frontiers | Frontiers in Forests and Global Change

TYPE Original Research
PUBLISHED 08 September 2022
DOI 10.3389/ffgc.2022.987010

Experimental short-time wildfire simulation—Physicochemical changes of forest mucky topsoil

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SPECIALTY SECTION
This article was submitted to
Fire and Forests,
a section of the journal
Frontiers in Forests and Global Change

RECEIVED 05 July 2022
ACCEPTED 24 August 2022
PUBLISHED 08 September 2022

CITATION
Kupka D, Khan MO, Kwika A, Stowik-Opoka E and Klamerus-Iwan A (2022) Experimental short-time wildfire simulation—Physicochemical changes of forest mucky topsoil. *Front. For. Glob. Change* 5:987010. doi: 10.3389/ffgc.2022.987010

Today, fires constitute one of the most important factors that can affect soil properties, acting at a rapid pace and on a large scale. They often result from climate change. The present study was aimed at examining how water capacity as well as carbon and nitrogen concentration change during a simulated fire of forest mucky soil under laboratory conditions. The combustion was carried out in two short-time variants—for 3 and 9 min. The results presented herewith show that even a short-term fire of the soil cover contributes to visible changes in the physicochemical parameters of the soil. Thermal decomposition of organic matter caused an increase in total carbon and nitrogen concentrations and a slight increase in the C_t/N_t ratio. The burning of soil samples caused a slight upward trend in soil pH and this was associated with soil organic matter (SOM) deprotonation. The experiment showed the effect of mucky soil burning on the change of its water relations. The 3-min combustion significantly increased the maximum water storage capacity (both after 4 and after 24 h of immersion in water), while the 9-min combustion showed significantly worse results.

KEYWORDS

water storage capacity, dewatered soil, temperate forest wildfire, simulated fire, soil organic matter, forest soil

Introduction

Forest ecosystems cover two-thirds of all land surfaces, which comprise all native plant species (Pimm and Raven, 2000), and sequester about 12% of human-induced carbon (C) dioxide emissions (Pan et al., 2011). Forest wildfires are a common occurrence in many terrestrial ecosystems in Europe, affecting over half a million hectares of forest ecosystems every year (Gray and Dighton, 2009; Khabarov et al., 2016). Such a large scale of the impact of forest fires causes that they temporarily impact the local C balances (Ribeiro-Kumara et al., 2020). Thus, forest fires contribute to the formation of mosaic complex of ecosystems, differing in the state of ecological succession (De Groot et al., 2013; Ribeiro-Kumara et al., 2020). There is a strong correlation between warming trends and forest wildfires (Dezzeo and Chacón, 2005;

Viegas, 2005; Castro et al., 2012); namely, increasing temperatures and periodic droughts make wildfires more likely (Coogan et al., 2019). Also wind is an important natural contributor to wildfires, especially when connected with dry weather and high temperatures (de Rigo et al., 2017). Wildfires are mainly a result of human activity, such as ignition, illegal grass burning, fireworks or smoking, while natural causes (e.g., lightnings or self-ignitions) account for a minority of wildfire causes (Trnka et al., 2021). It is well known that fire can alter forest soil properties (Neill et al., 2007), which influence critical processes such as hydrological and biogeochemical cycling (Neary et al., 1999). A widespread fire in forests can influence emissions of greenhouse gasses and aerosols, vegetation dynamics, and global C budgets (Krawchuk et al., 2009; Pellegrini et al., 2018; Walker et al., 2019), with subsequent feedback to future climate change (Bedia et al., 2015; Harris et al., 2016).

Although wildfires are not the main disturbing factor responsible for shaping forest ecosystem communities in Central Europe, they play important role in dry and moderately moist regions (Leuschner and Ellenberg, 2017). The impact of wildfires on forests in Central Europe has not been widely studied (Dzwonko et al., 2015). In particular, also the response of soils highly susceptible to fire was not thoroughly examined. Poland is classified as third country in Europe for the average yearly number of forest fires (Schmuck et al., 2010), which occur mainly during the summer period of drought and elevated surface temperatures. In Poland, in period 1990–2016, an area (consisting natural ecosystems) of more than 7,300 ha burned annually (San-Miguel-Ayanz et al., 2017). Given that recent climatic forecasts predict more frequent periods of favorable wildfire weather (Khabarov et al., 2016), reported area is likely to increase.

