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Forest Fire Impact on the Soil Carbon Content and Stock on the North Slopes of Rila Mountain (Bulgaria)

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Abstract. Forest fires are the major disturbing factor that can affect soil carbon content in a forest ecosystem and may have a particularly persistent effect on the carbon stock in the affected soils. Purpose of the study performed was to investigate the carbon content and stock changes in a soil under coniferous and mixed stands in result of a forest fire occurred on the north slopes of the Rila Mountain (Dolna Bania region). Stands of *Larix decidua* Mill. ranging in age from 25 to 35 years have been affected. Established sampling sites (SS) cover impacts of a crown fire (C1 and C2), surface fire (S1 and S2) and undisturbed stand (control U). Results obtained clearly show the influence of the forest fire on the soil carbon content. For the soil from C1 and C2, where the crown fire prevailed, a decrease in the soil carbon content in comparison with the control values have been observed. Opposite trend was documented for the soil carbon content in sampling sites influenced by surface fire. These values increased with about 1% and reached 3.45% of soil organic carbon (SOC). The SOC stock varied from 1.4 kg/m^2 to 2.5 kg/m^2 for the upper 5 cm and from 3.7 kg/m^2 to 4.6 kg/m^2 for the lower 15 cm soil layer. Soil from the fire-affected sites accumulated more carbon than the control (unburned) one. This finding is important by confirming the role of forest soil in the global carbon sequestration. The SOC stock values, however, differ depending on the trees species. For the upper 5 cm soil layer, the highest SOC stock was 2.52 kg/m^2 in the soil of the sampling site, afforested by Scot pine, followed by that below a mixed forest (*Pinus sylvestris* L. and *Quercus cerris* L.).

Key words: Forest fire, Soil carbon, Carbon stock, Rila Mountain

Introduction

Forest fires provoke various changes in ecosystems that affect the composition, structure and patern of the vegetation cover, as well as soil and water resources of ecosystems that are critical for their overall functions (NEARY *et al.*, 2005). Forest fires are considered as a driver for global biome distribution and for maintaining the structure and function of fire-prone communities (THONICKE *et al.*, 2001; BOND & KEELEY, 2005). From naturally occurring phenomena, forest fires become more often human dependent events during the last two decades. Fire frequency is expected to increase with human-induced climate change, especially where precipitation remains the same or is reduced (STOCKS *et al.*, 1998). A general but moderate increase in precipitation, together with increased

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productivity, could also favour generation of more flammable fine fuels. MIRANDA (1994) suggests an increase in risk, severity, and frequency of forest fires in Europe. It is well known that the world's forests are the main carbon pool, which is estimated to be 348 Gt C in vegetation and 478 Gt C in soil (to 1 m) (updated since DIXON *et al.*, 1994, by BROWN, 1998). Thus, they play an important role for offsetting carbon emissions and preventing (or at least slowing) global warming. Forest fires affect ability of forest ecosystems to store carbon. Typically changes occur in species distribution, net ecosystem production (NEP), net primary productivity (NPP), net biome productivity (NBP), elevated CO_2 emissions, as well as in climate variability and weather extremes (SMITHWICK *et al.*, 2009). Immediately after a fire, carbon is lost to the atmosphere through combustion. Stand-replacing fires kill living biomass in forests and reduce carbon gains to near zero (KASHIAN *et al.*, 2006). Strongest effect of fire on carbon cycling, however, occurs in the changing balance between carbon lost through subsequent decomposition and simultaneous carbon gains through growth of new vegetation. Stand-replacing fires switch ecosystems to being a net source of carbon as decomposition exceeds photosynthesis - a short-term effect (years to decades) that may be important over the next century if fire frequency increases.

Our previous studies showed that forest fires have a significant positive effect on the soil organic carbon (SOC) content in the surface soil layer if it occurs in coniferous forests (VELIZAROVA, 2011; VELIZAROVA *et al.*, 2011). Through affecting the more thermo-labile fractions of SOC, the forest fires favour the rate of the mineralisation processes (VELIZAROVA & FILCHEVA, 2011). However, the degree to which forest fire impacts the soil carbon stock has not been explored previously. Our goal was to advance the current knowledge and understanding of fire effects on carbon content and stock in soils on the north slopes of Rila Mountain, under different types of forests.

