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SOIL ORGANIC MATTER AND AGGREGATES STABILITY IN SOILS AFTER WINDSTORM AND FIRE DAMAGE IN THE HIGH TATRAS MOUNTAINS

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Abstract

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Soil is one of the largest reservoirs of organic matter and negative environmental changes can intensify the decomposition processes and lead to the loss of soil organic carbon. Mountain forest soils are rich in carbon and carbon is one of the most important factors influencing of aggregation. In November 2004 a windstorm in the High Tatra Mountains, Slovakia, damaged more than 12 000 ha of coniferous forest. In 2005 there last fire then damaged 250 ha of forests. Our study was conducted in three forest conditions: 1) after windstorm, where all the downed trees had been extracted; 2) after the windstorm downed trees were burned during the fire of 2005; 3) intact forest areas unaffected by the storm as a comparative reference. In the intact site the maximum extractable soil organic carbon was determined. In the destroyed sites the increase of hot water soluble carbon was determined. The most significant reduction of the soil organic matter stock within the soil was observed in the windstorm sample area. Soil from the fire damaged sample had the highest stability of aggregates. The lowest aggregates stability was observed in the soil from area one affected by the windstorm, where up to 31% had been lost compared with intact soil. The content of total carbon in water-stable aggregates was almost threefold that in micro-aggregates compared to macro-aggregates in soil after the windstorm as well as after the fire.

Key words: soil organic matter, aggregate stability

Introduction

Organic matter has a main role in the biogeochemical cycles of biogenic elements and the formation of chemical, physical and biological properties of soils. Prentice (2001) stated that soils contain twice as much carbon as the atmosphere. Therefore soils are integrated to the largest reservoir of organic matter. Negative environmental changes, for example forest fires or natural disasters, may intensify the degradation processes and cause loss of organic carbon. The results published by Gonet et al. (2009) confirmed this fact. Compared with Mediterranen countries like Greece, Spain or Croatia, fires in Slovakia fortunately do not affect large areas, but nevertheless do cause considerable damage. The soil environment after fire has considerably changed chemical and physical properties. Changes in soil organic matter content within soils after fire is reported by several authors (Mataix-Solera, et al., 2002; Garcia-Corona et al., 2004; Gonet et al., 2009), which is reflected mainly on soil structure (Arcenegui et al., 2008; Varela et al., 2010), because organic matter is a very important factor affecting the aggregation processes in soils (Tisdall, Oades, 1982).

In the High Tatras, after a windstorm in 2004 had destroyed 12 600 ha of forests there were subsequently broken trees extracted (totaling 2.5 mil. m^3 of wood). In 2005 the last fire in the High Tatras damaged about 250 ha of forests. Of course all these natural disasters have an impact on the soil environment. Therefore, the aim of this paper was to evaluate the impact of windstorm and fire on the changes of soil organic matter and aggregate stability in the National Park of the High Tatras.

Material and methods

The High Tatras Mountains are located in the northern part of Slovakia on the border with Poland. It covers a relatively small area (a ridge with a length of 26 km and 32 valleys) and features the smallest mountains in the world. The area of the Tatras is divided into the Západné and Východné Karpaty Mts. The Východné Karpaty Mts are further divided into the High Tatras and Belianske Tatry Mts. They differ in geological structure and vegetation. The High Tatras are built of crystalline rock whilst in the Belianske Tatry Mts limestone and dolomite dominate. The high mountain ranges of the High Tatras occur in Cenozoic, formed by the elevation of granite massif above the ground and reached their final form following the action of glaciers in the Post-tertiary period. The High Tatras is a cool climate region with a cold mountain climate featuring an average annual temperature of 2 °C and mean July temperatures of 10 to 12 °C. Annual rainfall is up to 2000 mm. The forest boundary reaches an altitude of 1500 m.