Fire is a major threat across various forest types (Harden et al., 2000; Schoennagel et al., 2017; Pellegrini et al., 2018) because of its effects on the soil's physical, chemical, and biological properties (Certini, 2005; Boerner et al., 2009; Alcañiz et al., 2018). The abundance, biomass, activity, and biodiversity of microorganisms are all affected by fire (Mataix-Solera et al., 2009). Burning changes soil acidity, water storage capacity, and nutrient concentration by consuming plant biomass, litter layers, and soil organic matter (Certini, 2005; Hubbert et al., 2006; Hamman et al., 2008). There is evidence that fire increases soil water repellency, decreasing permeability and stimulating runoff (Imeson et al., 1992; DeBano, 2003). This is mainly due to the degree of soil dryness, even reaching the "critical soil moisture thresholds" (Dekker and Ritsema, 1996; Doerr and Thomas, 2000). During the fire, the nutrient content of the soil is immediately reduced because of volatilization, smoke, ash, leaching, and erosion (Arocena and Opio, 2003; Wanthongchai et al., 2008). The effects of fire on soil properties depend on several variables, such as fire type, intensity, terrain, region, and fire weather conditions (e.g., temperature, precipitation, and drought) (Certini, 2005; Fonseca et al., 2017; Alcañiz et al., 2018).

Fire changes specific physicochemical properties of burned soil (Wondafrash et al., 2005), and soil heating changes occur in particle size distribution in burned soils by aggregating clay and silt particles into coarse and sand particles (Ketterings et al., 2000; Zavala et al., 2014; Doerr and Santín, 2016). Consumption of organic matter and loss of macro-pores (>0.6 mm) also affect the organic matter content, bulk density, and porosity of soils, particularly in the top few centimeters (Ketterings et al., 2000; Zavala et al., 2014; Doerr and Santín, 2016). Increased bulk density and soil organic matter loss render burnt soils less effective at storing water.

A fire can increase nutrient availability mainly by increasing ash production and mineralization. The heat from the fire can produce ashes with a variety of properties, whereas increased pH values can enhance the availability of nutrients—e.g., the availability of Fe, Mn, and Zn decreases with increasing pH values. Fires, however, can also lead to decreased nutrient availability over time because organic matter and microbial biomass release nutrients into the ecosystem, which are removed by leaching and runoff (Wüthrich et al., 2002; Miesel et al., 2012).

The significance of fire in the terrestrial C cycle and nutrient dynamics has been studied extensively in both indigenous and planted forests in boreal and temperate zones and tropical slash-and-burn agriculture (Carter and Foster, 2004; Geldenhuys and van Wilgen, 2004; Morley et al., 2004; Kashian et al., 2006; Gough et al., 2007; Irvine et al., 2007; Kurz et al., 2008; Meigs et al., 2009). However, there are still a lot of uncertainties in a temperate zone forest of Central Europe, particularly in dry or drained carbon-rich soils subjected to fire. Intended draining of these soils disturbs hydrological relations by lowering the water table position, thus exposing whole ecosystems to more severe and frequent wildfires (Turetsky et al., 2011; Reddy et al., 2015). Fires in forest ecosystems with mucky or peat soils are worrying due to the considerable emissions to atmosphere of terrestrially stabilized carbon (Reddy et al., 2015). Because the effects of fire on soils are so diverse (Ponder et al., 2009; Chen et al., 2018), it is essential to comprehend how fire affects soil carbon and nutrients in temperate zone forests in order to sustain soil fertility in areas where fires have occurred.

This research is conducted in laboratory, with the aim to evaluate the impact of simulated short-term fire durations on physicochemical and hydrological properties of forest dewatered soil in temperate zone forest. We hypothesize that short-time fire has significant impact on (1) chemical properties of forest mucky topsoil (particularly the content of carbon, nitrogen and pH); (2) short-time fire causes deterioration of physiochemical properties of forest mucky topsoil. The obtained results may contribute to the understanding of physiochemical changes in soils particularly susceptible to fires, which are undoubtedly drained peatlands, i.e., mucky soils.

