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SOIL ORGANIC MATTER CHANGES IN RESULT OF FOREST FIRES IN VITOSHA MOUNTAIN

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Abstract

Forest fires in Bulgaria are frequent in recent years, especially when summer droughts are prolonged. The carbon biogeochemical cycle is the most sensible to forest fires. The goal of the present investigation was to study the changes in the quantity and stocks of soil organic carbon in result of the forest fire, occurred on the territory of Biosphere Reserve (BR) 'Bistrishko branishte' and 'Vitoshko lale' in Vitosha Mountain during the summer of 2012. Both territories of Vitosha Natural Park, affected by fires in year 2012 have been mapped. It was established that the total carbon content in the soils in Biosphere Reserve 'Bistrishko branishte' and 'Vitoshko lale' area decreased significantly as a consequence of the fire. This diminution is more substantial for Biosphere Reserve 'Bistrishko branishte' – about 7 %. The fires have led to a significant decrease of organic carbon stocks (ΔSOC_{stock}) in both regions – respectively with about 22 tC·ha^{-1} for BR 'Bistrishko branishte' and from 8.0 tC·ha^{-1} to 25 tC·ha^{-1} for 'Vitoshko lale'. In only one sampling area in 'Vitoshko lale', an increase in the carbon stocks by about 10 tC·ha^{-1} has been registered.

Key words: Biosphere Reserve 'Bistrishko branishte', soil organic carbon content, soil organic carbon stocks.

Introduction

Forest fires cause more sizable consequences in the environment during the recent decades (Pausas et al. 2008, Bowman et al. 2009). Global trends are to increase the frequency of fires and the damage they cause, which lead to loss of wood material, forest and soil degradation. According to Rapid Damage Assessment, established within European Information System for Forest Fires (EFFIS), in 2012, affected by fire forest areas in 22 countries in Europe and the Mediterranean are about 950,020 ha (Schmuck et al. 2013).

Forest fires in Bulgaria are frequent in recent years, especially when summer droughts are prolonged. The burned forest areas in Bulgaria for 2012 were 12,729.8 ha (Konstantinov 2013).

Carbon biogeochemical cycle seems to be the most sensible of all biogeochemical cycles to forest fires. The vegetation keeps on Earth's surface about 500 PgC (Prentice 2001), while in the soil is kept around 1.5 PgC (Rice 2002).

The sustainability of carbon stocks in forest ecosystems depends on various natural and anthropogenic factors (Larionova et al. 2002), including forest fires (Overby et al. 2003). Consequences of fires on forest ecosystems are enormous, taking into account the fact that forests cover an area of about 4.1 Gha and represent the main 'sink' for terrestrial carbon stocks (Dixon and Wisniewski 1995).

Forest fires affect the soil organic carbon content both by destruction of forests, as a result of which the input of organic materials is reduced and by removal of surface soil layer in result of soil erosion (Elliot 2003). Moreover, the burning of biomass from large areas, including surface organic horizons of the soil, is a huge source of greenhouse gases emissions – carbon dioxide (CO_2) and methane (CH_4) (Crutzen and Goldammer 1993, Nave et al. 2011) that are released into atmosphere and contributing to climate change (Levine 1994). Previous studies performed in Vitosha Mountain have been devoted to assessment of damages in spruce forests by wind fall through Landsat and ICONOS images (Gikov and Pironkova, 2005), and on age structure and historical development of Bistrishka River watershed forest (Tsvetanov and Panayotov 2013). Limited investigations have been performed in relation to the forest fire, occurred in July 2012 and its consequences on the forest ecosystem.

The purpose of present investigation was to study the changes in quantity and stocks of soil organic carbon in result of the forest fires, which occurred on the territory of Biosphere reserve 'Bistrishko branishte' and 'Vitoshko lale' in Vitosha Mountain in 2012.

