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Original Paper

The effect of different severity of fire on soil organic matter and aggregates stability

Katarína Muráňová*, Vladimír Šimanský

Slovak University of Agriculture in Nitra, Slovakia

Fire affects many of physical, chemical and biological soil properties directly by the transport of the heat to the soil or indirectly because of the vegetation changes and dynamic of nutrients and organic matter. This impact depends on many factors therefore the aim of this study was to consider the impact of different severity of fire on the changes in quantity and quality of soil organic matter (SOM) and soil structure in sandy dystrict Fluvisol. The samples were taken in the Zbehy district (autumn 2012) from three localities: 1. Unburned soil – the control, 2. Higher severity of fire, and 3. Lower severity of fire. The results showed the increase of SOM content due to higher severity of fire; on the other hand, the SOM quality was decreased. The stability of water-stable aggregates was clearly decreased because of higher fire-severity. Overall, our results indicate that the breakdown of soil structure was affected by higher severity of fire.

Keywords: fire, stability of water-stable aggregates, soil structure

1. Introduction

The soil is considered as a main part of an environment and as a necessary condition for living. The soil also gives a possibility to practice agriculture and has an irreplaceable position in providing nutrition. Organic matter as an integral part of soil, which despite of its lower proportion (0.4–10 % in soils of temperate climate zone) has a major influence on the soil evolution, the existence of soil organisms as well as on the soil fertility in comparison with mineral matter (Smith et al., 1993). Soil properties are influenced by the complex of different factors in many ways (Šimanský et al., 2008).

According to Bowman et al. (2009), fire is considered as a global phenomenon that influences bigger part of Earth´s surface compared to another natural disaster. Fire has a significant impact on SOM, chemical, physical and biological properties of soils (Certini, 2005; Mataix-Solera et al., 2009; Šimanský et al., 2012). It has been widely demonstrated that fire induces changes in SOM and it has been affected mainly by the interval of temperatures reached at different soil depths and intensity of fire (De la Rosa et al., 2012). While lower intensity of prescribed burning is considered to have mainly low or no effect on soil aggregates, soil structure is widely affected during high temperature of fire (Urbanek, 2013). According to Horn and Smucker (2005), soil structure is under influence of constant transformation as a result of changes in soil humidity and temperature. Mataix-Solera et al. (2011) claimed that different factors, for instance severity of fire, different soil properties and soil conditions affect the aggregate stability.

In this research we assumed that different severity of fire would have different effect on SOM and soil structure. Therefore the aim of this study was to (1) quantify the influence of different fire-severity on quantity and quality of SOM in sandy dystrict Fluvisol and (2) quantify the impact of fire on soil structure of sandy dystrict Fluvisol.

2. Material and methods

The study area is located in Zbehy, a village situated northwest of Nitra city and in altitude 142–239 m (above sea level). The concrete locality is placed in south-eastern border of Nitra loess upland, alluvial flat of river Nitra, near to junction with small river Radošinka. The geological ground is composed of cenozoic sediments which are covered by loess and alluvial deposits with different granularity. This area is a part of warm climate zone, slightly dry. The average annual temperature is 9.7 °C and average annual rainfall is between 600–700 mm.

Soil samples were taken from the arenic dystric Fluvisol (classified according to WRB, 2006) from the field (size approx. 1.8 ha). The soil contained 9.7 g kg^{-1} of total soil organic carbon and the pH was slightly acidic (5.9) on average. The soil contained also 57.5 % of sand, 27.6 %

***Correspodence:** Katarína Muráňová, Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Department of Soil Science, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia, e-mail: muranova.katka@gmail.com

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of silt and 14.9 % of clay. The winter wheat was grown on the area before sampling. The straw was burned out after the harvest. In autumn 2012, the soil samples were collected from following areas:

1. Unburned soil – control (Co).
2. Higher severity of fire (HSF) – soil samples taken from plots, where the straw was accumulated after the harvest, and we hypothesized higher severity of fire due to burning of higher amount of dry biomass.
3. Lower severity of fire (LSF) – soil samples taken from plots, where the field was burned, but there was not accumulated straw of wheat and therefore we hypothesized lower severity of fire (whole amount of biomass was obviously smaller in these places).

