil structure (Jirků et al. 2013) during the vegetation period was neglected in this paper.

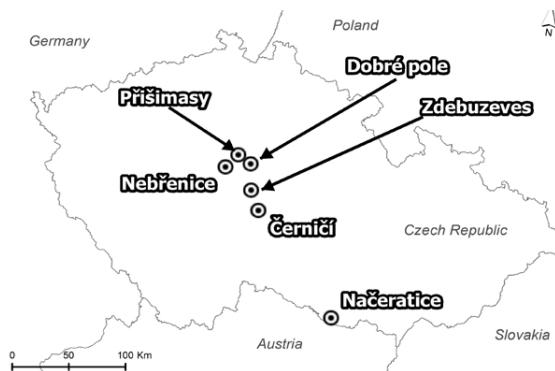


Figure 1. Site localisation

Table 1. Site description

Soil type ¹	Land use	Symbol	Locality	Soil samples	Location ²	Approx. sampled area (ha)	Climatic region ³	Description of climate ⁴	Mean annual precipitation (mm)	Mean annual temperature (°C)	Average altitude (m)	Parent material/bedrock
Haplic Chernozems	cropland	CHC	Načeratice	11	X: 16.1255 Y: 48.8062	150	T4	very warm and dry	550	9.5	240	loesses
Haplic Luvisols	cropland	LVC	Příšimasy	3	X: 14.7485 Y: 50.0557	5	MT10	mildly warm and dry	606	8.4	312	loess and loess loam
	fallow land	LVF	Zdebuzevy	3	X: 14.9614 Y: 49.7791	5	MT10	mildly warm and slightly dry	625	8.0	423	moldanubicum paragneiss/regional metamorphosis of proterozoics sediments
Haplic Cambisols	cropland	CMC	Nebřenice	9	X: 14.6129 Y: 49.9437	35	MT10	mildly warm and wet	623	7.8	457	
	fallow land	CMF	Černičí	4	X: 15.0835 Y: 49.6205	12	MT9	mildly warm and wet	724	7.3	512	
	cropland	CMC	Dobré pole	3	X: 14.9128 Y: 49.9943	3	MT9	mildly warm and wet	591	8.4	390	

¹Soil type according to FAO (2014); ²WGS84 coordinate system; ³Climatic region defined by Quitt (1971); ⁴Climatic regionalization designed by Moravec and Votýpka (1998)

Soil sampling and analyses. Soil samples were collected during the summer time between the years 2010–2012 from the upper soil horizons at the depth of 10–20 cm. The fallow land represents the land that was left fallow, providing habitats for the development of free succession for 10 years.

In total the following number of samples were taken: 48 disturbed soil samples pre-treated by 2 mm sieve (ISO 11464, 2006) for determination of basic chemical parameters of the soil texture (ISO 11277, 2009), C_{ox} – total oxidized carbon – TOC (ISO 14235, 1998) and analysis of potentiometric pH – measured in 1 mol/L KCl solution (ISO 10390, 2005) and 48 samples with undisturbed soil structure for MWDs testing (Le Bissonais 1996) were taken. Furthermore, 34 soil cores (100 cm³) for constant head saturated hydraulic conductivity measurement (ISO/CSN 721020, 1991) were sampled. The soil cores on the Nebřenice site were not collected. All samples were taken at the same time close to each other (from 1 m² of a sampling area).

For MWD index 5–10 g of air dried aggregates (3–5 mm) were tested by three mechanisms: (i) fast wetting – MWD (A): dry aggregates were suddenly wetted into 50 cm³ of distilled water for 10 min, aggregates were disintegrated by entrapped air (slaking process)/simulation of heavy rainfall; (ii) slow wetting – MWD (B): dry aggregates were placed on Bultex[®] material ($d = 30 \text{ kg/m}^3$), wetted by capillary elevation forces, the slaking was restricted in order to simulate the gently rain; (iii) mechanical disaggregation – MWD (C): the aggregate was firstly stabilised in 50 cm³ of EtOH (30 min), decanted and gently immersed into 200 cm³ of distilled water in a 250 cm³ flask, and mechanically disturbed by slaking (10 times upside down). All of the wet aggregates were stabilised, 5 times being immersed into 0.5 L of pure EtOH on 0.05 mm sieve according to Féodoroff (1958) method, gently oven-dried (40°C) and dry sieved and weighted in terms of fraction size (> 2; 1–2; 0.5–1; 0.2–0.5; 0.1–0.2; 0.05–0.1 mm).