Materials and Methods

The studied soil and forest litter samples were collected from the area of Biosphere Reserve 'Bistrishko branishte' (BRBB) and 'Vitoshko lale' (VL), located in Vitosha Natural Park (NP), affected by the fire in the summer of 2012. It was performed one month after the fire. Two soil profiles and two mattocks (total three replications at each point) have been established at BRBB – named SS 1 and SS 2. Additionally, two sampling sites have been established in the unburned territory of the BBBR, designated as U1 and U2, respectively. At the same sampling sites, forest litter was also collected. The spatial distribution of soil profiles at BRBB is presented in Figure 1.

The altitude of sampling sites varies between 1490 and 1969 m a.s.l. The slopes are steep (up to 55 %). The soil profiles from the territory of BRBB have a dark brown coloured surface horizon with depth of 50–55 cm, followed by a light brown horizon. There is no clear boundary between the horizons. The chemical and morphological characteristics are representative for the group of Mollic Cambisols (WRBSR 2006).

From the affected by the fire of 12.10.2012 area in the region of 'Vitoshko lale', four soil profiles and two mattocks in the vicinity of each of the soil profiles (three replications) were established three weeks after fire occurrence. The sampling sites, where the soil profiles were established are identified as follows – SS 3, SS 4, SS 5 and

