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THE EFFECT OF LONG-TERM PEATLANDS DRAINAGE ON THE PROPERTIES OF SOILS IN MICRORELIEF IN THE DŁUGIE MOKRADŁO BOG (CENTRAL SUDETES – SW POLAND)

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Abstract. The aim of the study was to assess the impact of long-term drainage on the morphology and selected properties of shallow peatland soils in microrelief. The study was conducted within strongly drained peatland (Długie Mokradło bog) located on elevated plateau in the Central Sudetes. The study area is covered by spruce stands introduced by man. Long-term drainage has changed morphology of study soils which were classified as Ombric Fibric Dystric Histosols or Histic Dystric Gleysols. Some peat horizons were strongly silted. The depth of organic materials varied within the range of 30–55 cm. Peat humification process showed greater activity in surface horizons than in deeper ones. This phenomenon was especially visible in the shallow places in drainage ditches. Soil reaction was strongly acidic. In soil horizons, in old drainage ditches, high-

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er values of effective cation exchange capacity (CECe) were recorded, whereas base saturation (BS) did not exceed 20%.

Keywords: peat soil, mountain peatland, Sudetes, old ditches, peat cores morphology

INTRODUCTION

Drying of peatlands located on many plateau areas in the Stołowe Mountains at the turn of the 19th and 20th centuries led to the changes of landscape morphology in the macro- as well as in the microrelief (Migoń *et al.* 2011). Drained peatland is a labile ecosystem closely linked to groundwater levels and to changing vegetation structure (Hokka *et al.* 2008, Sarkkola *et al.* 2010). Processes occurring within drainage peatlands such as subsidence, reducing the depth of peat, its mineralization were affected by condition and functioning of drainage ditches (Laiho 2008). Among ditch trenching factors there are also: organic matter slime (Sallantaus 1988, Prevost *et al.* 1999) and periodic bank ditch washing by retaining water (Rantonen and Paivanen 1999) – in the steep area the collapse of ditch walls is often observed, furthermore it might be also the consequences of peat freezing and erosion (Berry and Jeglum 1991). Water takes part of the soil from the walls and bottom of the ditches. The shallow organic soils are especially exposed to erosive drainage. Because of vegetation, shallow drainage ditches are exposed to quick overgrowing (Minayeva *et al.* 2009, Marttila and Klove 2010). The blocking of water flow in channels by sediments, and various groups of plants (e.g. mosses, sedges, grasses) intensified this process (Varry 1988). Soil material accumulated in lower ground forms is usually enriched in macronutrients in comparison to material occurring between ditches (Pietilainen and Rekolainen 1991, Joensuu *et al.* 1999).

The aim of the work was to assess the current structure and properties of soils within the strongly drained area, after more than 100 years of implementation of land melioration. In this study the comparison of soils in drainage ditches and the area between them (mounds) were done.

MATERIALS AND METHODS

The study was carried out on the Długie Mokradło bog located in the Skalniak plateau. Study peatland is covered by *Calamagrostio villosae-Piceetum* (L.) and sphagnum subgroup *Calamagrostio villosae-Piceetum sphagnetosum* (L.) class (Glina 2014). Within the study area two sampling sites were established. Sampling site 1 (16°17'28.1"E, 50°28'28.7"N) included a fragment of a 20-year-old spruce monoculture, whereas sampling site 2 (16°17'43.8"E, 50°28'25.1"N) – the fragment of 70–90-year-old spruce stands. The peatland surfaces were "cut" witch a shallow drainage system of 2 m × 2 m spacing. This type of drainage system was rarely used in the past in peatlands without trees in Norway (Braekke 1978). The drainage was generally made to a depth of 50 cm or – in some cases – to mineral bedrock. The total length of ditches in the Stołowe Mountains National Park is ca. 250 km (Ciężkowski and Kiełczawa 2008). The drainage ditches system and the location of the peat cores within the study area is visible in the LIDAR photo (Fig.1) (geoportal.gov.pl).