Soil samples were taken from six randomly chosen areas of each plot. Mixing samples together we got the average sample and we determined the SOM and soil structure parameters. We determined: total organic carbon (C_{org}) (Dzadoviec and Gonet, 1999), labile carbon (C_L) (Loginow et al., 1987), hot-water soluble carbon (C_{HWD}) and cold-water soluble carbon (C_{CWD}) (Kőrsensen, 2002), composition of organic substances and optical properties of SOM (Dzadowiec and Gonet, 1999). Soil samples for determination of soil structure parameters were also air dried and pre-sieved over a series of sieves, before being bulked into seven size fractions (>7, 7–5, 5–3, 3–1, 1–0.5, 0.5–0.25, <0.25 mm), which were used to determine individual size fractions of water-stable aggregates (WSA) according to the Baksheev method (Hraško et al., 1962). In obtained size fractions of water-stable microaggregates (WSA_{mi} – defined as aggregates <0.25 mm) and macroaggregates (WSA_{ma} – defined as aggregates >0.25 mm) was determined total organic carbon (C_{org}) (Dzadowiec and Gonet, 1999). The index of aggregate stability (*Ks*) was calculated according Equation (1):

$$Ks = \frac{A}{B} \qquad (1)$$

where:

A – the weight of water-stable aggregates in size fractions from 0.25 to 10 mm

B – is the weight of water-stable aggregates less than 0.25 mm.

The results were statistically evaluated. For particular evaluation of monitored parameters (depth and severity of fire) there had been used multiple factor analysis (ANOVA). The differences between plots were measured by Least Significant Difference test with $P \leq 0.05$.

3. Results and discussion

Statistical evaluation of SOM parameters in dependence on soil depth and severity of fire is presented in Table 1. The SOM quantity was higher in surface layer (0–5 cm) in comparison to the depth 5–20 cm. Fire-severity had also statistically significant influence on SOM parameters. In comparison to lower severity (LSF), the higher severity (HSF) increased values of C_{org} (by 24 %), C_{HWD} (by 29 %), C_{CWD} (by 15 %) and C_L (by 108 %). In consequence of LSF we noticed significant decrease (by 19 %) in content of C_L in compare to the Co. The ratio of humic acid carbon to fulvic acid carbon ($C_{HA} : C_{FA}$) is considered as an important indicator of SOM quality (Sotáková, 1982). The $C_{HA} : C_{FA}$ ratio was statistically higher in the depth 0–5 cm than in 5–20 cm. HSF had a negative effect on quality of SOM while on the other hand we observed a positive influence due to lower severity of fire. We evaluated the quality of SOM with regard to the fire-severity as well as by the optical parameters of humus substances $\left(Q^{4/6}_{HA}\right)$ and humic acid $\left(Q^{4/6}_{HS}\right)$ therefore it is very important indicator of SOM (Sotáková, 1982). The values of $Q^{4/6}_{HS}$ were statistically lower in the depth 5–20 cm than in 0–5 cm.

Table 1 Statistical evaluation of soil organic matter due to different soil depth and severity of fire

Factors	**Parameters of soil organic matter**						
	C_{org}	C_L	C_{HWD}	C_{CWD}	$C_{HA} : C_{FA}$	$Q^{4/6}_{HS}$	$Q^{4/6}_{HA}$
	%	**mg kg^{-1}**					
Depth in cm							
0–5	1.19b	1588a	724b	253b	1.73b	4.13b	3.70a
5–20	0.98a	1516a	589a	227a	1.54a	3.98a	3.67a
Fire severity							
Control	0.98a	1295b	574a	227a	1.63b	3.92a	3.57a
Lower severity of fire	1.02a	1092a	609a	229a	1.89c	3.99a	3.65b
Higher severity of fire	1.26b	2269c	787b	264b	1.38a	4.24b	3.84c

C_{org} – organic carbon content, C_L – labile carbon, C_{HWD} – hot-water soluble carbon, C_{CWH} – cold-water soluble carbon, $C_{HA} : C_{FA}$ – carbon of humic acid to carbon of fulvic acid ratio, $Q^{4/6}_{HS}$ – colour quotient of humus substances, $Q^{4/6}_{HA}$ – colour quotient of humic acid.
Data within a line followed by the same letter are not significantly different at $P < 0.05$ according to LSD-test.

