

# Temperature influences water sorptivity of soil aggregates

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**Abstract:** The aim of this study was to determine the potential development of water sorptivity of soil aggregates by heating. Soil aggregates were sampled from arable layer of 5 Polish soils: Haplic Luvisol 1 from Czesławice, Haplic Luvisol 2 from Wierzchucinek, Haplic Cambisol from Felin, Gleyic Mollic Cambisol from Chylice, and Haplic Phaeozem from Grabiec. Three aggregates of each soil type with minimum diameter between 4 and 10 mm were heated in the oven for at least 3 hours at temperatures 20, 100, 200, 250, and 360°C. After each temperature treatment the soil aggregates were conditioned at the room temperature for 16 hours. Laboratory measurements of water sorptivity of soil aggregates were performed under a negative tension  $h_0 = -2$  cm using tension infiltrometer. It was found that the exposure to temperatures between 100 and 200°C tends to decrease water sorptivity of aggregates from all the studied soils but one (Haplic Luvisol 1), followed by about two- to four-fold increase in water sorptivity for exposure to temperatures of 250°C (in Haplic Luvisol 1, Haplic Luvisol 2, and Haplic Phaeozem) or 360°C (in Haplic Cambisol and Gleyic Mollic Cambisol).

**Keywords:** Soil; Aggregate; Sorptivity; Temperature; Water repellency.

## INTRODUCTION

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles (Glinski et al., 2011). Soil aggregation is closely connected with the soil water regime, soil erodibility and soil nutrient availability (Zádorová et al., 2011). Soil organic carbon, microbial biomass and thermostable protein glomalin, produced by arbuscular mycorrhizal fungi, act as important binding agents for aggregation (Feeney et al., 2006; Zhang et al., 2012). The desired size of aggregates is related with the soil function. The ideal seedbed agrees well with larger aggregates (diameter about 15 mm), because they enhance infiltration and/or provide depressions for water and thus allow more time for infiltration, delaying run-off generation. A coarser aggregate structure may also diminish the rate of evaporation and stimulate ion exchange processes (Josa et al., 2010; Slawinski et al., 2011).

Surfaces of soil aggregates are mostly covered by organic matter that finally controls wettability, sorption, and transfer properties of the flow pathways (Leue et al., 2010). The optimized saturated hydraulic conductivities of aggregate coatings were found to be one to two order of magnitude lower than the saturated hydraulic conductivities of the aggregates (Fér and Kodešová, 2012). Bartoli and Dousset (2011) found that the greater the apparent contact angle value, the smaller the water sorptivity value and the greater the proportion of water-stable aggregates. Small changes in wetting angle can cause switches between wettable and water repellent soil behavior (Czachor et al., 2010). Subcritical water repellency was found to be common feature of soil aggregates (Hallett et al., 2001), and it is potentially sensitive to extreme climatic events, such as droughts and heat waves (Goebel et al., 2011). Smaller aggregates (5–8 mm) expressed higher level of repellency as bigger (12–15 mm) ones (Urbanek et al., 2007). Ellerbrock et al. (2005) found that for soil organic carbon (SOC) contents < 10 g kg<sup>-1</sup>, wettability increased with SOC content while it decreased for SOC contents > 10 g kg<sup>-1</sup>.

Stubble burning is a recognised management practice in cropping systems all over the world (e.g. Malhi and Kutcher,

2007). It is used as a means of reducing crop residue on the soil surface, and as a substitute for herbicides and pesticides in the control of weeds, pests and diseases (Valzano et al., 1997). However, it changes the soil water repellency and aggregate stability due to an increase in soil temperature (Kodešová et al., 2009; Novák et al., 2009; Kořenková et al., 2011; Mataix-Solera et al., 2011). The changes in soil water repellency depend on the clay (mainly kaolinite) content (Dłapa et al., 2004; Lichner et al., 2006).

The aim of this study was to determine the potential development of water sorptivity of soil aggregates by heating. The soils, chosen for this study, are typical for central and south-eastern part of Poland. As the fuel load (straw) in agricultural fields is lower than in the forests, low and moderate soil surface temperatures for forest fires (100, 200, 250, and 360°C) were chosen for this study.