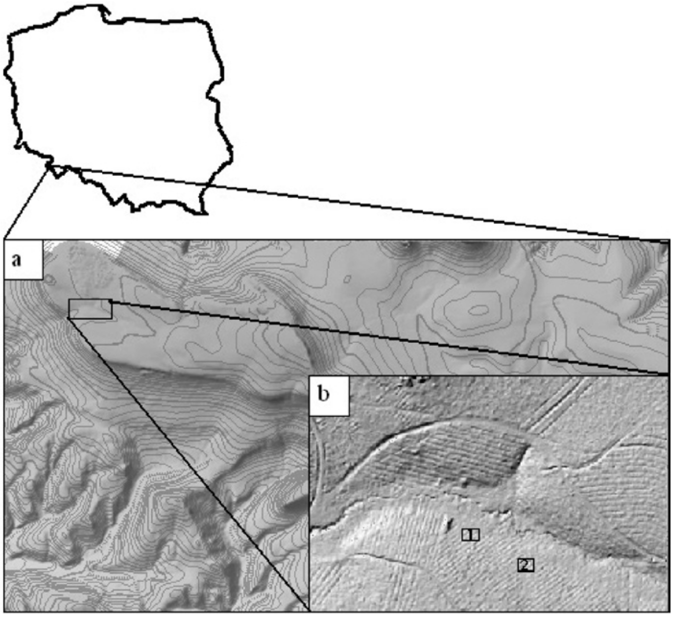

Fig. 1. Location of Stołowe Mountains a – Długie Mokradło bog, b – location of sampling sites; 1, 2 – number of fields

Peatland under study is supplied with water primarily by atmospheric deposition (ombrogenic type) and partially (the edge parts) by local stream Czermnica (fluviogenic type) (Jermaczek *et al.* 2012). In each sampling sites, five peat cores were retrieved and described. Half of them represented soils from old drainage ditches, nowadays overgrown by plants and filled with peat. The rest of cores were collected from the mounds between ditches (Fig. 2). Soil material for laboratory analysis was sampled by genetic soil horizons, packed into the plastic bags and transported to laboratory. In total, 48 soil samples (40 organic and 8 mineral) were collected. In fresh (moist) materials, following properties were determined: peat decomposition rate using SPEC method (Lynn *et al.* 1974), degree of secondary peat transformation by coefficient W_1 index by Gawlik (2000), pH in water and 1mol·dm^{-3} KCl (ratio 1:2.5). Whereas in the dry material ash content after placing dried samples for 5h in a muffle furnace (Bojko and Kabala 2014), the hydrophobic potential using MED method (Doerr 1998), content of acid cations

(H^+, Al^{3+}) extracted with 1mol·dm^{-3} HCl using titration methods, the content of exchangeable base cations (S) (Ca^{+2}, Mg^{+2}, K^+, Na^+) extracted with 1mol·dm^{-3} CH_3COONH_4 at pH 7.0 using AAS analyzer (Van Reeuwijk 2002) were determined. The effective cation exchange capacity (CECe) and base saturation (BS) were calculated. The more detailed characterization of the peat soils from the Długie Mokradło bog was reported by Glina *et al*. (2016, 2017).