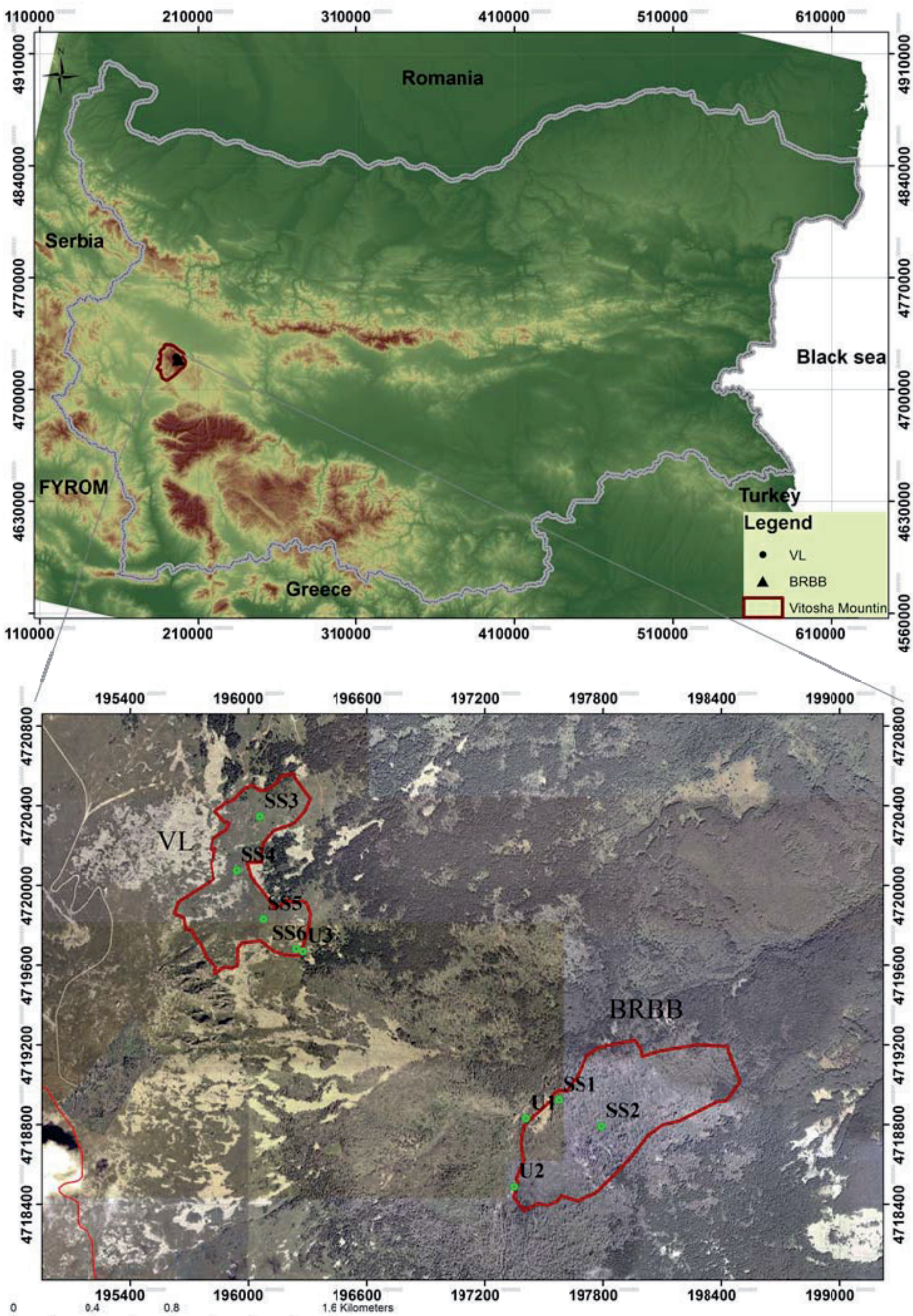

Fig. 1. Map of sampling sites in NP Vitosha, BR 'Bistrishko branishte'and 'Vitoshko lale'.

Table 1. Characteristics of the experimental sampling sites.

Studied area	Sampling sites (SS)	Dominant vegetation	Altitude, m	Geographical positions
BR 'Bistrishko branishte' (BRBB)	SS 1	*Picea abies* (L.) Karsten	1520	42°33'48.5"N 23°18'56.9"E
	SS 2		1529	42°33'44.6"N 23°19'6.7"E
	U 1		1494	42°33'45.3"N 23°18'49.9"E
	U 2		1490	42°33'34.1"N 23°18'47.9"E
'Vitoshko lale' (VL)	SS 3	*Juniperus sibirica* L. *Vaccinium. uliginosum* L.	1969	42°34'32.4"N 23°17'47.9"E
	SS 4		1965	42°34'23.5"N 23°17'43.3"E
	SS 5		1925	42°34'15.8"N 23°17'49.6"E
	SS 6		1856	42°34'11.2"N 23°17'57.1"E
	U 3		1856	42°34'10.8"N 23°17'58.6"E

SS 6 (Figure 1 – VL). The control soil profile was set up near to affected area at the same altitude and exposure and designated as U3. The soil depth from VL area was between 70 and 80 cm. The surface horizon is dark brown and about 40–45 cm thick, followed by a skeletal BC horizon. Gravel, stones or boulders occur throughout the profile development. According to WRBSR (2006) description, the soil from 'Vitoshko lale' area belongs to Mollic Cambisols). The main characteristics of fire space are provided in Table 1.

The fire affected areas were delineated and mapped with GPS. Through 32 points with GPS coordinates, it was found that the fire affected area BR 'Bistrishko branishte' is 51.81 ha. Because of the rugged terrain, the fire affected area of 'Vitoshko lale' was delineated and mapped through 68 points with GPS coordinates. It was found that it is 33.68 ha. Maps are presented in Figure 2.

Soil samples were taken from layers 0–5 cm and 5–20 cm. Forest litter was collected with a 20×20 cm frame in order to calculate its carbon stocks. The main characteristics of the soil – pH, organic carbon (*C* %) and bulk density were determined by standard methods described by Donov et al. (1971).

Soil bulk density was determined from a sample taken in undisturbed state by a steel ring of a known size. Total nitrogen content in the soil was determined through Kjeldahl method. Soil organic carbon was determined by its oxidation to CO_2 using $K_2Cr_2O_7$ as oxidant in sphuric acid.