In 2006, soil samples were taken from A horizons (0–0.15 m) on three localities (S1 – after windstorm, S2 – after the fire, S3 – intact soil). Detailed characteristics of individual locations are showed in Table 1. To determine soil reaction and the parameters of soil organic matter, soil samples were taken and mixed to produce an average sample. The soil samples were dried at laboratory temperature and grinded. For the determination of the param-

T a b l e 1. Characteristics of study sites.

Study sites		Parent materials	Soil classification (WRB, 2006)	Plant cover
S1	(Starý Smokovec) After windstorm altitude 1030 m	Granite, milonit	Stagni Cambisols	*Chamerion angustifolium, Carex montana*
S2	(Tatranská Polianka) After the fire altitude 1010 m	Granite, milonit	Cambic Podzols	*Carex montana*
S3	(Popradské pleso) Intact soil altitude 1220 m	Granite, milonit	Stagni Cambisols	*Picea abies, Larix decidua*

eters of the soil structure stability, soil samples were collected with the aid of a spade to maintain the sample soil within its natural aggregates. Soil samples were also air-dried at laboratory temperature, pre-sieved over a series of sieves, and then bulked into seven size fractions. These size fractions (dry sieve) were used for the determination of water-stable aggregates (WSA). Soil pH was determined potentiometrically (Fiala et al., 1999). We determined also: organic carbon content (C_{org}) according to Tyurin method (Dziadowiec, Gonet, 1999), labile carbon content (C_L) (Loginow et al., 1987), water soluble carbon (C_{HWD}) (Körschens, 2002), fractional composition of humic substances according to Tyurin in modification Ponomareva-Plotnikova (Dziadowiec, Gonet, 1999). We also calculated the stability index of water-stable aggregates (S_w) by Henin (Zaujec, Šimanský, 2006) and the values of the sum of mean weight diameters (MWD) in fractions of aggregates. For size fractions of WSA, we determined the organic carbon content.

Data was analyzed using the statistic software Statgraphic Plus. Significant differences between soil parameters in different locations were calculated using the single factor ANOVA and LSD. For all tests, statistically significant differences were assigned to $P < 0.05$ and $P < 0.01$.

Results and discussion

In 2004, after a windstorm had destroyed 12 600 ha of forest, there were subsequently sawyer and broken trees extracted, which resulted in the humus content. The carbon content was determined as being about 16% lower than intact soil. In general, the deforestation resulted in a significant loss of organic matter (Vogt et al., 1995). The subsequent burning also resulted in burning of organic matter and therefore reduced carbon content. This also confirmed results of Gonet et al. (2009). These authors published conclusions that soil 13 years after fire had about 50% lower humus content in comparison to non-buried area. Our results show a 17% increase of total carbon content in the site after the fire as compared with intact soil (Table 2). We noted that the fire was in autumn 2005 and soil samples were taken in the summer of 2006. Guerrero et al. (2001) presented that fire does not necessarily reduce organic matter content in topsoil in a significant manner, but on the other hand low intensity fires have even been reported to increase organic matter (Knicker et al., 2006; Varela et al., 2010). Every exogenous change of environment is reflected on soil properties. In control, the highest labile carbon content from total carbon was determined and the same portion of C_L from C_{org} (16.3%) was detected in soils after windstorm and after fire. Hot water soluble carbon belongs to the dynamic fractions of the soil organic matter, it directly takes part in the organic matter transformations in soil and is a source of the plant nutrients (Kubát et al., 2002). The highest hot water soluble carbon from organic carbon was on the site after windstorm (4.1%) > after fire (3.8%) > intact soil (1.8%). It means, the highest reduction of soil organic matter is detected on the site after windstorm (Table 2).

T a b l e 2. Organic carbon contents and its forms in soils.

Study sites	C_{org}	C_L		C_{HWD}	
	($g.kg^{-1}$)	($g.kg^{-1}$)	% of C_{org}	($g.kg^{-1}$)	% of C_{org}
S1 After windstorm	51.2	8.3	16.3	2.10	4.1
S2 After the fire	71.0	11.5	16.3	2.68	3.8
S3 Intact soil	60.8	10.3	17.0	1.10	1.8

Notes: C_{org} – organic carbon, C_L – labile carbon, C_{HWD} – hot water-soluble carbon.