Materials and methods

Study site and sampling

Soil samples were collected from a forest complex in the Krzeszowice Forest District, southern Poland. The forest stand in the study site is multistoried and consists of birch, with a minor contribution of oak, larch, alder, and spruce. The habitat is moderately moist, with rainwater being the dominant moisture regime (Bureau of Forest Management and Geodesy Branch Office in Krakow, 2012). A brief summary of the study site characteristics can be found in **Table 1**.

According to the World Reference Base of Soil Resources, the soil in the study site is classified as Umbric Gleysol (Arenic) (FAO, 2014). The topsoil in the study plot consisted of muck with an average thickness of about 5 cm. This is due to disturbed water relations associated with past drainage and lowering of water table on the forested area. The soil is developed on Quaternary glacial sands.

The average annual temperature in the study site is about 8°C. The highest average air temperature occurs in July and reaches 18°C, while the lowest average air temperature occurs in January and is –2°C. Annual rainfall is about 600 mm, with a maximum in July (100 mm) and a minimum in February (30 mm) (Bureau of Forest Management and Geodesy Branch Office in Krakow, 2012).

In the study site, six soil cores were taken randomly with a minimum distance of 3 m between each plot. The sampling was performed using steel frames (25 cm width × 25 cm length × 15 cm height) to collect the intact topsoil with organic (O) horizon. The organic overburden consisted mainly of branches and litterfall. Sampling took place in June during summer, when the litter is dry and there is a high risk of wildfire. Moreover, litter derived during the previous fall could undergo the process of initial decomposition. Intact soil samples were stored in plastic bags and transported to the laboratory.

TABLE 1 Description of study site.

Characteristic	
Coordinates	50°08′08.7″N 19°30′18.6″E
Soil type	Umbric Gleysol (Arenic)
Forest stand species	Silver birch (*Betula pendula* Roth), Pedunculate oak (*Quercus robur* L.), European larch (*Larix decidua* Mill.), Black alder [*Alnus glutinosa* (L.) Gaertn.] European spruce [*Picea abies* (L.) H. Karst]
Forest stand age (years)	36

FIGURE 1
Burning of soil samples. Photographs by Anna Klamerus-Iwan.

TABLE 2 Particle size distribution of analyzed soil.

Ø [mm]	**% of weight**
Ø > 5	6
5 > Ø ≥ 2	6
2 > Ø ≥ 1	4
1 > Ø ≥ 0.5	14
0.5 > Ø ≥ 0.25	34
0.25 > Ø ≥ 0.1	26
Ø ≤ 0.1	9

Laboratory analysis

After transporting the frames with intact soil samples from the research site to laboratory, they were immediately subjected to analyzes. Four of the six frames were subjected to burning of the top layer using a propane-butane blow lamp. The average temperature that was used, given by the manufacturer, is 1,700 degrees Celsius. Two frames were left as a control. The burning was divided into two stages, i.e., two frames were burnt for 3 min and two frames were burnt for 9 min (**Figure 1**). The combustion area was small (625 cm^2) compared to large-scale fires; therefore, the burning times were also relatively short.

The choice of 3 and 9 min was due to earlier control tests and the appearance of the sample after a longer and shorter fire simulation time. After 3 min, the top layer of the litter was burnt, and after 9 min, we could observe the symptoms of burning in deeper layers of soil. Frames were burnt separately, after which were left to smolder. The burning was performed from a distance of about 5 cm above the soil surface (**Figure 1**). Burning was done in regular bands, evenly covering the soil in the frames.

After the burning, 20 intact soil samples were collected from the topsoil of each group (control, 3 min and 9 min of burning). To standardize the sampling procedure, we collected soil samples using 100 mL Kopecky cylinders (5 cm of diameter, 5.1 cm of height).

15 soil samples collected into the cylinders from each group were subjected to a maximum water storage capacity (S_{max})

analysis. In total, 45 samples were tested. The soil-filled cylinders were closed and weighted. The cylinders were then watered with deionized water and left for 24 h. After 4 and 24 h, the weight of the samples was measured. The samples were then dried at 105°C for 24 h. The dried samples were weighted again. Previously, the empty cylinders were also weighted to know the absolute weight of the samples. The procedure of calculating the maximum water storage capacity is described in section "Statistical analysis."