Soil carbon stocks was determined according to the methodology described in detail by Stolbovoy et al. (2007). The main steps for calculation are the following:

$$SOC_{site} = \sum_{layer=1}^{j} [SOC_{content} \cdot BD \cdot D \cdot (1-F)] \qquad (1),$$

where:

$SOC_{content}$ – total soil organic carbon content (C_{total}), % of mass $\frac{C, kg}{Soil, kg} \cdot 100$;

BD – soil bulk density, $\frac{kgSoil}{dm^3}$;

D – thickness of the sampled layer, dm;

F – volume of coarse fragments (d > 2 mm), % of mass or $\frac{Stone, m^3}{Soil, m^3}$.

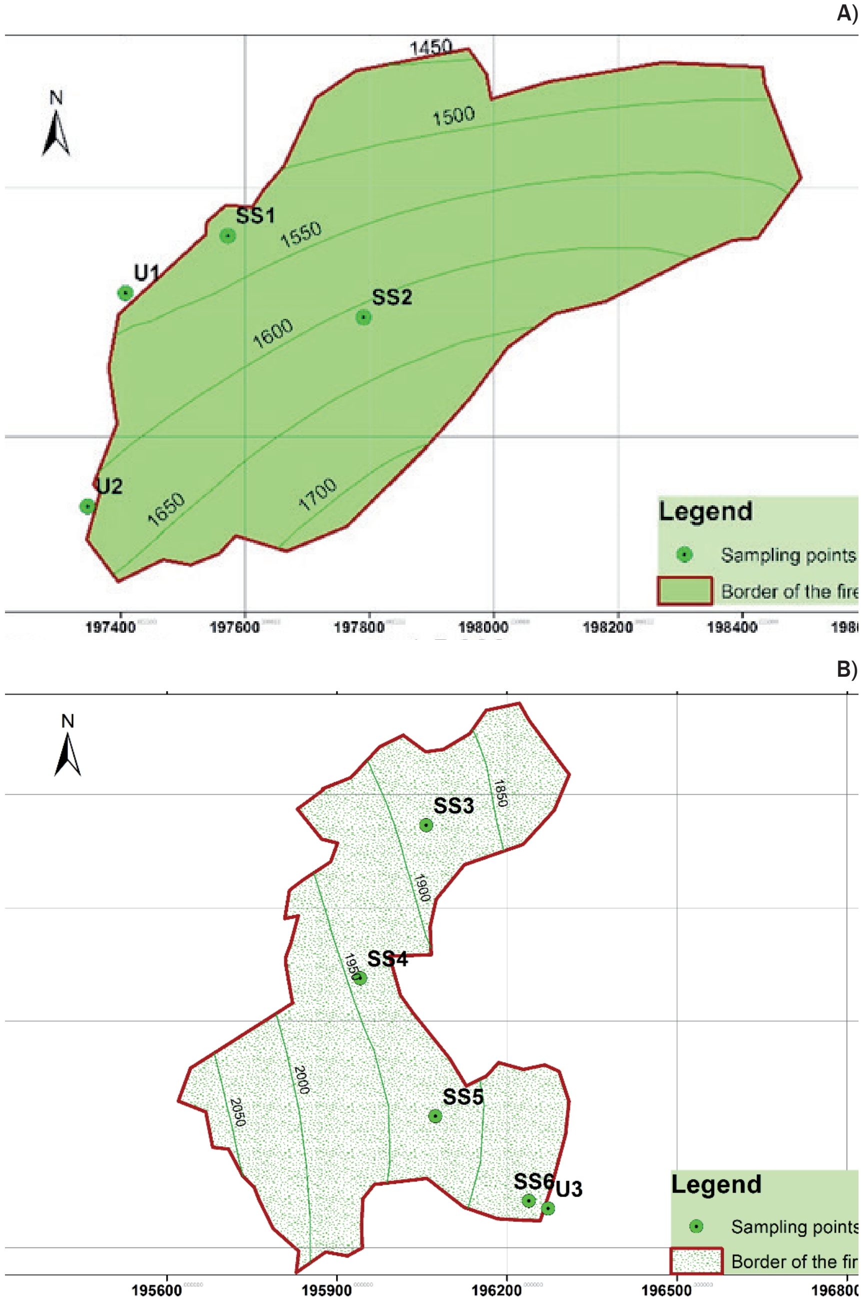

Fig. 2. Maps of the areas of the BR 'Bistrishko branishte' (A) and 'Vitoshko lale' (B), affected by fire.