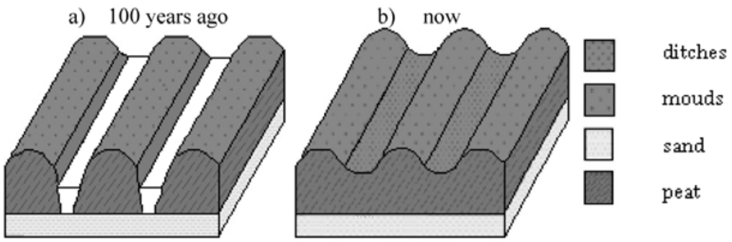

Fig. 2. Microrelief of the sampling sites

RESULTS AND DISCUSSION

Morphology of soil profile

Study soil consisted of hemic and fibric material in particular. The layers of sapric peat material were observed directly over sandy bedrock or near the soil surface in a sampling site 1 (Fig. 3 and Fig. 4). Thickness of organic materials did not exceed 50 cm. Soils formed the ditches which were often less different from the neighboring soils, showing generally moderate to low degree of peat decomposition. Soil materials of higher degree of decomposition were accumulated generally in ditches. It is the result of moisture conditions changes caused by surface run off (Chambers 1983). In deeper soil horizons, higher contribution of sand material was recorded than in upper horizons (Table 1). This situation might be the result of drainage ditches installation, which bottom reached the mineral materials (Joensuu *et al.* 2002).

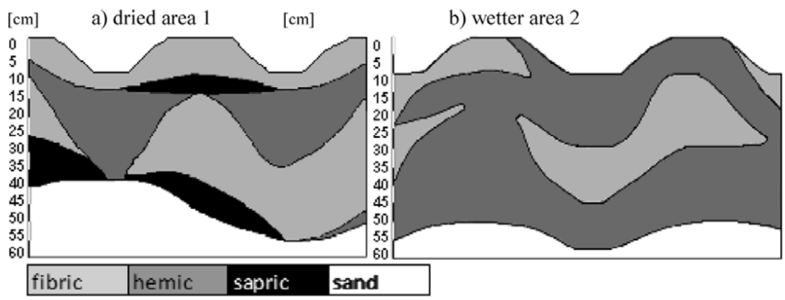

Fig. 3 and 4. Morphology of organic soils profiles in old drainage areas (current state)

Sand admixture in the surface horizons can also be associated with deforestation of adjacent areas, leading to increased erosion (Jermaczek *et al.* 2012). Plowing shallow ditches and furrow deposition also contributed to the movement of soil material, creating numerous horizons of low density (Table 1, Fig. 1 and Fig. 4). Earlier studies conducted by Bogacz and Roszkowicz (2010) in the Krągłe Mokradło bog showed the occurrence of thick (several centimeters) sandy layers in the organic soils. It was most probably related to the changes in the morphology of the drained areas (Ingram 1992) or the different speed of transportation and deposition of mineral and organic materials in ditches (Van Rijn 1987). The plant material that builds the organic levels of the soils of two research surfaces 1 and 2 were mainly the remains of plants of the genera: *Sphagnum* (L.) and *Eriophorum* (L.). Sometimes these materials also included remains of wood and bark fragments. The remains of *Polytrichium sp.* (L.) were also found (Glina *et al.* 2017).

Physical properties of soil

More than half of the organic samples in the drainage areas are not silted according to Okruszko (1993), containing less than 25% of the mineral material in dry mass of sample. Low ash content is determined by the dominance of moss vegetation (Pakarinen and Gorham 1984) and type of water supply of soil, mainly by precipitation. On the analyzed areas, there was observed tendency to increase the ash content with depth in the profile ($r=0.45^*$, $n=48$, $p<0.05$) (Table 3). The highest values of particle density above 2.00 $g \cdot cm^{-3}$ were calculated for peat with sand materials admixture and strong degree of organic matter decomposition (Table 1). This data are converging with the research provided by Wang *et. al.* (2016) on mountain organic soils with both underlying and interbedded mineral material. However, recorded values of particle density slightly exceeded 1.50 $g \cdot cm^{-3}$. Bulk density is strongly associated with ash content, peat botanical composition degree of peat decomposition and drying (Nichols and Boelter 1984). In study soils, bulk density varied within a narrow range from 0.10 to 0.40 $g \cdot cm^{-3}$ (Table 1). The total porosity (Pc) of organic horizon varied widely in the profile and ranged from 82.5 to 93.1% of soil volume. The molarities ethanol droplet test (MED) revealed strong to extreme hydrophobicity of organic horizons. The litter horizons (Ol) and slightly decomposed peat (Oi) were generally stronger water repellent than others. More hydrophobic properties represented organic horizons in profiles (1–5) from mounds rather than (6–10) from ditches (Table 1). Research conducted by Łachacz *et al*. (2009) on numerous samples of the post boggy soils in the north-eastern part of Poland indicated the dependences between the values of the MED test, type of peat, content of organic matter and, above all, the stapes of its decomposition. There were different stages of secondary transformation (index W_1) of organic matter in the studied drained area (Table 1). The values of W_1 index ranged from 0.26