## MATERIAL AND METHODS

Soil aggregates were sampled from arable layer (0–30 cm) of 5 Polish soils (coordinates of the sites in brackets): Haplic Luvisol 1 (WRB, 2006) from Czesławice (51°18'23"N, 22°16'02"E), Haplic Luvisol 2 (WRB, 2006) from Wierzchucinek (53°16'N, 17°47'E), Haplic Cambisol (WRB, 2006) from Felin (51°14'43"N, 22°34'13"E), Gleyic Mollic Cambisol (WRB, 2006) from Chylice (52°04'43"N, 21°03'44"E), and Haplic Phaeozem (WRB, 2006) from Grabowiec (50°49'16"N, 23°32'48"E). It should be mentioned that two soils (Gleyic Mollic Cambisol and Haplic Luvisol 2) have been subjected to long-term static organic fertilizer experiment since several decades and their  $C_{org}$  content is relatively high.

The basic chemical and physical soil properties (Table 1) were obtained using standard laboratory procedures under constant laboratory temperature of 20°C as follows: grain-size distribution by the Casagrande method (WRB, 2006), the soil pH(H<sub>2</sub>O) and pH(KCl) according to ISO 10390 (1994), the CaCO<sub>3</sub> content according to Dobrzański and Zawadzki (1981), carbon content in humic acids according to Schnitzer and Khan,

**Table 1.** Physical and chemical properties of the soils studied.

Soil	Sand (%)	Silt (%)	Clay (%)	CaCO <sub>3</sub> (%)	C <sub>org</sub> (%)	pH(H <sub>2</sub> O) (–)	pH(KCl) (–)	C-HA (g/kg)	C-FA (g/kg)	P (–)
Haplic Luvisol 1	30	59	11	< 0.05	0.98	7.13	7.13	2.0	2.8	0.480
Haplic Luvisol 2	32	58	10	< 0.05	1.11	6.55	n.d.	2.47	1.93	0.370
Haplic Cambisol	63	29	8	< 0.05	1.06	6.59	5.77	2.4	2.9	0.426
Gleyic Mollic Cambisol	61	21	18	< 0.05	2.15	6.12	n.d.	3.27	2.63	0.402
Haplic Phaeozem	27	36	37	< 0.05	1.44	5.59	5.59	2.7	2.6	0.498

n.d.: not determined; C-HA: carbon content in humic acids; C-FA: carbon content in fulvic acids.

(1978), and carbon content in fulvic acids according to Schnitzer and Khan (1978). Organic carbon content was measured by means of applying 0.4N potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>) for organic components oxidation (Kononowa, 1968). Porosity *P* of each individual aggregate was estimated from its weight in the air *G* and its hydrostatic lift in the mercury *H* by means of the equation:

$$P = 1 - \frac{\rho_{Hg} G}{\rho_s (G - H)}, \quad (1)$$

where  $\rho_{Hg} = 13.6 \text{ g cm}^{-3}$  mercury density and  $\rho_s = 2.65 \text{ g cm}^{-3}$  soil solid phase density.

Air-dry soil aggregates were sieved through two sieves with 10 mm and 2 mm meshes, and three aggregates of each soil type with minimum diameter of about 4 mm were chosen for further investigations. All aggregates were heated in the oven for at least 3 hours at temperatures 20, 100, 200, 250, and 360°C. After each temperature treatment the soil aggregates were conditioned at the room temperature for 16 hours. Laboratory measurements of water sorptivity of soil aggregates were performed under a negative tension  $h_0 = -2 \text{ cm}$  using tension infiltrometer (Fig. 1), constructed after the apparatus of Leeds-Harrison et al. (1994). A saturated sponge (2 mm ID) enabled a good contact to the measured aggregate. Water infiltration into the aggregate was measured by means of scaled capillary with 1 mm<sup>3</sup> accuracy. Imbibition rate  $Q$  was determined from the steady-state part of the  $V(t)$  relationship. In principle water uptake  $V$  is proportional to time  $t$  until a near-saturation state of aggregate is reached. Water sorptivity  $S$  of an aggregate was calculated from the equation (Leeds-Harrison et al., 1994):