Table 2 Statistical evaluation of water-stable aggregates and stability coefficient of water-stable aggregates due to different soil depth and severity of fire

Factors	Size fractions of water-stable aggregates in mm							K_s
	>5	5–3	3–2	2–1	1–0.5	0.5–0.25	<0.25	
Depth in cm								
0–5 cm	3.21a	5.08a	7.01a	11.81a	29.63b	26.87a	16.47a	5.07
5–20 cm	7.47b	5.65a	9.08b	11.25a	20.67a	24.49a	21.43a	3.67
Fire severity								
Control	5.97b	4.69a	9.07b	14.86b	29.42b	28.26a	7.86a	11.72
Lower severity of fire	3.41a	3.49a	5.14a	12.02b	29.59b	25.07a	21.36b	3.68
Higher severity of fire	6.65b	7.92b	9.94b	7.72a	16.44a	23.72a	27.64b	2.62

K_S – stability coefficient of water-stable aggregates,
Data within a line followed by the same letter are not significantly different at P <0.05 according to LSD-test

Table 3 Statistical evaluation of content of organic carbon in size fractions of water-stable aggregates due to different soil depth and severity of fire

Factors	Content of organic carbon in % in individual size fraction of water-stable aggregates in mm						
	>5	5–3	3–2	2–1	1–0.5	0.5–0.25	<0.25
Depth in cm							
0–5	1.41a	1.46a	1.37a	1.56a	1.17a	0.83b	0.88b
5–20	1.20a	1.26a	1.24a	1.35a	0.99a	0.69a	0.79a
Fire severity							
Control	1.40a	1.29a	1.34a	1.38a	0.98b	0.80a	1.05b
Lower severity of fire	1.21a	1.38a	1.19a	1.15a	0.72a	0.74a	0.74a
Higher severity of fire	1.30a	1.42a	1.39a	1.84b	1.55c	0.75a	0.71a

Data within a line followed by the same letter are not significantly different at P <0.05 according to LSD-test

The same tendency was observed in values of $Q_{HA}^{4/6}$ (without statistical significance). Increasing intensity of fire caused the decreasing of SOM stability.

Soil structure is repeatedly influenced during high severity of fire whilst the lower severity of prescribed burning is considered to have low or neutral influence on soil aggregates (Urbánek, 2013) therefore we evaluated the effect of different fire-severity on individual fractions of WSA as one of the most important indicator of soil structure stability. Favourable soil structure and high aggregate stability are important for the increase of soil fertility, porosity and often are expressed as a rate of aggregate stability (Bronick and Lal, 2005). Šimkovič et al. (2008) claimed that the effect of higher fire-intensity on the content of WSA lead to their decrease and it could be caused also by the more intense process of thermal oxidation of SOM above the level of temperature (200 °C). We observed the differences between individual size fractions of WSA in comparison to different soil depth and fire-severity (Table 2). Statistically significant higher values of WSA_{ma} >5 mm (by 132 %), and WSA_{ma} 3–2 mm (by 30 %) were observed in the depth 5–20 cm. Lower severity of fire negatively affected the breakdown of WSA_{ma} in size fractions: >5 mm; 5–2 mm; 0.5–0.25 mm, however, the statistical significance in size fractions >5 and 3–2 mm was observed. Our results are consistent with the results of Andreu et al. (2001) who observed significant decrease of macroaggregates and on the other hand the increase of microaggregates due to higher severity of fire. The negative effect of fire was also confirmed by lower values of the index of aggregate stability of WSA (in Co = 11.7; in LSF = 3.68; in HSF = 2.62). The higher severity of fire resulted in the lower values of the index of aggregate stability. It indicates worse soil structure state. One of the eventual explanations of the breakdown of higher size fractions of macroaggregates onto smaller macroaggregates could be the opinion of Albalasmeh et al. (2013). The burning of moist soil aggregates during high temperatures leads to evaporation of water which is inside of them and growing pressure affecting them has an influence on the destruction of internal bonds and this all leads to decomposition of soil aggregates. According to this, on soils which are at first waterproof

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and they have organic matter as a main cementing factor conduces the decrease of aggregate stability consistently with increasing fire severity (Doerr et al., 2000). Organic proportion in soil matter is an integral part of soil and has a main influence on soil evolution, existence of soil organisms and particularly on soil fertility (Smith et al., 1993) and it is significantly involved in the formation of soil aggregates (Tisdall and Oades, 1982).