Regardless of the S_{max} analysis, five soil cylinders (15 cylinders in total) were prepared from each of the three groups (control, 3-min burning and 9-min burning), and subjected to chemical analysis. Samples were air-dried at room temperature. After removal of roots, 100 g of the soil was used to determine particle size distribution using the sieving method. The remaining soil was sieved through a 2 mm sieve. From samples thus prepared, subsamples (10 g each) were taken and ground in a ball mill (Fritsch) for the analysis of total carbon (C_t) and total nitrogen (N_t) concentrations in a LECO TrueMac Analyser (Leco, St. Joseph, MI, United States). The remaining sieved soil was used for the estimation of pH and total acidity. The soil pH was measured using a potentiometric method in distilled water (pH_{H2O}) and in 1 M potassium chloride (pH_{KCl}) solution (1:5 mass to volume) (Buurman et al., 1996). The total acidity (TA) was measured after extracting 10 g of soil with 30 mL 1 M calcium acetate [$(CH_3COO)_2Ca$], shaken for 1 h and filtered. 25 mL of the extract obtained was titrated by potentiometric titration (using automatic titrator, Mettler Toledo, Inc., Columbus, Ohio) to pH 8.2 with 0.1 M sodium hydroxide (NaOH) (Buurman et al., 1996).

Statistical analysis

To check the normality of the distribution within analyzed groups (control, 3 min of burning, 9 min of burning), the Shapiro-Wilk test was performed. Kruskal-Wallis ANOVA was used to examine the differences in the studied parameters between groups. Duncan's test was used as a *post hoc* analysis. Mann-Whitney test was used to compare two groups. In order