TABLE 1. PHYSICAL PROPERTIES OF SOIL

Profile										
N°	Soil horizon	Depth (cm)	Ash content (%)	ρ_w (g·cm^{-3})	ρ_o (g·cm^{-3})	Pc (%)	RF (%)	PI	MED (%)	W_1
mounds 1–5	Ol	4–9	4.81–8.67	1.50–1.55	0.11–0.13	91.9–92.7	50–66	5	24–36	0.66–0.71
		6	6.34	1.52	0.12	92.4	57	5.0	32	0.68
	Oi	7–26	3.57–32.3	1.50–1.80	0.11–0.22	82.5–93.1	52–78	3–6	24–36	0.26–0.59
		13	10.2	1.55	0.13	91.8	63	5.0	26	0.41
	Oe	4–15	2.51–48.4	1.50–1.98	0.10–0.28	82.5–93.1	18–40	0–6	24–36	0.39–0.55
		9	19.2	1.66	0.16	89.3	29	3.4	25	0.44
	Oa	5–15	22.4–77.8	1.70–2.31	0.18–0.40	82.6–89.3	7–16	1–3	24–26	0.36–0.61
		10	52.6	2.03	0.30	85.5	12	2.0	25	0.46
ditches 6–10	Ol	3–4	6.76–10.9	1.50–1.53	0.11–0.12	92.2–92.7	53–64	5–6	24–36	0.67–0.79
		3	8.83	1.52	0.11	92.4	59	5.5	30	0.73
	Oi	4–23	4.68–23.4	1.50–1.70	0.11–0.18	89.4–92.7	44–87	5–7	13–36	0.41–0.89
		14	11.8	1.59	0.14	91.3	55	6.0	24	0.56
	Oe	5–17	7.4–69.9	1.53–2.19	0.12–0.37	83.3–92.3	26–40	2–6	24–36	0.31–0.69
		10	24.7	1.72	0.20	89.5	35	4.1	27	0.47

TABLE 2. PHYSICOCHEMICAL PROPERTIES OF SOIL

Nº	Soil horizon	pH H_2O	H^++Al^{+3}	Ca^{+2}	Mg^{+2}	K^+	Na^+	S	CECe	BS
			Profile (cmol(+) kg^{-1})							(%)
	Ol	3.9–4.4	12.8–16.0	0.96–1.20	1.14–1.27	0.37–0.80	0.16–0.20	2.90–3.30	15.7–19.3	17.0–18.5
		4.1	14.4	1.09	1.20	0.59	0.18	3.07	17.5	17.6
mounds	Oi	3.2–4.0	23.2–29.6	0.87–2.0	0.25–1.16	0.09–0.40	0.06–0.25	1.60–3.40	24.8–31.8	6.4–13.0
		3.7	25.6	1.41	0.69	0.16	0.17	2.43	28.1	8.7
	Oe	3.3–4.5	11.6–28.0	0.95–5.74	0.10–1.41	0.09–0.50	0.04–0.22	1.59–7.70	13.3–30.8	6.6–26.2
1–5		3.8	22.6	2.50	0.79	0.23	0.15	6.93	23.6	14.6
	Oa	3.3–3.4	8.0–23.2	0.80–1.20	0.52–0.69	0.07–0.22	0.12–0.17	1.70–2.10	9.70–25.1	7.4–17.3
		3.3	17.1	0.99	0.61	0.12	0.15	1.90	19.0	11.4
	Ol	4.5–4.7	12.0–24.0	1.20–1.60	0.91–1.24	0.60–0.70	0.20	2.90–3.70	15.7–26.9	10.8–23.8
ditches		4.6	18.0	1.40	1.08	0.65	0.20	3.30	21.3	17.3
	Oi	3.6–4.4	24.8–32.2	0.79–3.99	0.16–1.13	0.05–0.45	0.14–0.65	1.44–5.40	30.2–35.8	6.5–17.9
		4.1	29.8	2.15	0.50	0.32	0.30	3.28	33.0	10.6
6–10	Oe	3.1–4.5	13.6–40.0	0.95–3.83	0.16–1.06	0.07–0.35	0.06–0.21	1.32–4.50	15.8–38.8	6.8–14.1
		3.8	27.4	1.69	0.50	0.19	0.16	2.54	28.7	8.9