The effects of soil depth and fire-severity on C_{org} in WSA are presented in Table 3. The content of C_{org} in size fractions of WSA_{ma} >5 and 5–0.5 mm decreased in consequence of increasing soil depth (without statistical significance). The content of total organic carbon is considered to be highly variable and it depends on many factors such as fire type and severity, vegetation cover and a terrain (De la Rosa et al., 2009; Fernández et al., 1997). In 5–20 cm, lower values of C_{org} in WSA_{ma} 0.5–0.25 mm (by 1400 mg kg^{-1}) and in WSA_{mi} (by 900 mg kg^{-1}) were observed in comparison to 0–5 cm (Table 3). LSF had statistically significant influence on decrease of C_{org} in WSA_{ma} 1–0.5 mm as well as in WSA_{mi}. On the other hand, HSF had significant influence on increase of C_{org} in WSA_{ma} 5–0.5 mm what is confirmed by researches of many authors (Atanassova et al., 2009; Mataix-Solera et al., 2002) but according to them it is not unusual and this increase could be affected by the content of burned plant residues in soil (Johnson and Curtis, 2001).

4. Conclusions

Organic matter is in close relation to the soil structure which is more or less influenced by fire due to severity of fire itself. Obtained results pointed out to a fact that the increase of fire-severity had an impact on the increase of SOM, but on the other hand the SOM quality was worse. Higher severity of fire increased the content of water-stable macroaggregates in size fractions >5–2 mm and content of water-stable microaggregates, whilst the content of smaller size fractions of water-stable macroaggregates (>2 mm) decreased as well as the content of soil organic carbon in size fractions of water-stable macroaggregates 5–0.5 mm increased. Overall, the aggregate stability due to higher severity of fire was lower. All in all, we summarize that higher severity of fire decreased the soil structure of sandy dystrict Fluvisol. In our case, the key factor of stability of soil structure is probably particle-size distribution – mainly higher content of sand. To confirm the findings, more research is required in the future.

Obtained results did not confirm absolute effect of SOM on the aggregate stability of sandy dystrict Fluvisol. The connection between SOM and soil structure may serve as an initial indication of behaviour of these parameters in sandy dystrict Fluvisols with dependence on fire. To the future we suggest to expand the database onto another soil types so we can predict their behaviour and changes of soil properties due to the fire.

5. References

ALBALASMEH, A. A. et al. (2013) Degradation of moist soil aggregates by rapid temperature rise under low intensity fire. In *Plant Soil*, vol. 362, pp. 335–344.
DOI:http://dx.doi.org/10.1007/s11104-012-1408-z

ANDREU, V. et al. (2001) Temporal changes in soil macro and microaggregation induced by forest fires and its incidence on water erosion. In *Catena*, vol. 44, pp. 69–84.
DOI:http://dx.doi.org/10.1016/S0341-8162(00)00177-6

ATANASSOVA, I. et al. (2009) Characterisation of a fire affected catena sequence from Lyulin Mountain Bulgaria. In *Bulgarica Journal of Agricultural Science*, vol. 15, pp. 333–340.

BOWMAN, D.M.J.S. et al. (2009) Fire in the Earth system. In *Science*, vol. 324, 481–484.

BRONICK, C.J. and LAL, R. (2005) The soil structure and land management: a review. In *Geoderma*, vol. 124, no. 1–2, pp. 3–22.
DOI:http://dx.doi.org/10.1016/j.geoderma.2004.03.005

CERTINI, G. (2005) Effects of fire on properties of forest soils: a review. In *Oecologia*, vol. 143, pp. 1–10.
DOI:http://dx.doi.org/10.1007/s00442-004-1788-8

De la ROSA, J. M. et al. (2009) Structural properties of non combustion derived refractory organic matter which interferes with BC quantification. In *Journal of Analytical and Applied Pyrolysis*, vol. 85, pp. 399–407.

De la ROSA, J. M. et al. (2012) Characterization of wildfire effects on soil organic matter using analytical pyrolysis. In *Geoderma*, vol. 191, pp. 24–30.
DOI:http://dx.doi.org/10.1016/j.geoderma.2012.01.032

DOERR, S.H. et al. (2000) Soil water repellency: its causes, characteristics and hydro-geomorphological significance. In *Earth-Science Reviews*, vol. 51, pp. 33–65.