The changes of soil carbon stock for a given area (ΔSOC_{stock}) could be calculated through the equation:

$$\Delta SOC_{stock}=SOC_{new}-SOC_{ref.stock} \quad (2),$$

where:

$SOC_{ref.stock}$ is soil carbon stocks value, calculated by equation 1, and refers to values, obtained for unburned territory (control) sampling site;

SOC_{new} – refers to soil carbon stocks after the influence of forest fire.

Results and Discussion

The results for total soil organic carbon content $SOC_{content}$ vuv formulata izglezda po drug nachin in the surface 0–5 cm of the soil from BRBB show that it is about 10.0 %, while in the control sampling sites (U1 and U2) is much higher and range from 17 to 18 % (Table 2). In the surface 0–5 cm soil layer from 'Vitoshko lale' area, $SOC_{content}$ ranged from to 14.2 % in the soil from SS 5 to 17.0 % in the soil of SS 3. A probable reason for this variation in $SOC_{content}$ is the difference in the content and composition of forest litter stocks, which is formed on the surface of the mineral soil layer. Cui et al. (2014) found that the total amount of SOC in the surface 0–10 cm of soil was dynamic after fire disturbance, and the direction and magnitude of the changes largely depended on burning severity and post-fire period. The content of fallen biomass and forest litter stocks from BR 'Bistrishko branishte' suppose a higher fuel load and organic carbon input. In our study, a tendency for decreasing of soil organic carbon content was found for variants, affected by forest fire in comparison with values for control (unburned) sampling site – U1, U2 and U3. The differences in the values of this index for fire affected soils from BR 'Bistrishko branishte' and the control variant were –7.1 % and –7.7 %, while for the soil from 'Vitoshko lale' area were as a minimum of – 0.75 % for SS 3 and as a maximum of –3.50 % for SS 5. The higher severity of fire spread on the territory of BR 'Bistrishko branishte' has obviously caused a significant immediate carbon loss in topsoil through direct combustion. Similar results for coniferous forests have been reported by Cui et al. (2014). The deeper soil layer (5–20 cm) from BR 'Bistrishko branishte' was influenced by the forest fire to a lesser degree, than the surface one. The $SOC_{content}$ of this layer has decreased by about 3.0–3.6 % in comparison with control variants.

It was found that the fire has affected stronger the 5–20 cm soil layer from 'Vitoshko lale' area. Our results are in agreement with similar observations reported by other authors (Brender and Cooper 1968, Cole et al. 1992), established that effects of direct combustion are typically limited to the unconsolidated leaf litter. Thus, our results show that SOC_{conten} in the forest litter from BR 'Bistrishko branishte' was 30.1 % after the fire and 53.5 % before it. The average $SOC_{content}$ in the forest litter for 'Vitoshko lale' area after the fire was higher and varied from 43.0 % to 63.0 %. Obviously, the forest fire released the carbon (C) and nitrogen (N), stored in biomass and surface soil layers through combustion. The sensitivities of $SOC_{content}$ and *SCD* to fire disturbance were inconsistent due to changes in soil bulk density. It has been reported that post-fire increase in *SCD* resulted from the shrinkage (which associated with the destruction of macro-aggregate) of topsoil, while the magnitude of $SOC_{content}$ changes depend on the burning severity (Cui et al. 2014).

The results for SOD_{site} demonstrate the successive decline in soil organic car-

Table 2. Carbon stocks in soil/forest litter from BR 'Bistrishko branishte' and 'Vitoshko lale'.

