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INFLUENCE OF FIRE TO POOLS OF CARBON AND WATER RETENTION IN MEADOW AND FOREST PYROGENIC SOILS

Abstract. The research has aimed to determine the impact of fire on pools of soil organic matter and water retention in pyrogenic soil in meadow and forest areas. The following soil samples have been represented: moorsh, peat-moorsh, mineral moorsh and peat. The soil horizons represented: strongly dried peat-moorsh soil, medium-deep (MtIIc1 and MtIIIc1), mineral moorsh soil (Me11) and moorsh soil. Soil horizons have been determined on the basis of colour, decomposition of organic samples; bulk density and water retention have been analyzed in 100 cm^3 stainless Kopecky metal rings. Bulk density was measured in undisturbed samples by the volumetric method. Soil water retention characterized by pF2.0 has been measured using sandbox analyzer. Soil organic carbon content was detected with Bushi analyzer. The lowest carbon content has been indicated by horizons with high ash content. As a consequence of various fire temperatures, we can observe different soil colour spectrum between N, 10YR and 5YR. Generally, the pools of water retention decreases because of the fire. We can observe differences between SOM pools and water retention pools in the meadow and forest soil. Water retention of pyrogenic soils drastically decreases in mineral-organic soils with angular sharply edged structure and peaty-ash or ash horizons.

The impact of fire on soil total organic carbon (STC) is dependent on five formation factors: time, climate, topography, vegetation and parent material [2, 8, 15, and 20]. Fire-induced changes in SOM are related to the fire's impact on other soil physical properties, for example changes in structure [21] and water retention capacity [27]. Fire, generally, has influence on the STC decomposition rates in a moorsh process [19]. Fire leads to the fragmentation of habitats, both meadow and forest [7]. In the immediate period after the fire, the soil erosion processes begin [24]. Strong differences between soil organic matter pools in the areas after the fire severely limit their continued agriculture use [1]. Fires

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are limited by peat soil retention and depth of fire depends on the presence of incombustible inorganic substrate [12]. Burning or combustion is instantaneous physical decomposition process that not only mobilizes nutrients but also the remaining organic matter [23].

The research has aimed to determine the impact of fire on pools of soil organic matter and water retention in pyrogenic soil in meadow and forest areas. Additionally, the importance of soil structure to pyrogenic soils retention and STC has been determined.

MATERIALS AND METHODS

Soil samples have been collected from post-fire forest areas of Chocianów Forest Division, Gromadka Facility (GR), Wołów Division, Mikorzyce – Górowo Facility (MG) and meadow objects Lubsko (LU) and Sobin – Jędrzychów (SJ). Forest fires occurred in 1986 and 1992. Meadow fires happened in 2006 and 2008. The research has been conducted with 19 soil profiles using 81 soil samples in total. Forest soil samples were collected from profiles No 9–11 (MG) (12 years after the fire) and profiles No 1–8 (GR) - 21 years after the fire. Meadow soil samples were collected from profiles No 12–16 (immediately after the fire) and profiles No 17–19 (SJ) - 2 years after the fire. During field research no soil unaffected by the fire has been found for the tests. Soil samples have been represented by: moorsh, peat-moorsh, mineral-moorsh and peat ones. The soil horizons displayed strongly dried peat-moorsh soil and medium deep (MtIIc1 and MtIIIc1), mineral moorsh (Me11) and the moorsh soil [18]. Peat from the after-fire areas has been mainly characterized by high decomposition of organic matter [4, 5]. Soil cores were collected from each of the study areas using an Instorfu auger of 6.0 cm in diameter [14]. The colour of soil horizons has been determined according to Munsell Soil Color Charts. Soil cores were taken to underlying mineral substrate. Cores were sectioned to sub samples at intervals at major stratigraphic brakes. Sub samples were subsequently packed into plastic bags and taken to the laboratory for testing purposes. The ash (AS) was estimated by combusting the material in a muffle furnace at 550^0C for 6 hour, unrubbed (A) and rubbed (B) fibber volume of organic samples by half-syringe methods [14, 20], bulk density (Bd) and water properties were analysed in 100 cm^3 stainless Kopecky metal rings. Bulk density was measured in undisturbed samples by the volumetric method [3]. Specific density (*Sd*) was calculated by the equation [18]:

$$Sd = 0{,}011AS + 1.451 \tag{1}$$

where: 1.451- specific density of humus, *AS* - ash.