Materials and Methods

Representative sampling sites have been chosen within the coniferous forests on the territory of Dolna Bania Government Forestry Enterprises (GFE). Sampling sites were situated on the north slopes of the Rila Mountain, affected by forest fire in August 2012. Two sampling sites – C1 and C2 with forests, respectively Scots pine (*Pinus sylvestris* L.) and European larch (*Larix desidua*, Mill.), were affected by a crown fire. Both sampling sites were established within the Scots pine (*Pinus sylvestris* L.) forest S1 and mixed forest - Scots pine (*Pinus sylvestris* L.) and Turkey oak (*Quercus cerris* L.) – S2. Control experimental site was established in an unburned Scots pine (*Pinus sylvestris* L.) forest – designate like U. Detailed information for the sampling sites is presented in Table 1.

Table 1. Studied areas parameters.

Sampling sites (SS)	Studied cases	Dominant tree species	Altitude, m	Stand age	Area, ha	Geographical positions
C1	Crown fire	*Pinus sylvestris* L.	650	25	0.2	42°19'23.78" N 23°46'37.09" E
C2	Crown fire	*Larix desidua* Mill.	650	25	9.3	42°19'23.77" N 23°46'37.10" E
S1	Surface fire	*Pinus sylvestris* L.	650	25	4.4	42°19'23.75" N 23°46'37.11" E
S2	Surface fire	*Pinus sylvestris* L. *Quercus cerris* L.	650	25	0.9	42°19'23.58" N 23°46'36.89" E
U	Unburned	*Pinus sylvestris* L.	650	25	0.6	42°19'25.25" N 23°46'36.40" E

The five 1-m deep soil profiles (till to the rock material) were established using spade – four at the burned forest stands (Sampling sites - C1, C2, S1, S2) and one – at intact forest site (Unburned - U). Soil samples were taken from 0-5 cm and 5-20 cm depth of the mineral part of the soil profile. Additionally four soil samples from the surface mineral soil have been collected randomly at each sampling site. Sampling and sample preparation processing have been performed following the contemporary methodological approach, described in details at ICP Manual - (COOLS & DE VOS, 2010). The soil from observed sites belongs to the group of the Haplic Luvisols (WRBSR, 2006). Identification and classification was performed according to the morphological peculiarities of the established soil profiles and based on the data received from the following laboratory analyses.

Soil organic carbon stock (SOC) for soil and forest litter was calculated according STOLBOVOY *et al.* (2007). For the purpose of our investigation, the reference soil organic carbon stock (SOC_{ref}) represents the initial (baseline) amount of the total SOC of the forest plots (unburned in our case). In order to calculate the difference in soil organic carbon stock Δ SOC_{stoc}, provoked by forest fire, the sequence of equations 1 to 4 was used. Soil organic carbon content represents the percentage of carbon (C) by weight (kg C/kg soil) × 100, and thus does not show the absolute carbon mass in the soil, which is sometimes inconvenient for comparing soils differing significantly in their density. Mass of C depends on the soil bulk density (e.g., a soil with a low percentage of C, but with a high bulk density may contain more mass of C compared to a low-density soil with a higher percentage of C).

Soil organic carbon density (SCD) for sampling site can be calculated according to the following equation (1):

$$SCD_{site} = \sum\nolimits^{j}_{layer=1} (SOC_{content} \times BulkDensity \times Depth \times (1 - frag))$$

Where:

$SOC_{content}$ - SOC content, % of mass $\frac{kg\ C}{kg\ Soil} \times 100$

Bulk Density - soil bulk density, $\frac{kg\ Soil}{dm^3}$

Depth - thickness of the sampled layer, dm;

Frag. - volume of coarse fragments, % of mass or $\frac{m^3 Stone}{m^3\ Soil}$

Parameter SCD_{site} provides an average value for the sampling site, which is derived from a composite sample as indicated in Equation 1.