The value of mean weight diameter (MWD_j) were computed for each of the test ($j = A, B, C$) as follows:

$$MWD_j = \sum_{i=1}^7 \bar{X}_i W_i \quad (1)$$

Where: X_i – mean aggregate size collected on the sieves (mm); W_i – weight distribution ratio. The MWD value is a mean of the three tests ($n = 3$) MWD_j and were calculated as follows:

$$MWD = \frac{1}{n} \sum_{j=1}^n MWD_j \quad (2)$$

The slaking effect (SE) for MWDs was calculated as follows:

$$SE = \frac{[MWD(A) - MWD(B)]}{MWD(A) + MWD(B)} \quad (3)$$

For a small rainfall simulator (Kamphorst 1987) a laboratory experiment about 5 kg of presieved 3–5 mm air-dried aggregates where tested. Two wetting processes were simulated: (i) fast wetting similarly to MWD A with dry aggregate and (ii) slow wetting similarly to MWD B with wet aggregate (pre-wetted by capillary elevation on Bultex[®] materials for 30 min) within two subsequent 4-min cycles of a simulated rainfall with the intensity of 6 mm/min. The raindrops fell from the height of 400 mm, the diameter of drops was 5.9 mm, kinetic energy of rain was 4 J/m²/mm. The catching area 0.0625 m² was covered with 100 mm layer of 3–5 mm aggregate which was placed in the slope of 4°.

Similarly to MWDs the slaking effect for simulated soil loss (SE_{sim}) was calculated as follows:

$$SE_{sim} = \frac{[DRY - WET]}{DRY + WET} \quad (4)$$

Statistical evaluation of analyses. The values of soil structure stability MWDs were correlated with selected soil parameters by Pearson's correlation coefficients. The differences in the soil parameters between the land uses (cropland/fallow land) were tested by the Mann-Whitney pairwise test (comparing two independent samples). The data of MWDs distribution of each soil type and their land uses were processed by two-way analysis of variance (ANOVA); multiple comparison procedures (post-hoc testing) were performed by the Scheffe's test. All measurements were statistically evaluated at the level of confidence ($\alpha = 0.05$) by Statistica 10 software (StatSoft 2012).

RESULTS AND DISCUSSION

The basic soil properties (Table 2) have shown a typical, relatively high content of fine silt (0.01–0.05 mm) for Luvisols, which is logically related to soil substrate/loess loam (Table 1) and predetermines these soils to crustability and high erosion risk (Morgan 2005).

The resulting correlation of MWDs with basic soil properties (Table 3) has shown a poor cor-

doi: 10.17221/357/2015-PSE

Table 2. Soil properties

	CHC	CHF	LVC	LVF	CMC	CMF
< 0.002 (%)	24.55 ± 5.93	12.90 ± 0.71	21.40 ± 2.43	24.87 ± 3.47	12.37 ± 4.24	11.79 ± 3.25
0.002–0.01 (%)	12.27 ± 4.79	5.15 ± 2.62	13.57 ± 0.47	14.27 ± 0.99	15.52 ± 4.80	17.74 ± 6.26
0.01–0.05 (%)	30.04 ± 10.64	14.45 ± 1.34	52.47 ± 1.63	48.03 ± 1.27	33.05 ± 15.09	32.83 ± 11.78
0.05–0.25 (%)	13.66 ± 4.62	17.10 ± 3.82	10.37 ± 2.02	11.23 ± 1.85	16.43 ± 4.91	21.97 ± 7.19
0.25–2 (%)	19.48 ± 16.93	50.40 ± 3.25	2.17 ± 0.06	1.63 ± 0.29	22.61 ± 16.44	15.66 ± 13.23
pH _{KCl}	6.38 ± 0.94	4.51 ± 0.35	5.52 ± 0.99	5.19 ± 0.11	5.21 ± 0.54	4.80 ± 0.51
C _{ox} (%)	1.37 ± 0.35	0.84 ± 0.40	1.02 ± 0.39	1.28 ± 0.34	1.18 ± 0.31	1.89 ± 0.76
K _{sat} (cm/day)	146.7 ± 274.5	1004.4 ± 392.8	13.1 ± 18.1	563.5 ± 916.9	270.2 ± 436.4	626.7 ± 566.0