$$S = \sqrt{Qf / 4bR}, \quad (2)$$

where  $Q = V/t$  is water flux to the aggregate (mm<sup>3</sup> s<sup>-1</sup>),  $f$  is aggregate porosity,  $b$  is a parameter that depends on the soil-water diffusivity function, and  $R$  is radius of connecting sponge (mm). The value of  $b$  can be in the range  $0.5 \leq b \leq \pi/4$  with  $b = 0.55$  being an “average” value (Hallett and Young, 1999) used here.

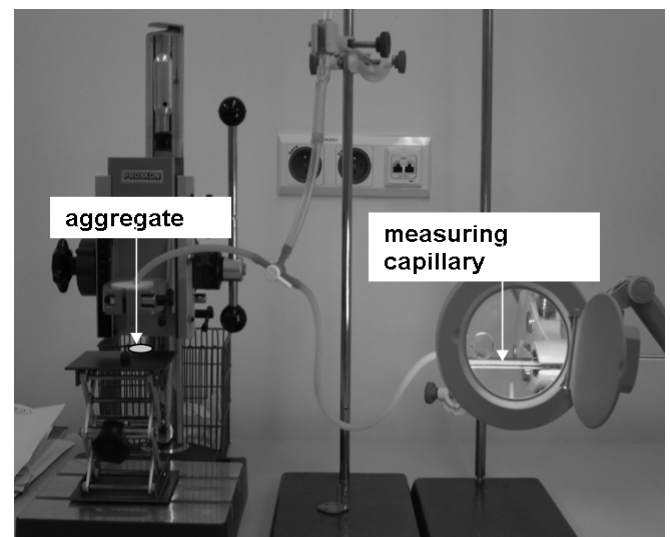
## RESULTS AND DISCUSSION

Water sorptivities of aggregates exposed to different temperatures are presented in Table 2 and Fig. 2. It was found that the exposure to temperatures between 100 and 200°C tends to decrease water sorptivity of aggregates from all the studied soils but one (Haplic Luvisol 1), followed by about two- to four-fold increase in water sorptivity for exposure to tempera-

tures of 250°C (in the 1<sup>st</sup> group of soils, i.e. Haplic Luvisol 1, Haplic Luvisol 2, and Haplic Phaeozem) or 360°C (in the 2<sup>nd</sup> group of soils, i.e. Haplic Cambisol and Gleyic Mollic Cambisol). Taking into account that the water sorptivity is inversely proportional to water repellency/contact angle (Bartoli and Dousset, 2011), our findings are in agreement with the findings of Doerr et al. (2005). They showed for initially water repellent soils with soil organic carbon contents between 0.4% and 6.8% that exposure to temperatures from 20 to 200°C tended to increase soil water repellency (SWR), followed by a decline in SWR at exposure to 250°C and destruction of SWR at 300°C.

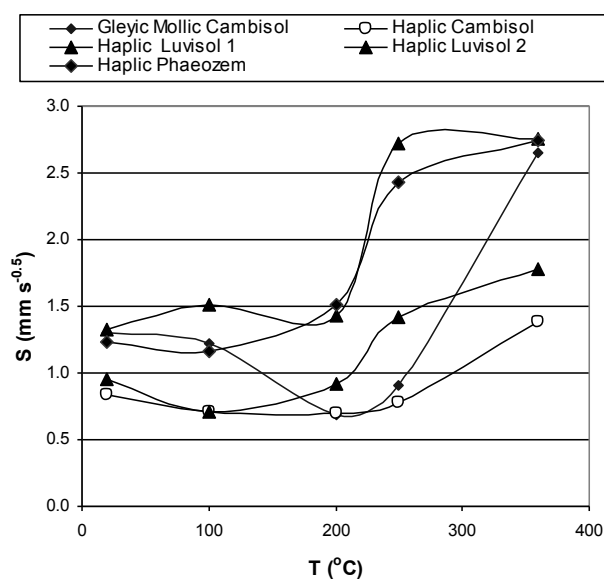
As the fire-induced breakdown of SWR can be attributed to the selective degradation of aliphatic structures during fire (Almendros et al., 1988), difference in breakdown temperature for these two groups of soils could result from different chemical composition of organic matter. The only notable difference in physical or chemical properties, presented for these two groups of soils in Table 1, is sand content, which is about 2-times greater in Cambisols in comparison with Luvisols and Phaeozem. But this difference cannot account for the difference in breakdown temperature.