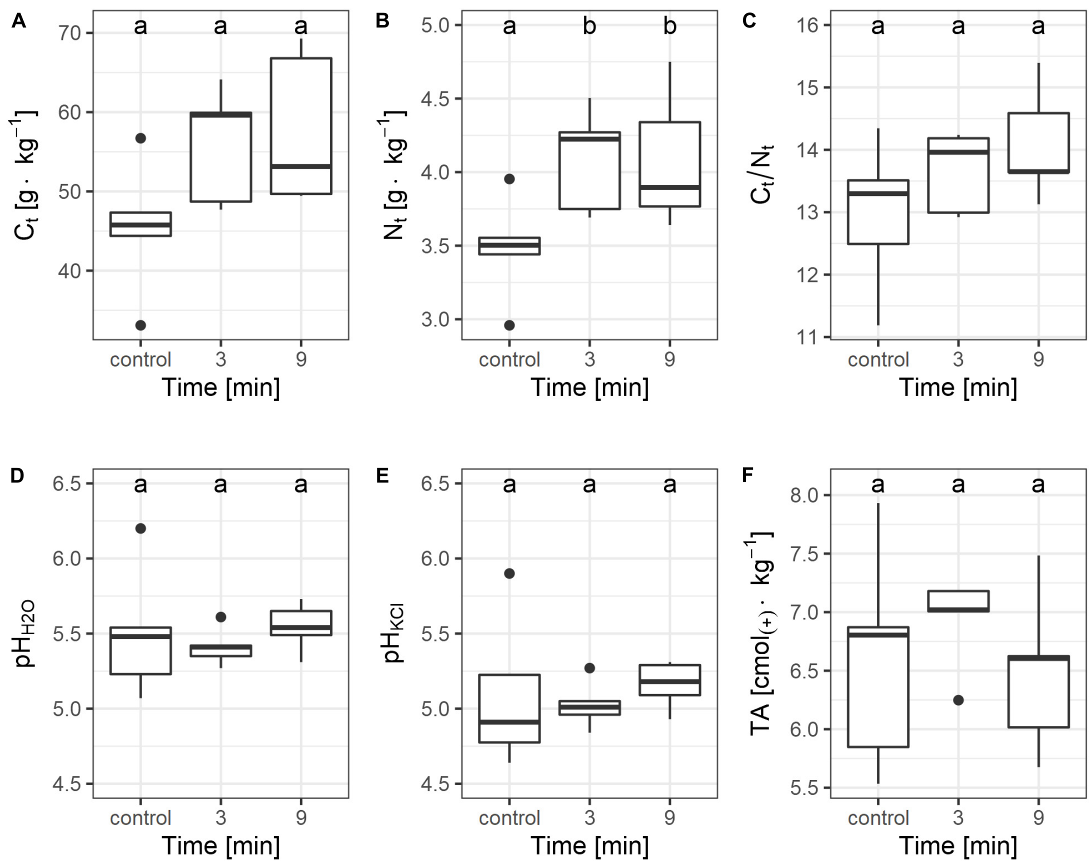

FIGURE 2
Total C **(A)**, total N **(B)**, C_t/N_t ratio **(C)**, pH in H_2O **(D)** and in KCl **(E)**, total acidity **(F)** plotted against the time of soil burning. Different letters on this figures indicate significant differences between the groups (according to Duncan test, $p < 0.05$). The line within the box represents median; the box represents interquartile range; the whiskers represent the largest and the smallest value within 1.5 times interquartile range above 75th and below 25th percentile, respectively; the points represent outliers.

to evaluate relationships between investigated soil properties, we calculated the Pearson's correlation coefficients, as well as conducting principal component analysis (PCA). Significance was defined at $p < 0.05$.

The method for determining the maximum water storage capacity (S_{max24}) involves calculating the difference in mass between absolutely dry samples and the mass of the same samples fully immersed in water for 24 h.

The maximum water storage capacity was calculated according to the formula (1) (Klamerus-Iwan et al., 2020):

$$\mathbf{S_{max24}} = \frac{\mathbf{W_{gw}} - \mathbf{W_{gs}}}{\mathbf{W_{gs}}} \cdot \mathbf{100\%} \quad (1)$$

where: S_{max}—maximum water storage capacity after 24 h of soaking in water; W_{gw}—water-saturated soil mass after 24 h in water; W_{gs}—dry soil mass.

In addition, we checked whether the water storage capacity changes during soaking. To accomplish this, soil samples were additionally weighed after 4 h of soaking, which resulted in obtaining the S_{max4} parameter.

All statistical analyses were performed using R statistical software, using packages "ggplot2" and "factoextra" (Wickham, 2016; Kassambara and Mundt, 2020; R Core Team, 2022).

Results

In overall, the analyzed soil consisted mainly of medium sand with a small admixture of gravel, silt and clay (**Table 2**).

No significant differences in C_t concentration were observed between the studied groups (**Figure 2A**). However, the comparison of the control group with the merged burned samples highlighted the significant effect of burning on C_t concentration (control vs. combustion for 3+9 min, mean ± std. deviation: 45.5 ± 8.4 g kg^{-1} vs. 56.8 ± 8.1 g kg^{-1}; $p < 0.05$ according to Mann-Whitney test). Regardless of the duration, burning caused an increase in the concentration of N_t (**Figure 2B**). The mean concentration of N_t in control group was 3.5 ± 0.4 g kg^{-1}, whereas in the merged burned samples, it was 4.1 ± 0.4 g kg^{-1} ($p < 0.05$). The C_t/N_t ratio did not differ between the groups (**Figure 2C**), despite increasing the value along with burning time (trend near statistical significance, $p = 0.09$; $R^2 = 0.2$). The pH of the samples, analyzed for all groups, was moderately acidic (pH_{H2O}, mean ± std. deviation: 5.49 ± 0.26; pH_{KCl} 5.05 ± 0.33) (**Figures 2D,E**). Although combustion did not result in a statistically significant increase in Ct, slightly higher averages were observed in the burned samples (**Figure 2A**). There were no significant differences between the groups in terms of total acidity values (**Figure 2F**).

Burning of the topsoil caused an increase in S_{max} of the tested samples. After 4 h, and again after 24 h, the burned samples had a higher S_{max} value compared to the control group (**Figures 3A,B**). The S_{max} value of the samples burned for 9 min after 4 h (S_{max4}) was almost equal to the S_{max} after 24 h of soaking in water (S_{max24}). In contrast, the S_{max24} value of samples burned for 3 min was higher than S_{max4}.