Several authors (Guo, Gilfford, 2002; Tobiašová, 2006) claim that extractability of humic substances is influenced by soil type, chemical composition of plant residues or the method of extraction used. In our case, the soil type and method of extraction used were the same. This means that extractability of humic substances was influenced by plant residues in the sites. In intact soil (control), the highest exctractability (65.5%) was determined. On the other hand in site after windstorm the lowest exctractability of humic substances (36.6%) was determined. The fresh organic matter in soil decreases extraction of humic substances (Zaujec, Šimanský, 2006). The share of humic substances fractions affected by windstorm or by the fire in comparison to control (intact soil) is shown in Figs 1 and 2. In the soil samples taken from the area affected by fire, 10 multiple increasing fraction of fulvic acids bound with divalent cations were determined. At the same time we determined a decrease of free fraction of fulvic acids (by 40%) and fulvic acids bound with monovalent cations (by 66%) in comparison to control (intact soil). There was observed an increase (by 25%) of humic acids bound with monovalent cations. The sample affected by the windstorm showed a similar

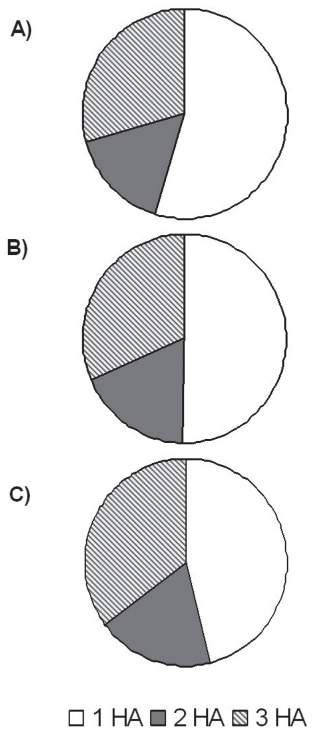

Fig. 1. Humic acid fractions in soils: A) after the fire, B) after windstorm, C) intact soil.
1 HA – humic acid bound to monovalent cations; 2 HA – calcium or magnesium humate; 3 HA – humic acid bound with clay minerals or oxides of Fe^{3+} and Al^{3+}.

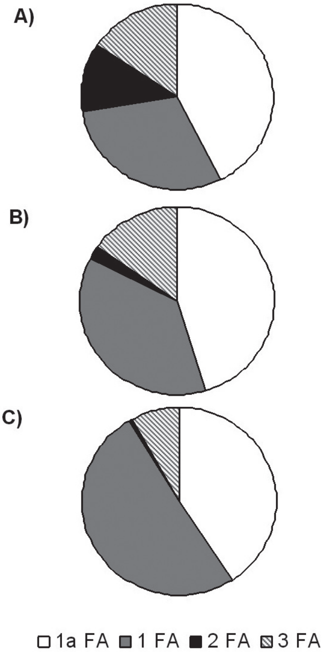

Fig. 2. Fulvic acid fractions A) after the fire, B) after windstorm, C) intact soil.
1a FA – free "aggressive" fulvic acids; 1 FA1 – fulvic acid bound to monovalent cations; 2 FA – calcium or magnesium fulvate; 3 FA – fulvic acid bound with clay minerals or oxides of Fe^{3+} and Al^{3+}.

tendency as the sample affected by fire in terms of the portion of fulvic acids observed. All the same, in the sample affected by the windstorm the portion of humic acid fractions was significantly lower than control. The portion of humic substances in individual sites was reflected on the ratio of humic and fulvic acids. The ration between humic and fulvic acids has often been used as a criterion of the quality of humus (Kubát et al., 2002). Humus quality was following: after the fire (0.90) > after windstorm (0.87) > control (0.50).