Sampling site	Horizon, cm	Soil/*FL organic carbon content ($SOC_{content}$), Mean (± SD)	Total soil nitrogen (N), % Mean (± SD)	C/N	**BD, kg soil·dm^{-3} or FL mass, kg·m^{-2}	Soil carbon density (SCD_{site}), kg C·m^{-2}	SCD_{site} (for each studied soil depth), t·ha^{-1}	SCD_{site}, t·ha^{-1}	Soil organic carbon stocks ΔSOC_{stoc}, tC·ha^{-1}
SS 1	*FL* 1 (L+F+H)	31.20 (1.077)	0.38 (0.065)	82.1	109.64	–	–	342.10	–223.6
	0–5	10.39 (0,142)	0.66 (0.081)	15.8	0.39	2.03	20.25	53.74	–21.4
	5–20	7.44 (0.097)	0.44 (0.055)	16.9	0.30	3.35	33.48		
SS 2	*FL* 2 (L+F+H)	28.94 (1.066)	0.31 (0.054)	93.4	101.25	–	–	395.10	–198.7
	0–5	9.77 (0.112)	0.59 (0.043)	16.6	0.34	1.66	16.61	47.44	–22.0
	5–20	6.85 (0.107)	0.40 (0.047)	17.1	0.30	3.08	30.83		
U 1	*UFL* 1 (L+F+H)	53.51 (1.174)	0.86 (0.104)	62.2	22.14	–	–	118.50	
	0–5	18.11 (0.126)	0.77 (0.087)	23.5	0.26	2.35	23.54	75.12	
	5–20	11.09 (0.097)	0.48 (0.055)	23.1	0.31	5.16	51.57		
U 2	*UFL* 2 (L+F+H)	51.77 (1.233)	0.75 (0.075)	69.0	18.61	–	–	96.40	96.4
	0–5	16.94 (0.118)	0.77 (0.075)	22.0	0.25	2.12	21.18	69.48	
	5–20	9.79 (0.104)	0.48 (0.044)	20.4	0.33	4.38	48.29		
SS 3	*FL* 3 (L+F+H)	54.45 (1.211)	nd	–	20.09	–	–	109.40	
	0–5	16.95 (0.123)	0.59 (0.045)	28.7	0.35	2.97	29.7	111.0	–25.2
	5–20	11.30 (0.088)	0.54 (0.041)	20.9	0.48	8.14	81.4		
SS 4	*FL* 4 (L+F+H)	43.80 (1.066)	nd	–	21.19	–	–	92.80	
	0–5	15.00 (0.115)	0.57 (0.055)	26.3	0.45	3.38	33.8	120.4	–15.9
	5–20	10.50 (0.082)	0.52 (0.043)	20.2	0.55	8.66	86.6		
SS 5	*FL* 1 (L+F+H)	63.45 (1.532)	nd	–	30.68			194.70	
	0–5	14.20 (0.077)	0.58 (0.043)	24.5	0.46	3.27	32.7	128.1	–8.2
	5–20	10.10 (0.067)	0.43 (0.037)	23.5	0.63	9.54	95.4		
SS 6	*FL* 1 (L+F+H)	42.75 (1.306)	nd	–	18.45			78.90	
	0–5	15.75 (0.113)	0.57 (0.054)	27.6	0.50	3.94	39.4	146.1	9.9
	5–20	10.95 (0.123)	0.37 (0.022)	29.6	0.65	10.68	106.8		
U 3	0–5	17.70 (0.233)	0.60 (0.051)	29.5	0.30	2.66	26.6	136.3	
	5–20	13.80 (0.118)	0.54 (0.035)	25.6	0.53	10.97	109.7		

Note: nd – no data; *FL – Forest litter; **BD – Soil bulk density.

bon density (*SOCD*) for 0–5 cm soil layer from SS 1 and SS 2 sites, while the *SOCD* was significantly elevated for all variants from VL fire affected area. The forest fire in BRBB consumed more litter and soil organic material, which suggest a more severe burning.