Analysis of the correlation matrix, presented in **Table 3**, showed that the burning time of the samples was not significantly correlated with the studied soil physicochemical properties. S_{max4} was significantly correlated with C_t and N_t, while S_{max24} value was not. However, the PCA provided more precise insights. The first two PCA variables explained altogether 76% of the variance. Projecting the cases onto the component plot showed that the samples of the three analyzed groups were three separate clusters (**Figure 4A**). Soil samples from the control group occupied the upper and lower left quadrants of the plot. Samples burned for 3 min were the group in the lower right quadrant, and samples burned for 9 min were in the upper right quadrant. A projection of the variables onto the component plot proved a positive correlation of combustion time with the concentration of C_t, N_t and C_t/N_t ratio (**Figure 4B**). Positive correlation was also found for burning time and S_{max}, as well as pH values. There was a negligible correlation between the burning time and total acidity.

Discussion

An impact of fire on soil C and N

Among natural disasters occurring in forests, fires occupy a leading place, and their eradication has a fundamental impact on biocenosis. They cause damage to tree stands, but above all they contribute to changes in the properties of the soil—the component of the ecosystem without which the proper growth and development of phytocenoses is not possible. Fire is a violent, even extreme ecological phenomenon, particularly in the ecosystems exposed to burning due to disrupted hydrological properties. Fires can appear as a result of natural factors such as spontaneous ignition or electrical discharges. At the same time, however, the main perpetrator of fires is man through activities resulting from non-compliance with safety rules, e.g., by burning fires in the forest or burning grass (Wiler and Wcislo, 2007). However, it should be mentioned that wildfires also provide a number of ecosystem services, such as creating new habitats for plant communities, controlling pests, regulate biogeochemical cycles (Pausas and Keeley, 2019).

The effects of a fire in the environment depend on many factors such as duration, severity, weather, forest type, soil moisture or geomorphological situation (Certini, 2005; Benscoter et al., 2011). The research presented in this paper is a brief case study of the effects of wildfires on temperate forest's dewatered mucky topsoil. In the past, the area from which the soil samples were taken had belonged to peatlands with locally stagnant water. However, land reclamation and anthropogenic

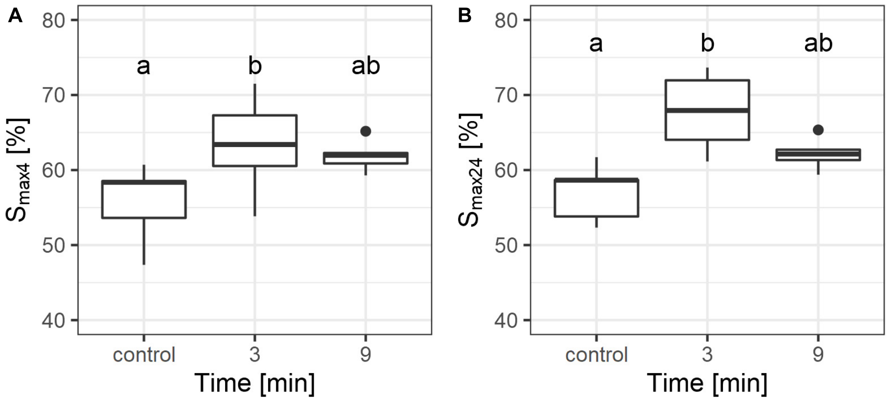

FIGURE 3
Maximum water storage capacity after 4 h **(A)** and after 24 h **(B)** of soil subjected to different combustion times. Different letters on this figures indicate significant differences between the groups (according to Duncan test, $p < 0.05$). The line within the box represents median; the box represents interquartile range; the whiskers represent the largest and the smallest value within 1.5 times interquartile range above 75th and below 25th percentile, respectively; the points represent outliers.

TABLE 3 Pearson correlation coefficients between the burning time and physicochemical soil properties.

	Burning time	C_t	N_t	C_t/N_t	pH_{H2O}	pH_{KCl}	TA	S_{max4}
C_t	0.48							
N_t	0.47	0.98*						
C_t/N_t	0.45	0.93*	0.84*					
pH_{H2O}	0.10	0.30	0.19	0.47				
pH_{KCl}	0.25	0.36	0.29	0.48	0.95*			
TA	−0.15	0.07	0.13	0.04	−0.61*	−0.55*		
S_{max4}	0.37	0.57*	0.60*	0.52	−0.01	0.10	0.38	
S_{max24}	0.24	0.40	0.47	0.30	−0.22	−0.08	0.44	0.86*

*$p < 0.05$.