Our findings that the elimination of water repellency of aggregate coatings due to the exposure to temperature from 250 to 360°C resulted in about two- to four-fold increase in sorptivity are in agreement with the findings of Gerke and Köhne (2002) that scalping (= removal) of aggregate coatings resulted in about three-fold increase in water sorptivity of aggregates from clay-loam soil (Stagnic Calcaric Regosol).

**Fig. 1.** Device for water aggregate sorptivity measurement.

**Table 2.** Statistical parameters of water sorptivity of aggregates exposed to different temperatures.

Soil	T (°C)	S (–2cm) (mm s <sup>-0.5</sup> )			
		Minimum value	Maximum value	Mean value	Standard deviation
Haplic Luvisol 1	20	0.313	0.532	0.420	0.089
	100	0.303	0.654	0.479	0.143
	200	0.373	0.508	0.454	0.059
	250	0.481	1.212	0.869	0.300
	360	0.689	0.988	0.872	0.131
Haplic Luvisol 2	20	0.264	0.326	0.301	0.027
	100	0.231	0.244	0.237	0.005
	200	0.270	0.320	0.289	0.022
	250	0.384	0.504	0.450	0.050
	360	0.446	0.657	0.562	0.087
Haplic Cambisol	20	0.219	0.254	0.237	0.018
	100	0.179	0.278	0.227	0.040
	200	0.219	0.254	0.237	0.018
	250	0.217	0.258	0.238	0.017
	360	0.287	0.522	0.438	0.107
Gleyic Mollic Cambisol	20	0.234	0.636	0.413	0.167
	100	0.243	0.629	0.386	0.173
	200	0.198	0.239	0.217	0.017
	250	0.283	0.643	0.434	0.152
	360	0.672	1.089	0.838	0.181
Haplic Phaeozem	20	0.365	0.436	0.389	0.033
	100	0.310	0.448	0.368	0.058
	200	0.361	0.701	0.480	0.156
	250	0.600	0.943	0.770	0.140
	360	0.759	0.976	0.867	0.088

**Fig. 2.** Water sorptivity of soil aggregates after thermal treating in the indicated temperature for (a) Haplic Luvisol 1 from Czesławice, (b) Haplic Luvisol 2 from Wierzchucinek, (c) Haplic Cambisol from Felin, (d) Gleyic Mollic Cambisol from Chylice, and (e) Haplic Phaeozem from Grabiec.

## CONCLUSIONS

The temperature induced changes of aggregate water sorptivities depend on soil organic carbon content. The biggest shift was observed for Gleyic Mollic Cambisol, Haplic Luvisol 2 and Haplic Phaeozem where the organic carbon contents are the

largest. The exposure to temperatures between 20 and 200°C tends to decrease water sorptivity of aggregates from Gleyic Mollic Cambisol, Haplic Cambisol, Haplic Luvisol 2 or it remains almost stable for two other soils Haplic Luvisol 1 and Haplic Phaeozem. One can suppose that this phenomenon is related to the transformation of some organic compounds into more hydrophobic one which cause an increase in wetting angle. For a given soil and the applied temperature range the ratio of biggest and the lowest sorptivity varies from 1.98 for Haplic Cambisol to 3.85 for Gleyic Mollic Cambisol. All the studied soils subjected to 360°C show the highest water sorptivities, which can be attributed to a removal of soil organic matter and related decrease of soil water wetting angle.

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