In the fire-affected soil of BR ’Bistrishko branishte‘, the total nitrogen content decreases in comparison with the control variant – for both studied soil layers – 0–5 cm and 5–20 cm (Table 2). As reported in the literature, clearly, the type and composition of the vegetation affect nitrogen content of soil after a fire (Bonan 1990, Barbosa et al. 2009). More considerable losses (about 40.0 %) of the total content of nitrogen were observed in the forest litter. In a review of the impacts of fire on nutrient cycling, Boerner (1982) reported net losses of 30–100 % of litter N during fire as the result of direct volatilization and ash convection. Direct losses of nitrogen (in form of NH_3 and NO_x) in the course of organic matter (OM) destruction were reported by Gleixner et al. (2001). It can be concluded that the decomposition and nitrogen availability in result of forest fire is a function of substrate quality, the soil thermal regime, or their interactive effects.

In order to compare the results of soil organic carbon stocks changes (SOC_{stock}) the results in Table 2 are normalized for an area of 1 ha. For this area, the soil organic carbon stocks was range from 70 to 75 tC·ha^{-1} in the unaffected by forest fire soil, but much higher in forest litter – 100–120 tC·ha^{-1}. The results show that the carbon stocks in the surface 20 cm hsoil layer decreased by about 22.0 tC·ha^{-1} due to the fire in BRBB area. Depletion of SOC_{stock} to a different extent was established also for SS 3, SS 4 and SS 5 of ’Vitoshko lale‘, however, the decrease ranges from 8 to 25 tC·ha^{-1}. Only for the soil from SS 6, a slight increase in carbon stocks by about 10 tC·ha^{-1} was found. As the vegetation cover of ’Vitoshko lale‘ area was presented mainly by shrubs, bushes and grass and rarely by spruce trees, forest litter was not formed. Thus, the fire severity was due to living biomass load and surface soil organic carbon content. The importance of dominant C concentration gradient for fire severity was discussed in more detail by Kasischke et al. (2005).

Conclusions

The territories of Biosphere Reserve ’Bistrishko branishte‘ and ’Vitoshko lale‘ area of Vitosha Natural Park, affected by fires in year 2012 have been mapped. A v matmet i cel e edin pozar

It was established that the total carbon content in the control (unaffected) soils in Biosphere Reserve ’Bistrishko branishte‘ is between 17.0 % and 18.0 % but decreases significantly as a consequence of the fire to about 10.0 %.

The decrease in total carbon content in soils from ’Vitoshko lale‘ is maintained as a trend, but the differences in comparison with the control soils are much lower – from 0.75 % for SS 3 to a maximum of 3.50 % for SS 5.

In fire-affected soils in ’Bistrishko branishte‘, the nitrogen content decreases. Similar tendency was established in fire-affected soils in ’Vitoshko lale‘. In these soils the nitrogen content decreases after fire.

Organic carbon stocks in the surface 20 cm soil layer (for a unit area – 1 ha), are 70.0–75.1 tC·ha^{-1} in the soils of ’Bistrishko branishte‘ and 140 tC·ha^{-1} in the soils of ’Vitoshko lale‘ area.

The fires have led to a significant decrease of these organic carbon stocks in both regions (SOC_{stok}) – respectively with about 22 tC·ha^{-1} for BR 'Bistrishko branishte' and from 8.0 tC·ha^{-1} to 25 tC·ha^{-1} for 'Vitoshko lale'. In only one sampling area in 'Vitoshko lale', an increase in the carbon stocks by about 10 tC·ha^{-1} has been registered.

Among the various possible factors leading to a different degree of carbon stocks reduction in the investigated soils, the main reasons could be attributed to different severities of the fires and peculiarities of the vegetation covers in both studied regions. Changes in the soil bulk density can also influence the organic carbon stocks.

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