Total porosity (*Tp*) was calculated according to the equation:

$$Tp = (Sd - Bd)\, Sd^{-1}\, 100\ (\%) \tag{2}$$

Soil water retention (SWR) was determined using sandbox analyzer [25] (in pF range 0–2.7) and high-pressure (in pF range 3.2–4.2) chambers [28], potential useful water retention (PRU) (W_{vol}. at pF2.0-W_{vol}. at pF4.2), effective useful water retention (ERU) (W_{vol}. pF2.0-W_{vol}. at pF2.7). Soil total carbon content was estimated with Bushi analyzer. Pools of carbon and water were calculated at the depth of 0–20 cm using equation:

$$C\ (\text{kg m}^{-2}) = a\ (\text{g kg}^{-1}) \cdot b\ (\text{g cm}^{-3}) \cdot c\ (\text{mm})/100 \quad (3)$$

where: a – carbon content, b – bulk density, c – depth; and

$$SWR\ (\text{mm}) = d\ (\text{mm}) \cdot \text{e}\ (\%_{\text{volume}}) \quad (4)$$

where: SWR – soil water retention, d – depth, e – moisture.

Differences between pools of carbon and water retention in soils were described by: x – arithmetic means, SD – standard deviation, dx – difference of arithmetic means. Statistical analyses have been made using Statistica 8.0.

RESULTS AND DISCUSSION

High temperature in the deep fires has lead to a significant reduction in carbon content [7] often by 75 to 90 % of the content before the fire. In the ash horizons carbon content decreased in comparison to non-burned horizons. In some soil horizons affected by the fire, from 4 to 6 times less (STC) has been displayed than in the deeper horizons (Table 1). The carbon content in forest soils is lower on the surface than in the subsurface layers. Similar results have been noted in other Polish forest soil fires [13]. This difference concerned the ash horizons in forest soils. In soil horizons we can observe different soil colour spectrum between N, 10YR and 5YR. Peat horizons are usually characterized by fibre or amorphous-fibre structure. Moorsh horizons with ashes and ash horizons are described as angular, sub-angular or sharply edged structure. The lowest carbon content is found in strongly decomposed moody horizons. The highest STC is displayed in single soil horizon of low peat; it exceeded 500 g kg^{-1} of soil. It is a consequence of fire in low temperature (Table 1). Generally the pools of soil water retention (SWR) and organic carbon (STC) strongly differ after the fire (Figs. 1, 2). We find differences between (STC) pools and soil water retention pools (SWR) in the meadow and forest soil (Figs. 1, 2). Losses of organic matter can occur at relatively low temperatures 150–350^{0}C [15]. The increase of organic matter content in pyrogenic soils has been noted in Siberian Pentlands by [11]. Analysis of the organic horizons in Siberian Pentlands Has indicated that the increase of carbon content is related to the low intensity of the fire and depth. After carbonization of the peat, the next processes are secondary dehydration, condensation and predominantly decarboxylation [9, 10]. Given the analysis of fibber content according to the [20] majority of the organic matter, it is normally described as sapric or hemic. Fibber content after rubbing consists of fragments of wood, charcoal and sharply edged aggregates as a result of increased soil temperature. These results are similar to other studies [26]. The organic horizons due to their smouldering and sand inclusion are attributed with the high ashes and strongly moody. It also shows high values of specific and bulk density (Table 1). Burning and smouldering of organic horizons results in a significant reduction of field water capacity (PPW) at pF2.0. The value of this parameter in ashes surface horizons is often found about 50 % lower than the peat horizons (Table 1). Fire significantly reduces the amount of water available to plants and it is expressed in terms of the ratio of potential useful water retention (PRU) pF2.0–4.2. In the ash horizons the quantity of water available for plants is lower than 20 % of soil volume. The amount of effective useful water retention (ERU) pF2.0–2.7 in ash horizons (As) is low and does not exceed 6 % of that soil volume. Decrease in retention capacity of soil is displayed by many profiles; especially those which are affected by intensive surface fire and in the soils which consist of mineral horizons with ash. Low retention in pyrogenic soils is caused mainly by the high volume of soil macro pores in the horizons with ash and presence of sharply edged structure. The changes in soil horizons of soil structure after the fire led to changes in soil compaction. This phenomenon confirms the correlation coefficient between bulk density (Bd) and STC ($r=-0.77^{**}$, $p<0.01$, $n=70$) (Table 2). Pools of carbon (STC) in the chosen post-fire facilities of the Lower Silesia are positively correlated with pools of water retention of soil (SWR), ($r=0.46^{**}$, $p<0.05$, $n=19$). This regards the surface layers with a depth of 0–20 cm (Table 3). Soil moisture measured at pF2.0 is strongly correlated with (PRU) ($r=0.82^{**}$, $p<0.01$, $n=70$) and (ERU) ($r=0.63^{**}$, $p<0.01$, $n=70$). These changes of soil water retention (SWR) in burned or smouldered horizons are also confirmed by other authors [6]. Lower water retention pyrogenic soils in Moscow region are also referred to [27].