Data reported as means ± standard deviation. CHC – Chernozems/cropland; CHF – Chernozems/fallow-land; LVC – Luvisols/cropland; LVF – Luvisols/fallow-land; CMC – Cambisols/cropland; CMF – Cambisols/fallow-land

relation of coarse texture slightly under the significance level ($\alpha < 0.05$). The positive correlation trends are demonstrated in bigger particles of fine and coarse sands (0.05–2.0 mm) and negative in smaller texture categories (< 0.05 mm), including the clay particles. Many of these differences could be explained by high dependency of MWD on the content of large sand particles (Kodešová et al. 2009), when a gravel particle > 2 mm is counted in MWD stable fraction. A significant spatial and topographic difference of sites caused a wide range of TOC fluxes and low correlation with MWD. The measurement of TOC (C_{ox}) content may not be a sufficiently discriminating factor. It is, above all, the quality of organic particles that plays a crucial part in forming the soil structure (Spaccini et al. 2002). A high negative correlation of exchange soil reaction (pH_{KCl}) and a highly positive correlation of saturated hydraulic conductivity (K_{sat}) with MWD (52%, resp. 59%; Table 2) is surely related to an accelerated development of vascular plants on the fallow land. The detrit acid from the plant affects soil reaction (Percival et al. 2000), the development of plant roots, expansion of soil microorganisms and filamentous fungi, and their exudates and excrements, which dominantly form a soil structure (Bast et al. 2014) and improve soil

pore system and hydraulic properties (Kodešová et al. 2011).

Statistically significant changes occurred on plots of land 10 years after discontinuing agricultural production (Figure 2); above all, there was a significant soil structure stabilisation (MWD, Figure 2a) and an increase in infiltration potential (K_{sat}, Figure 2b) as well as a statistically provable increase in organic matter (Figure 2c) and even a slight soil acidification (Figure 2d).

All these effects are reflected in the MWD detailed evaluation (Figure 2), where the grass cover of the fallow land has decreased the erosion risk for every evaluated soil type.

High proportions of disintegrated particles are most apparent for the soil type Luvisol when comparing the different breaking mechanisms of MWDs for three soil types (Figure 2). In the most destructive test/fast wetting process, it was the Luvisol soil type which resulted in lowest particles (0.23 ± 0.03 mm, compared to CHC 0.56 ± 0.29 mm and CMC 0.89 ± 0.40 mm, Figure 2). The risk of crustability in the silty rich soil type is very high if the vegetation cover is not sufficient (Amezketta et al. 1996). On the other side, the Cambisols are more tolerable to heavy rain and show a variable risk of erosion (Figure 2). The difference

Table 3. The Person's correlation coefficients mean weight diameter (MWD) with basic soil parameters

Soil parameter	< 0.002 0.002–0.01 0.01–0.05 0.05–0.25 0.25–2					pH _{KCl}	C _{ox}	K _{sat}
	(mm)							
MWDs correl. coeff.	–0.310	–0.229	–0.370*	0.346*	0.363*	–0.518*	–0.088	0.588*

Data reported a Pearson's correlation coefficients of MWD with soil parameters for each soil sample ($n = 48$), for soil hydraulic properties (K_{sat}) ($n = 34$), significant correlation ($P < 0.05$) marked as asterisk; C_{ox} – soil organic matter content