From the point of view of organic matter and aggregate stability information about soil reaction is very importnant. For example Chenu et al. (2000) reported that aggregate stability is higher in acid soils. Aggregates are not stable under alkaline conditions due to the higher solubility of humic substances. In all soil sites, the average values of soil pH (pH_{H2O}) were from strong acid (4.45) to acid (4.91) and similar tendency was in pH_{KCl} values. Aggregate stability is influenced by the specific soil properties of each site.

The portion of size fractions of water-stable aggregates (WSA) is showed in Table 3. In all sites, the highest portion of WSA in size fraction from 1 to 2 mm was observed. In the soil affected by windstorm, the portion of WSA in size fraction from 1 to 2 mm was 46% and in soil affected by fire was 14% higher than intact soil (Table 3). In soil affected by windstorm, but also in soil affected by fire, statistically significant changes in redistribution of individual

T a b l e 3. Size fractions of water-stable aggregates content in soils.

Study sites	Size fractions of water-stable aggregates (in mm)						
	< 0.25	0.25–0.5	0.5–1	1–2	2–3	3–5	> 5
S1 After windstorm	5.5	7.3	10.1	33.6	15.3	21.3	6.9
S2 After the fire	9.4	9.2	13.2	26.4	17.2	16.3	8.3
S3 Intact soil	12.4	8.5	10.7	23.1	16.8	14.5	14.5
$LSD_{0.05}$	*1.12*	*0.49*	*3.82*	*3.07*	*1.31*	*1.59*	*1.28*
$LSD_{0.01}$	*1.69*	*0.75*	*5.79*	*4.65*	*1.98*	*2.41*	*1.93*

size fractions of WSA were determined. Also we determined a statistically significant decrease of micro-aggregates and macro-aggregate in size fraction > 5 mm in soils affected by windstorm and soils affected by fire in comparison to control (intact soil).

Soil structure stability in individual sites was different (Fig. 3). Soil affected by fire, despite the smallest MWD values had the highest stability of aggregates, which confirmed the results of Arcenegui et al. (2008). These authors published data showing that soil after fire has a higher stability of aggregates due to higher water repellency. The soil with the lowest aggregates stability was the sample affected by windstorm which showed an decrease of up to 31% compared with intact soil.

For instance, the decrease in aggregate stability is associated with a decrease in organic mater content because of fire (Soto et al., 1991). Content of total carbon in WSA was almost threefold in micro-aggregates than in macro-aggregates in soil affected by windstorm as well

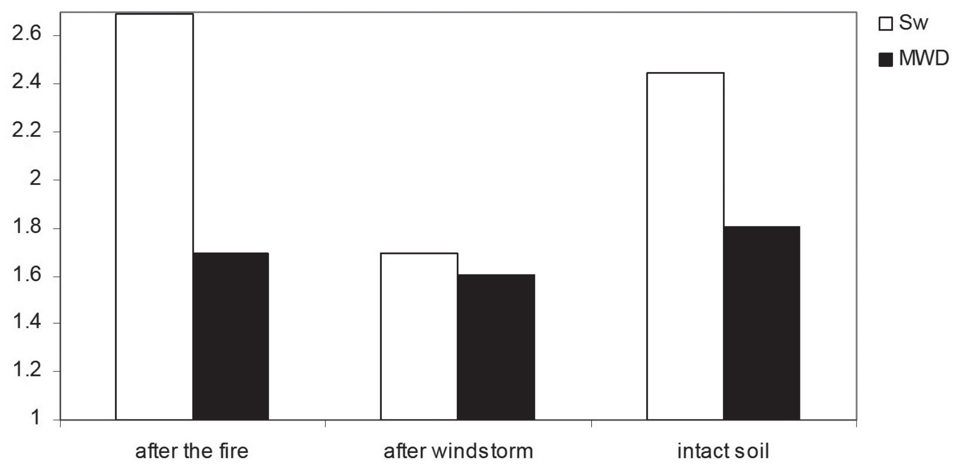

Fig. 3. Aggregates stability in soils.
Sw – index stability of water-stable aggregates ($LSD_{0.05}$ = 0.128; $LSD_{0.01}$ = 0.213)
MWD – mean weight diameter of water-stable aggregates ($LSD_{0.05}$ = 0.413; $LSD_{0.01}$ = 0.684)

Table 4. Organic carbon contents (g kg^{-1}) in size fractions of water-stable aggregates.