Next step in the calculation of the difference in soil organic stock is calculation of the mean (arithmetic average) soil carbon density (DCS) for a given plot.

$$S\overline{C}D_p = \frac{1}{n} \sum\nolimits_{site=1}^{n} SCD_{site} \qquad (2)$$

Where:

SCD_{site} is calculated according to Equation 1;

n - number of the sampled sites within the plot.

Reference soil organic carbon (SOC_{ref}) stock for the plot was calculated according the equation:

$$SOC_{ref} = S\overline{C}D_p \times A_p \qquad (3)$$

Where:

$S\overline{C}D_p$ is estimated by Equation 2.

A_p is the area of the plot.

In our case, we assumed that the areas of the plots are equal to **1**ha in order to be able to identify the influence of the forest vegetation.

The changes in organic carbon stock (ΔSOC_{stock}) for the plots were calculated, using the equation:

$$\Delta SOC_{stock} = SOC_{new} - SOC_{refstock} \qquad (4)$$

Where:

The $SOC_{refstock}$ is as indicated in Equation 3 and refer to values obtained for unburned reference sampling site.

The SOC_{new} refers to soil carbon stock after the influence of forest fire.

Results and Discussion

A summary of the characteristics of soils from the studied sampling sites is given in Table 2.

The measured values for soil pH after forest fire are higher in all experimental variants compared to the control pH values (unburned sites). More pronounced differences was observed for the upper 5 cm of the soil and for all sampling sites, affected by crown fire. The highest difference of about 1 unit of pH was found in the soil after fire for sampling site - C2 - under European larch forest. The burning of the organic materials from tree crowns and above-ground biomass makes nutrient elements such as Mg and Ca more available (MOLINA *et al.*, 2007; SCHAFER & MACK, 2010). A similar trend for soil pH changes after a crown fire under 25 years stands of *Pinus sylvestris* L. was found previously (VELIZAROVA *et al.*, 2001). Our results show that the soil pH increased also in the layer 5 – 20 cm in all studied variants.

Table 2. Basic soil characteristics and results for the soil carbon stock changes

Sampling sites	Soil depth, cm	pH (H_2O)	Soil organic carbon content, (SOC) %	Total soil nitrogen N, %	C/N	Soil bulk density kg soil/dm^3	Soil carbon density (SCD*site*) kg C/m^2	*SCD site*, t/ha (for each studied soil depth)	*SCD site*, t/ha
C1	0 - 5	6.06	1.66	0.04	39.71	1.66	1.37	13.7	56.0
	5 - 20	5.53	1.38	0.03	44.09	2.04	4.22	42.2	
C2	0 - 5	6.42	1.93	0.08	22.76	1.92	1.85	18.5	55.2
	5 - 20	6.12	1.24	0.07	17.74	1.97	3.67	36.7	
S1	0 - 5	5.81	2.35	0.10	24.59	2.15	2.52	25.2	63.7
	5 - 20	5.40	1.79	0.08	21.90	1.43	3.84	38.5	
S2	0 - 5	6.12	3.45	0.13	26.58	1.40	2.41	24.2	70.5
	5 - 20	5.85	2.21	0.10	22.51	1.40	4.63	46.4	
U (SOC_{ref})	0 - 5	5.47	2.07	0.09	22.21	1.34	1.39	13.9	43.4
	5 - 20	5.26	1.10	0.05	21.19	1.78	2.95	29.5	

The soil pH changes in result of the forest fire depend not only on the fire type – crown or surface, but also on the differences of forest vegetation cover. Besides *Larix Desidua* Mill., the mixed forest of *Pinus sylvestris* L. and *Quercus cerris* L., subjected to fire, provokes a respective increase in the soil pH. The specific chemical composition of the forest litter and tissues of the different forest vegetation are known to cause variability in quantity and quality of burned organic material (KEVIN *et al.*, 2003).