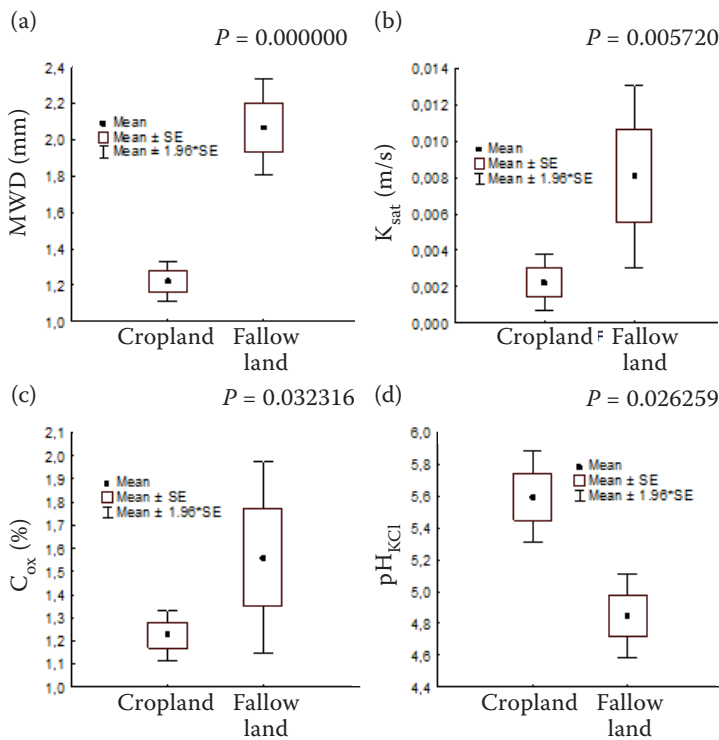


Figure 2. *T*-tests of (a) mean weight diameter (MWD); (b) soil hydraulic properties (K_{sat}); (c) soil organic matter content (C_{ox}) and (d) pH_{KCl} ; *P*-value < 0.05 detected a statistical significant difference on 0.95 level of confidence. SE – standard error

between the cropland and the fallow land is deepened within each soil type when the low destructive process impacted soil surface (slow wetting). Within the slow wetting process, an interesting stabilising effect was recorded in crop treatment on Chernozems (1.35 ± 0.43 mm, Figure 2). This effect can be attributed to mutual effect of two stabilisation (binding) agents: (i) soil organic matter and/or (ii) bivalent Ca organic coating and infilling (Spaccini et al. 2002). The MWD values of crop treatment on Cambisols (CMC) are comparable to Chernozems (CHC), higher for fast wetting and lower for slow wetting and mechanical disaggregation (Figure 2). However, the cause is different. The soil texture

plays a key role in Cambisols – weathering of parent material – paragneiss (Table 1)/source of free Fe, Al oxides or/and Si-O binding agents throughout sol-gel processes (Barral et al. 1998).

There is low relevance of the results for fallow land Chernozems (CHF), which relates to the physical difference of this site and refers to the fact that lands left as fallow are frequently shallow/eroded soils with low productive potential (moreover often used as an illegal dumping at high risk of pollution).

Disintegration of soil structure was physically checked by testing soil aggregates on a small rainfall simulator (Table 4).

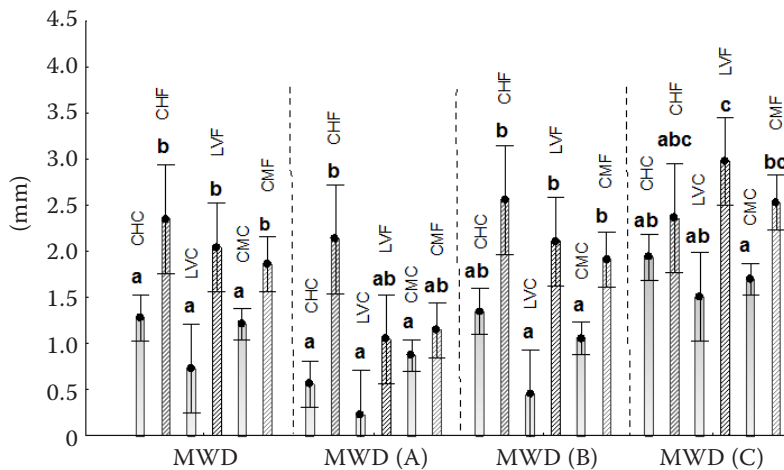


Figure 2. Two-way ANOVA were processed for each mean weight diameter (MWD) test separately; different letters above bars indicate significant differences of Sheffe's test among six categories: CHC – Chernozems/cropland; CHF – Chernozems/fallow-land; LVC – Luvisols/cropland; LVF – Luvisols/fallow-land; CMC – Cambisols/cropland; CMF – Cambisols/fallow-land