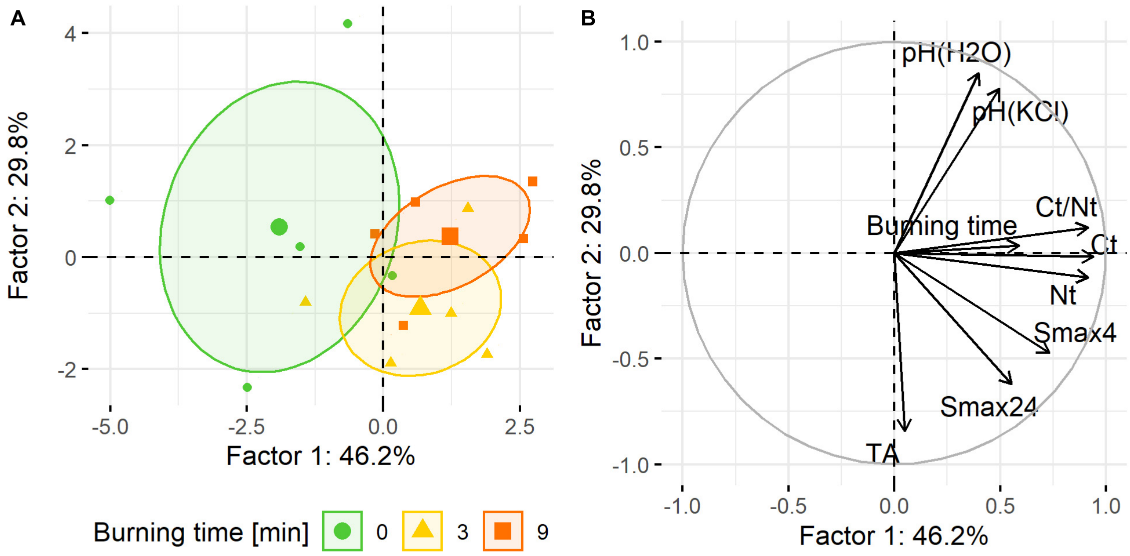

FIGURE 4
Plot of individuals (PCA) **(A)** and principal component analysis **(B)** for the physicochemical properties of soil samples subjected to burning.

disturbances of local water relations, as well as progressing climate changes, caused drainage of the topsoil and lowering of the water table. Therefore, the analyzed soil is even more threatened by fire, thus protection of peatlands and maintenance of their proper water relations are crucial—particularly today, in the era of efforts to sequester CO_2 in the soil and to accumulate stable soil organic matter (SOM) fractions (Turetsky et al., 2011).

The greatest intensity of changes in forest ecosystems occurs immediately after the fire, but they are also visible after a few years (Bissett and Parkinson, 1980) or even several dozen years (Monleon and Cromack, 1996; Neary et al., 1999). The results presented in our study demonstrate that even a short-term soil cover fire contributes to visible changes in soil physical and chemical parameters. Thermal decomposition of SOM resulted in increased concentrations of C_t and N_t, as well as a slight increase in the C_t/N_t ratio (**Figures 2A–C**). The spread, time and intensity of topsoil burning depend precisely on the thickness of the organic layer, and its complete combustion can occur only with unlimited access to oxygen. During the topsoil burning, access to oxygen is significantly limited, which makes the combustion incomplete—on average, 50% of the organic C accumulated in the soil is burned during a fire (Prieto-Fernandez et al., 1998; Santín et al., 2015). Such finding contributes to our results, demonstrating a positive correlation between burning time and C_t concentration in soil (**Figures 2A**, **4B**).

According to Walker et al. (2019), although some part of SOM is released during combustion, the remaining post-fire SOM accumulates in the forest soil. Such SOM (known also as pyrogenic C) is reported to be more resistant to decomposition, which positively induces soil C pools. On the one hand, an increase in C_t is generally a desirable phenomenon because it provides several benefits (e.g., increases soil biodiversity, improves humus quality, increases the share of stable SOM fraction, thus contributing to soil C sequestration) (Lal, 2005, 2013; Bossio et al., 2020; Li et al., 2021). On the other hand, we should note that in the studied samples, the C_t/N_t ratio also increased with burning time. Having said that, the values of this ratio did not exceed 20, therefore it can still be concluded that there were good conditions for SOM decomposition. However, a more significant increase in C_t/N_t ratio could be an important indicator of deterioration of soil fertility and biological activity.