The data on soil bulk density and its changes are presented in Table 2 and Fig 1. The fire influenced soil showed increased bulk density values in comparison with that of the control sampling site. This increase is higher for the surface 5 cm layer and a maximal value of 0.81 kg soil/dm^3 was established for S1. Rather smaller changes were found for this indicator in the 5 – 20 cm soil layer. Increase in the bulk soil density of up to 0.26 kg soil/dm^3 was established for the soil from sampling sites, influenced by crown fire. Surface fire led to decrease in soil bulk density with 0.35 kg soil/dm^3 – 0.38 kg soil × dm^3 at this depth. BOERNER *et al.* (2009) and CERTINI (2005) found that heat and flames of forest fires transform/destruct the soil aggregates, clay minerals and the biomass, disperse formed ash, filled up soil pores and, thus, decrease soil porosity and permeability. Changes in soil bulk density influence the values of soil carbon density (SCD).

The most significant event occurring during a forest fire is burning of biomass and soil organic matter (CERTINI, 2005).

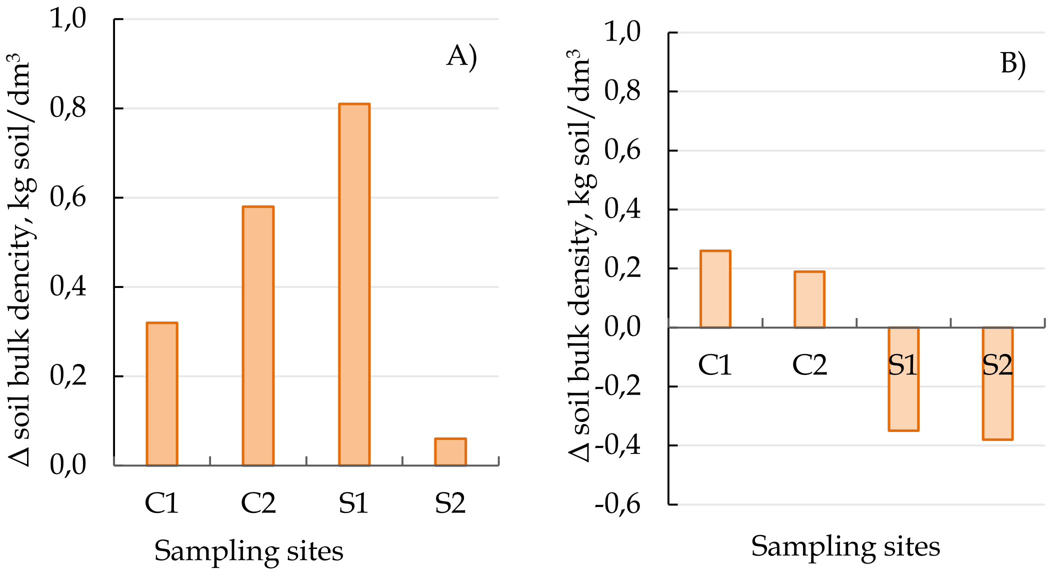

Fig. 1. Soil bulk density changes in 0 - 5 cm (A) and 5 -20 cm (B) soil layer.

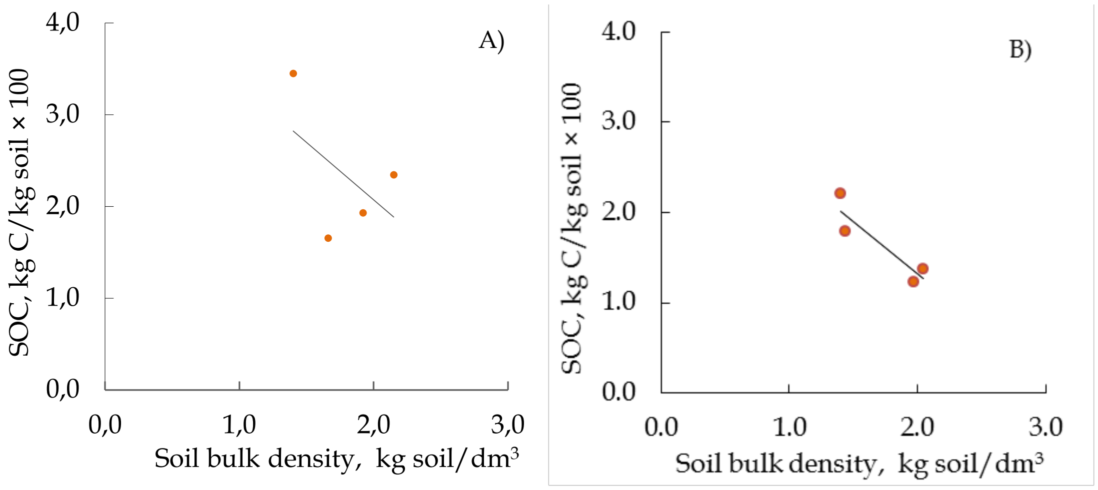

Fig. 2. Correlation between the SOC content and soil bulk for 0 – 5 cm soil layer (A) and for 5 -20 cm soil layer (B).