doi: 10.17221/357/2015-PSE

Table 4. Small-rainfall simulation testing

Soils type	Type of aggregate	Rain time (min)	Treatment	Surface runoff (L)	Soil loss (g)	Infiltration (mm)	Infiltration (%)	Soil loss (g/m ²)
Haplic Chernozems (CH)	dry	4	D1	0.063	1.65	23.10	96	26.40
		8	D2	1.190	11.97	7.05	29	191.52
	wet	4	W1	0.475	0.66	17.24	72	10.56
		8	W2	0.720	1.41	13.75	57	22.56
Haplic Luvisol (LV)	dry	4	D1	0.470	16.20	17.31	72	259.20
		8	D2	1.360	38.15	4.63	19	610.40
	wet	4	W1	1.000	1.67	9.76	41	26.72
		8	W2	1.470	2.45	3.07	13	39.20
Haplic Cambisol (CM)	dry	4	D1	0.220	0.28	20.87	87	4.48
		8	D2	0.950	1.51	10.47	44	24.16
	wet	4	W1	0.260	0.43	20.30	85	6.88
		8	W2	0.590	0.08	15.60	65	1.28

The rainfall simulation (Table 4) confirmed erosion risks of MWDs through extreme soil losses for Luvisols (259 g/m² for D1, resp. 610 g/m² for D2; Table 4). The potential soil loss after two rainfall cycles on a dry soil (D1 + D2) can be estimated for Luvisols at about 8.7 t/ha compared to Chernozems (2.2 t/ha) and Cambisols (0.3 t/ha). It was confirmed that the silty soils show a high erosion risk and gravel soils buffer slaking and eliminate soil crust formation (Le Bissonnais et al. 2007, Chaplot and Cooper 2015). The results from the rainfall simulator (Table 4) only partially proved the stabilisation effect in gentle rain situations (slow wetting process) for Chernozems.

The slaking effects (SE and SE_{sim}, Table 5) were quantified as well as their role in soil disintegration processes (Le Bissonnais et al. 2007).

Within the Luvisol soil type which is the most threatened by erosion (Table 5), the proportion of slaking effect on the final MWD value is little less than 33%. However, it follows from the results of simulated rainfall that slaking effect causes

enormous damage in Luvisols as a result of soil loss of particles (from 81%, resp. 88%; Table 5, compared to Chernozems and Cambisols). The stabilisation effect of Chernozems is manifested only within the first simulated rainfall (SE_{sim} (1); 43%, Table 5), when rainfall is repeated, it causes up to 79% of removing soil particles from a simulated area (similarly to Cambisols). As presumed, the lowest proportions of slaking effect are demonstrated in Cambisols. Gravel soils (CM) are not subject to the slaking phenomenon. It is presumed that the main impact on soil disaggregation is caused by the mechanical breakdown by raindrop (Le Bissonnais et al. 2007).

The results of slaking indicate the resistance to erosion and warn against a high erosion risk of cropland soils, especially Luvisol, without fully covered soil by vegetation, when it is rapidly wetted. In the Czech Republic there is a phenomenon of soil crusting formation for silty soils enhanced by soil compaction and declining quality of soil organic matter.

Table 5. The slaking effects of mean weight diameter (MWDs) and rain simulations

Character	CHC	CHF	LVC	LVF	CMC	CMF
Slaking effect of MWDs	0.41	0.09	0.33	0.34	0.13	0.23
Slaking effect of simulated soil loss after first 4 min. rain	0.43	–	0.81	–	0.21	–
Slaking effect of simulated soil loss after second rain	0.79	–	0.88	–	0.90	–

CHC – Chernozems/cropland; CHF – Chernozems/fallow-land; LVC – Luvisols/cropland; LVF – Luvisols/fallow-land; CMC – Cambisols/cropland; CMF – Cambisols/fallow-land

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Received on June 1, 2015

Accepted on May 10, 2016

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