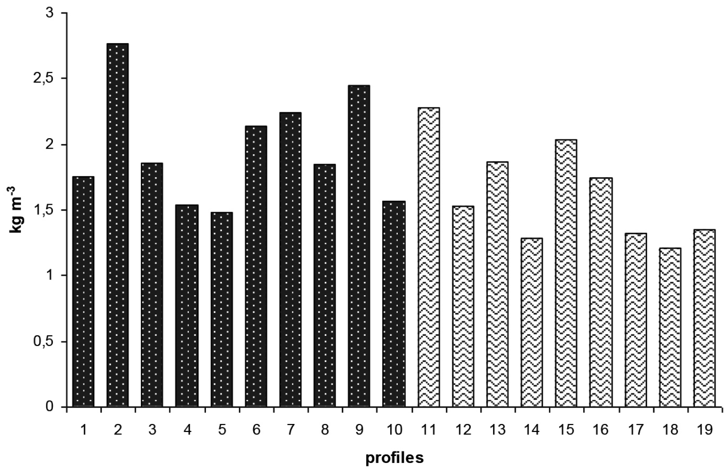

Fig. 1. Pools of organic carbon in 0–20 cm pyrogenic soil layers.
Explanation: ▩ - forest, ▨ - meadow.

TABLE 1. PROPERTIES OF PYROGENIC SOILS UNDER FORESTRY AND MEADOWS

Soil horiozn	Depth of horizon (cm)	r_w	r_o	Pc (%)	Soil color	pF2.0	PRU pF2.0–4.2	ERU pF2.0–2.7	Ash content (%) d.m.	STC (g kg^{-1})	Volume of fiber A	Volume of fiber B	Kind of soil material [22]
		(g cm^{-3})				(%) vol. of soil					A	B	
Forest pyrogenic soils													
Olfh	2–7* 4**	1.55–2.24 1.80	0.16–0.86 0.41	98.7–61.6 77.2	10YR 3/4**** N 3/0	60.6	22.7	15.3	9.11–72.2 31.8	139–475 333	53–44 49	4–33 21	fibric to sapric
As	4–34 11	2.29–2.38 2.34	0.51–0.64 0.58	73.1–77.7 75.0	N 3/0 5YR 5/5	66.3	–	–	76.4–84.5 80.6	72–127 102	–	–	–
Mt	5–17 9	1.48–1.84 1.63	0.15–0.43 0.24	72.9–90.7 85.2	N 2/0 5YR 2/1	44.5–70.5 58.7	33.0–56.6 41.5	5.1–12.6 8.8	3.35–35.4 16.8	349–497 428	67–36 48	1–39 20	fibric to sapric
Otni	5–30 13	1.48–2.33 1.77	0.16–0.65 0.29	72.1–89.6 83.4	10YR 2/1 10YR 5/3	64.0–78.1 72.3	30.5–62.4 47.1	4.5–15.3 9.6	3.14–79.8 28.7	189–519 375	16–66 39	2–40 14	fibric to sapric
Otpr	13–20 18	1.58–1.83 1.69	0.18–0.26 0.22	84.6–88.6 86.4	10YR 2/1 5YR 3/1	63.6–78.1 70.5	38.8–62.4 52.6	4.9–7.4 6.6	12.9–34.6 22.1	225–415 350	50–68 56	18–32 21	fibric to hemic
O/D	8–15 13	2.13–2.45 2.25	0.75–1.06 0.90	56.7–64.8 60.7	10YR 2/1 10YR 3/1	48.5–53.8 52.2	29.5–38.1 34.2	5.7–11.1 8.8	62.2–90.6 73.2	55.5–171 123.1	–	–	–

TABLE 1. CONTINUATION

Meadow pyrogenic soils													
As	4–15 9	2.31–2.81 2.43	0.43–0.77 0.61	70.2–81.9 74.9	5YR 3/2 N 2/0	14.1–38.6 26.5	7.0–29.7 18.5	2.4–5.6 4.0	78.6–97.2 85.6	25.5–112 62.4	–	–	–
Mt	5–11 9	1.69–1.98 1.87	0.31–0.38 0.34	79.6–83.5 81.4	10YR 2/1 7.5YR 4/4	44.4–60.5 53.5	14.6–40.2 31.5	5.2–8.4 6.3	21.7–47.8 38.4	253–375 288	54–75 61	14–34 22	hemic to sapric
Otni	1–30 15	1.78–2.30 2.07	0.15–0.75 0.56	62.5–91.6 73.2	5YR 2/1 7.5YR 3/3	43.3–64.1 55.0	13.7–40.9 28.5	3.8–7.2 6.5	30.3–77.1 56.7	154–389 248	34–97 56	12–31 18	hemic to sapric
O/D	10***	2.43	0.74	69.4	7.5YR 4/3	60.4	44.8	5.0	88.7	75.9	–	–	–

Explanation: Pc – total porosity, ρ_w – specyfic gravity, ρ_o – bulk density, v – not detected, PRU – potencial useful retention, ERU – effective useful retention, A – unrubbed fiber, B – rubbed fiber, * – range (min –max), ** – arithmetic means, *** – single results, **** – soil color range.