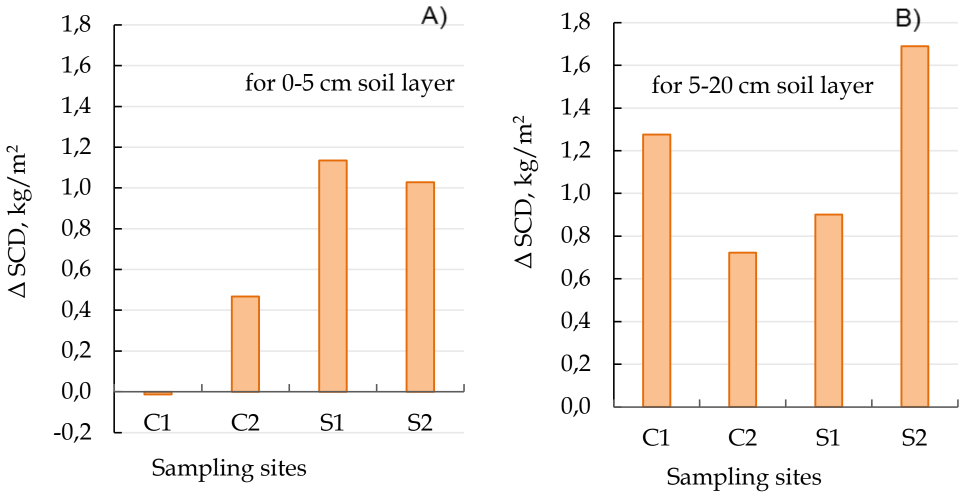

Fig. 3. Changes in soil organic carbon stock (ΔSOC_{stock}) for 0 – 5 cm soil layer (A) and for 5 -20 cm soil layer (B).

These processes are of great importance as the forests and soil organic matter are a part of the terrestrial carbon pool, which is in turn – a part of the global carbon cycle (Lal, 2005). In the 0-5 cm layer of the mineral soil, the SOC content varies from 1.65% to 3.45% (Table 2). For the soil from C1 and C2, affected by crown fire, SOC content decreased in comparison to that in control (U). The earlier (Hosking, 1938) and later studies (DeBano *et al.*, 1998) on heat-induced changes in organic matter have improved our understanding on the specific chemical changes that occur in organic matter during the course of heating. These and other studies demonstrated losses of organic carbon content in result of volatilization and carbonization of organic materials within the temperature interval from 200 °C to 400 °C (Schnitzer & Hoffman, 1964). Contrary, the surface fire, peculiar to S1 and S2 provoked an increase in soil organic carbon amount in the surface soil layer – by up to 3.45% in comparison to the value for the U site. A similar trend for the soil organic concentration in result of a surface fire has been reported for 25 years old Austrian pine plantations (Velizarova, 2000). A slight growth in soil OM content are also reported due to an increased deposition of dry leaves and charred plant materials after fires that affect the tree canopy and forest litter (Chandler *et al.*, 1983).

The complex interactions among vegetation variety, fire severity, loss or reduction of structure and porosity, water repellency, as well as geomorphic processes influence the organic carbon content distribution along the soil profile. As surface fires suppose greater heat transfer to soil, the organic matter transformation was expected to result in structural changes. The SOC content within the 5-20 cm soil layer showed higher values in all studied variants in comparison with the control site. This increase was evident in the soils from S1 and S2 sampling sites. DeBano (1981) hypothesizes that because of the steep temperature gradient in the upper 5 cm and deeper soil layers a small amount of organic matter can move downward and condense to form a water-repellent layer that would impede infiltration. Our results showing a negative correlation between the SOC content and soil bulk density for 5 -20 cm soil layer are in agreement with this hypothesis (Fig. 2).