Size fractions of water-stable aggregates (in mm)	Study sites		
	After the fire	After windstorm	Intact soil
< 0.25	148.6	197.1	46.6
0.25–0.5	36.3	72.2	60.8
0.5–1	41.3	72.3	58.4
1–2	38.1	65.9	56.1
2–3	40.7	61.0	56.6
3–5	44.2	55.8	59.4
> 5	49.1	60.2	86.4

as that affected by fire (Table 4). On the other hand, the organic carbon content was 17% lower in micro-aggregates than in macro-aggregates in intact soil (control). In soil affected by windstorm (y = -6.24Ln(x) + 15.96; r = 0.847; $P < 0.01$), as well as in soil affected by fire (y = -4.32Ln(x) + 10.95; r = 0.768; $P < 0.05$) decrease in organic carbon concentration in WSA by increasing size fractions of WSA was observed. On the other hand in control, the linear tendency of increasing organic carbon concentration in WSA by increasing size fractions of WSA was observed. Several authors (Hassink et al., 1997; Šimanský et al., 2008) published conclusions that carbon concentration is higher in large size fractions of WSA. Carbon stabilization in physical-protected soil pools represents one of the most important mechanisms of carbon sequestration in terrestrial ecosystems. Carbon on the inside of aggregates is decomposed slowly or not at all, which leads to aggregate stability (Beare et al., 1994). Carbon in larger fractions of WSA was not physically-protected and therefore we observed it decreasing in soil affected by windstorm and fire. Soil organic matter plays an important role in the formation of aggregates in many soils (Oades, 1993; Roldán et al., 1994). Fire-induced combustion of soil organic matter can be expected to induce the partial or complete destruction of soil aggregates. Our results did not confirm it (Table 3 and Fig. 3).

Table 5. Quantity carbon recalculated on the volume of water-stable aggregates in study sites.

Parameter	Size fractions of water-stable aggregates (in mm)	Study sites		
		After the fire	After windstorm	Intact soil
Total organic carbon content in size fraction of water-stable aggregates (g.kg^{-1}) recalculated on volume of water-stable aggregates	< 0.25	1.10	1.40	0.58
	0.25–0.5	0.53	0.33	0.52
	0.5–1	0.73	0.54	0.63
	1–2	2.21	1.01	1.30
	2–3	0.94	0.70	0.95
	3–5	1.19	0.72	0.86
	> 5	0.41	0.41	1.25

The quantity of carbon recalculated on the volume of WSA is in Table 5. The highest total carbon contents in size fracion from 1 to 2 mm of WSA were determined in soil affected by windstorm, but also in intact soil. The reason is actually connecting with the highest portion of this size fraction of WSA. Calculated results only confirmed that, despite the highest amount of carbon in the WSA, the highest content of carbon in micro-aggregates was in soil affected by windstorm and fire of course after taking into account the total WSA.

Conclusion

All in all, we summarise that maximum extractable SOC levels were determined in the intact site. The increase of hot water soluble carbon was determined in the destroyed sites. The most significant reduction of soil organic matter was observed in soil affected by windstorm. Soil affected by fire had the highest stability of aggregates. The lowest aggregates stability was the soil affected by windstorm that was up to 31% compared with intact soil. The content of organic carbon in water-stable aggregates was almost threefold in micro-aggregates than in macro-aggregates in soil affected by windstorm as well as by fire. It means that micro-aggregates play a very important role in carbon sequestration in soils after natural disasters.

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