TABLE 2. RESULTS OF CORRELATIONS BETWEEN SOIL PHYSICAL AND SOIL WATER PROPERTIES IN PYROGENIC ORGANIC SOILS

Value	A	B	STC	W_{vol}. pF2.0	PRU	ERU
B	0.44*					
(STC)	0.06	0.19				
W_{vol}. pF2.0	-0.19	0.08	0.03			
PRU	-0.19	-0.03	-0.06	0.82**		
ERU	-0.25	0.02	0.11	0.63**	0.62	
Bd	0.29	-0.13	-0.77**	-0.02	0.18	0.03

Explanation: * - significant at p=0.05, ** - significant at p=0.01.

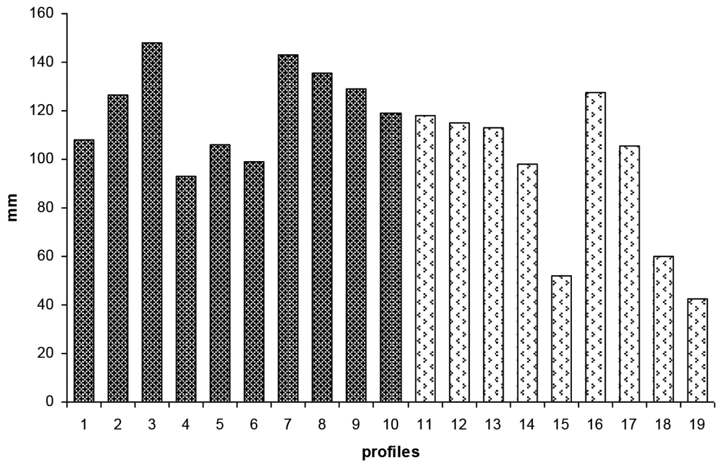

Fig. 2. Pools of water retention in 0–20 cm pyrogenic soil layers.
Explanation: -forest, - meadow.

TABLE 3. POOLS OF ORGANIC CARBON AND WATER RETENTION IN POST FIRE SOILS UNDER MEADOW AND FOREST

n=19	Type of use	x	SD	dx
Water retention pools in 0–20 cm	forestry	120.4	17.8	31.3
	meadow	89.1	32.6	
Organic carbon pools in 0–20 cm	forestry	1.95	0.36	0.33
	meadow	1.62	0.38	

Explanation: x-arithmetic means, SD-standard deviation, dx-difference of arithmetic means, n-number of samples.

CONCLUSIONS

1. Fire in organic horizons influenced pools of soil total carbon (C), soil water retention (SWR) and differentiation.

2. Peatlands fire drastically differentiated water retention in pyrogenic horizons, especially in upper ash or peat ash meadow soils horizons with angular sharply edged structure.

3. Pyrogenic forest soils had bigger pools of organic carbon and water retention than meadows soils in post fire areas.

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WPŁYW POŻARU NA ZASOBY WĘGLA I RETENCJĘ WODNĄ ŁĄKOWYCH I LEŚNYCH GLEB POPOŻAROWYCH

Celem badań było określenie wpływu pożaru na zasoby materii organicznej i retencję wodną w glebach popożarowych na obszarach łąkowych i leśnych. Próbki glebowe prezentują gleby torfowo-murszowe, murszowe, mineralno-murszowe i torfowe. Poziomy glebowe przedstawiają silnie przesuszone gleby torfowo murszowe, średnio głębokie (MtIIc1, MtIIIc1) i mineralno-murszowe (Me11) i murszowe. W poziomach glebowych określono barwę, stopień rozkładu materii

organicznej próbek, gęstość właściwą, gęstość objętościową, retencję wodna analizowano w próbkach o nienaruszonej strukturze metodą objętościową. Retencję wodną gleb charakteryzowano przez pF2,0, którą oznaczono przy użyciu bloku piaskowego. Zawartość węgla organicznego badano analizatorem Bushi. Niską zawartość węgla obserwowano w poziomach wysoko popielnych. Można było zaobserwować różnorodne spectrum wartości barwy gleby pomiędzy N, 10YR i 5YR będące konsekwencją różnych temperatur pożaru. Ogólnie zmniejszyła się po pożarze retencyjność wodna gleb. Widoczne było zróżnicowanie pomiędzy zasobami (SOM) i retencją wodną na glebach łąkowych i leśnych. Retencja wodna gleb popożarowych drastycznie zmalała w glebach organiczno-mineralnych z angularną, ostrokrawędzistą, koksikową strukturą i poziomach popiołowych i popiołowych z torfem.