DZIADOWIEC, H. and GONET, S.S. (1999) *Methodical guide-book for soil organic matter studies*. Prace Komisji Naukowych Polskiego Towarzystwa Gleboznawczego, N. 120, Komisja chemii gleb, Zespół Materii Organicznej Gleb, N II/16. (in Polish).

FERNANDEZ, I. et al. (1997) Organic matter changes immediately after a wildfire in an Atlantic forest soil: comparison with laboratory soil heating. In *Soil Biology and Biochemistry*, vol. 29, pp. 1–11.

HORN, R. and SMUCKER A. (2005) Structure formation and its consequences for gas and water transport in unsaturated arable and forest soils. In *Soil Till Res.*, vol. 82, pp. 5–14.
DOI:http://dx.doi.org/10.1016/j.still.2005.01.002

HRAŠKO, J. et al. (1962) *Soil analysis*. Bratislava: SVPL (in Slovak).

IUSS Working Group WRB (2006) World reference base for soil resources. In *World Soil Resources Reports* no. 103. Rome: FAO.

JOHNSON, D.W. and CURTIS, P.S. (2001) Effects of forest management on soil C and N storage: meta analysis. In *Forest Ecology and Management*, vol. 140, pp. 227–238.

KÖRSCHENS, M. (2002) Importance of Soil Organic Matter for Biomass Production and Environment a review. In *Arch Acker-Pfl Boden.*, vol. 48, pp. 89–94.
DOI:http://dx.doi.org/10.1080/03650340214162

LOGINOW, W. et al. (1987) Fractionation of organic carbon based on susceptibility to oxidation. In *Pol. J. Soil Sci.*, vol. 20, pp. 47–52.

MATAIX-SOLERA, J. et al. (2002) Soil organic matter and aggregates affected by wildfire in a Pinus halepensis forest in a Mediterranean environment. In *International Journal of Wildland Fire*, vol. 11, pp.107–114.

MATAIX-SOLERA, J. et al. (2009) Forest fire effects on soil microbiology. In: Cerdá, A. and Robichaud, P. (eds.), *Fire Effects on Soils and Restoration Strategies*. Enfield, New Hampshire: Science Publishers, pp. 133–175.

MATAIX-SOLERA, J. et al. (2011) Fire effects on soil aggregation: a review. In *Earth-Science Reviews*, vol. 109, pp. 40–60. DOI:http://dx.doi.org/10.1016/j.earscirev.2011.08.002.

ŠIMANSKÝ, V. et al. (2008) Soil tillage and fertilization of Orthic Luvisol and their influence on chemical properties, soil structure stability and carbon distribution in water-stable macro-aggregates. In *Soil Till. Res.*, vol. 100, no. 1–2, pp. 125–132. DOI:http://dx.doi.org/10.1016/j.still.2008.05.008

ŠIMANSKÝ, V. et al. (2012) Soil organic matter and aggregates stability in soils after windstorm and fire damage in the High Tatras Mountains. In *Ekológia* (Bratislava), vol. 31, no. 3, p. 322–330.

ŠIMKOVIČ, I. et al. (2008) Thermal destruction of soil water repellency and associated changes to soil organic matter as observed by FT-IR spectroscopy. In *Catena*, vol. 74, pp. 205–211. DOI:http://dx.doi.org/10.1016/j.catena.2008.03.003

SMITH, J.L. et al. (1993) Soil organic mater dynamics and crop residue management. In: METTINGBLAINE, F. (ed.), *Soil microbial ecology: applications in Agricultural and Environmental Management*. New York: Marcel Dekker, pp. 65–94.

SOTÁKOVÁ, S. (1982) *Organic matter and soil fertility*. Bratislava: Príroda. (in Slovak).

TINDSAIl, J.M. and OADES, J.M. (1982) Organic matter and water-stable agregates in soils. In *Soil Sci.*, vol. 33, pp. 141–163.

Urbanek, E. (2013) Why are aggregates destroyed in low intensity fire? In *Plant soil*, vol. 362, pp. 33–36. DOI:http://dx.doi.org/10.1007/s11104-012-1470-6