The soil organic matter consists of distracted to a different degree plant materials, wood debris, humified components and other organic fractions and thus it is important to discuss the SOC stock and its changes (ΔSOC_{stock}) for the fire influenced sampling sites (Table 2, Fig. 3). Our results for the SOC stock show that its values vary from 1.4 kg/m^2 to 2.5 kg/m^2 for the upper 5 cm and from 3.7 kg/m^2 to 4.6 kg/m^2 for the lower 15 cm. Comparing these values with that for control sampling site, it is evident that the soils from fire affected sites accumulated more carbon than the control one. The SOC stock values, however, differ with the forest types. For example – the soil from Scots pine stand affected by surface fire (S1) showed the highest SOC stock in the surface 5 cm - 2.52 kg/m^2, followed by that – for S2 – mixed forest (*Pinus sylvestris* L. *Quercus cerris* L.). The soil of these sampling sites (S1 and S2) showed higher carbon stocks also in the lower 15 cm layer – 3.85 kg/m^2 and 4.64 kg/m^2, respectively. Standardized SOC stock values for the studied 20 cm layer of the mineral soil exhibit the highest accumulation of 63.7 kg/m^2 and 70.5 kg/m^2 in the soil from surface fire affected sites. Obviously, the SOC stock in the fire-influenced sampling sites was dependent of fire characteristics (fire type and its severity) and the tree species We calculated the changes in soil organic carbon stock (ΔSOC_{stock}) as the difference between the reference soil organic carbon stock (SOC_{ref}) and SOC_{new} and use it as a measure for the forest fire influence on the soil organic matter (Fig. 3). The SOC stock differences in the surface 5 cm of the soil were ≈ 1.0 kg/m^2 in the S1 and S2 – sampling sites, related to the surface fire influence. Crown fire provoked lower SOC stock changes ≈ 0.4 kg/m^2 in the C2. All mentioned changes show positive accumulation trend. A decrease in the SOC stock - by - 0.01 kg/m^2 was found for the surface 5 cm of the soil from C1, influenced by crown fire.

Along the soil profile (the 5-20 cm layer), the SOC stock differences vary from 0.6 kg/m^2 to 1.7 kg/m^2. Based on the data obtained, we suppose that in deeper soil layers the forest fire influence was less significant and that the carbon stock changes were mainly due to downward movement processes of transformed soil organic compounds, as well as of fine soil particles. RAPALEE *et al*., (1998) found that for boreal soil the SOC stock accumulation is related to the soil permeability, which was confirmed also by other studies (DEBANO, 1981).

Conclusions

Our investigation highlights the importance of field-based site measurements in characterizing the soil organic carbon stocks. The SOC stock varied from 1.4 kg/m^2 to 2.5 kg/m^2 for the upper 5 cm and from 3.7 kg/m^2 to 4.6 kg/m^2 for the lower 15 cm soil layer. The soil from the fire-affected sites accumulated more carbon than the control (unburned) one. This finding is important by confirming the role of forest soil in the global carbon sequestration. The SOC stock values, however, differ depending on the trees species. For the upper 5 cm soil layer, the highest SOC stock was 2.52 kg/m^2 in the soil of the sampling site, afforested by Scot pine, followed by that below a mixed forest (*Pinus sylvestris* L. and *Quercus cerris* L.). Standardized SOC stock values for the studied 20 cm layer of the mineral soil show that the highest accumulation of 63.7 kg/m^2 and 70.5 kg/m^2 is achieved in the soil from the surface fire affected sites. The reasons leading to a higher SOC stock in the fire-influenced sampling sites were related to fire characteristics (type and severity), and to the type of tree species. Changes in soil bulk density induce changes in soil carbon density (SCD).

SOC stock differences stock (ΔSOC_{stock}) vary from 0.6 kg/m^2 to 1.7 kg/m^2. Downward movement processes of transformed soil organic compounds and fine soil particles seem to be the main mechanism for SOC stock accumulation. Forest fires influenced to a lesser degree the carbon stock changes in deeper (more than 5 cm) soil layers.

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