Effect of fire on other soil physio-chemical properties

Burning of the soil samples caused a slight upward trend in soil pH (evident both in pH_{H2O} and in pH_{KCl}). We assume that this phenomenon was related to deprotonation of SOM (dissociation of H^+ ions from SOM functional groups), probably connected with the hydrolysis of aluminum, which was reported by some authors (Gruba and Mulder, 2015). In further way, deprotonated SOM functional groups can form organo-mineral complexes with charcoal particles, which significantly contributes to carbon stabilization in soil (Eckmeier et al., 2010). Soil pH also increases after a fire, because OH^- groups are lost from clay minerals, oxides are formed, or exchangeable cations are increased in soils (Raison, 1979; Certini, 2005; Zavala et al., 2014). According to various studies, soil pH increases due to the production of potassium (K) and sodium (Na) oxides, hydroxides, and carbonates within the ashes (Ulery and Graham, 1993), as well as the denaturation of organic acids with heating (Scharenbroch et al., 2012). Also, the carbonates and hydroxides derived from burnt plant material can contribute to the increase in soil pH (Schafer and Mack, 2010). Our experiment demonstrated the effect of topsoil burning on changing its water relations but in a more complicated way. A 3-min burning significantly increased the maximum water storage capacity (both after 4 and after 24 h), while a 9-min burning provided visibly worse results (**Figures 3A,B**). This may indicate that longer simulation of the fire contributed to the (over)drying of the soil, resulting in increased SOM hydrophobicity. Overdrying of the soil and destruction of the natural cover causes frequent occurrence of negative water balance in areas affected by fires. A factor changing the sorption properties of the soil may include the increase in soil density caused by the sealing of pores by ash (Certini, 2005). The end result of sealing soil pores is a decrease in water capacity, a decrease in the rate of infiltration, and thus an increase in surface runoff (DeBano, 2003). Changes in the hydrological properties of the soil as a result of over drying constitute a complicated phenomenon, dependent on many factors. Some laboratory experiments (Doerr and Santín, 2016) indicate that a considerable increase in soil moisture does not necessarily lead to a significant reduction in hydrophobicity. Hydrophobic effect occurs when the surface tension of topsoil is lower than that of water (Zisman, 1964; Doerr and Santín, 2016). The time of combustion influences the degree of thermal decomposition of SOM and oxidation of its functional groups, which is manifested in the change of water, physical and chemical soil parameters. In our experiment, groups of soil samples with different duration of burning (0, 3, and 9 min) constituted three different groups, differing in physiochemical properties, basing on PCA analysis (**Figure 4A**). We suggest the mechanism that short burning caused in an increase in soil ash content with no increase in SOM hydrophobicity and no significant soil drying, leading to increased water storage capacity.

Further perspectives

Our results show that even short-term forest floor fires can contribute to changes in physiochemical properties of mucky soils in temperate zone forests. Therefore, in order to better understand the impact of fires, among other things, on the hydrological properties of the forest floor, further research is necessary, taking into account the quantity and quality of organic matter, especially since it is the organic matter that usually has a greater capacity to store water (Chen et al., 2018). The research agenda in undertaken topic should consider field experiments, which regard the impact of climatic and environmental factors, that could affect the hydrophysical soil properties. Also, considering different fire regimes in the background of climate change could fill an important gap in the relations between wildfires and ecosystem services (Pausas and Keeley, 2019). Future research should take into account the aforementioned factors as well as the different soil types and longer burning duration. In addition, in order to better understand the impact of fires on soil hydrology under global climate change conditions, further research should consider both the impact of drought on fire occurrence and the consequences of fires such as soil over drying.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AK-I and ES-O: conceptualization. AK-I, ES-O, and DK: methodology. AK-I, ES-O, DK, MK, and AK: validation, writing—original draft preparation, and writing—review and editing. All authors contributed to the article and approved the submitted version.

Funding

This research was financed by the Ministry of Science and Higher Education of the Republic of Poland and the Department of Ecological Engineering and Forest Hydrology.

Acknowledgments

We would like to thank Mateusz Karwan for his assistance with field and laboratory measurements. We also thank reviewers for their helpful suggestions, which improved the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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