in fibric peat horizons to 0.89 in the fibric material enriched with sand. The initially and weakly transformed peat is dominant on the elevated areas (mounds), while former drainage ditches were filed with strongly secondary transformed peat (Fig. 4). W_1 index indicated a much lower degree of transformation of the soil from drained forestry area of the Sudetes than the organic soils of other drainage areas in the 1950–1960s (Matyka-Sarzyńska and Sokołowska 2005, Kalisz *et al.* 2015). The above statements were also confirmed by Glina *et al.* (2016).

The strongly acidic reaction of all soil horizons, as well as their high values of exchangeable acidity (H^{+}+Al^{+3}), were favored high effective exchange cation capacity (CECe) and low values of base saturation (BS) (r=0.41*, n=40, $p<0.05$). In wet parts such as ditches, slightly higher pH values were observed rather than in soils from mounds. Drainage of peat soils intensified the process of soil acidification especially in areas between the ditches (Minkinen and Laine 1996). Peat aeration changed the microbe activation and degree of peat decomposition (Clymo 1983). Low value of soil pH was associated with a lower degree of organic matter hummification, expressed by the index (PI) (r=0.53*, n=40, $p<0.05$). There was an increase of the trophy status of soils in ditches, when compared to the soils formed on the mound. Mean values of the (CECe) and (S) were slightly higher in soil from the ditches than in the mounds (Table 2). This is probably due to the concentration of solid materials in the ditches (Joensuu *et al.* 1999) and, additionally, the effect of mineral bedrock in case of shallow organic horizons (Nieminen *et al.* 2010). Values of CECe were negatively correlated with the degree of peat transformation and ash content (Table 3). The base saturation (BS) is low in all tested soils and the value of this factor for individual horizons in general did not exceed 20%. Proportion of base cations (S) was the highest in litter and other more hydrophobic (MED) (r=0.38*, n=40, $p<0.05$) and stronger transformed W_1 (r=0.43* n=40 $p<0.05$) (Table 3) horizons.

TABLE 3. CORRELATION COEFFICIENT BETWEEN SELECTED PROPERTIES OF ORGANIC HORIZONS

Value	pH	W_1	PI	MED	Ash	RF	CECe	BS
Depth	-0.06	-0.19	0.12	0.25	0.45*	-0.09	-0.13	-0.02
pH		0.38*	0.53*	0.12	-0.34*	0.23	-0.06	0.41*
W_1			0.17	-0.02	0.11	0.18	-0.34*	0.43*
PI				0.25	-0.37*	0.64*	0.05	0.25
MED					-0.17	0.33	-0.18	0.38*
Ash						-0.53*	-0.55*	0.00
RF							0.04	0.06
CECe								-0.44*

Correlation ratio at: * $p<0.05$, $p<0.01$, n=40

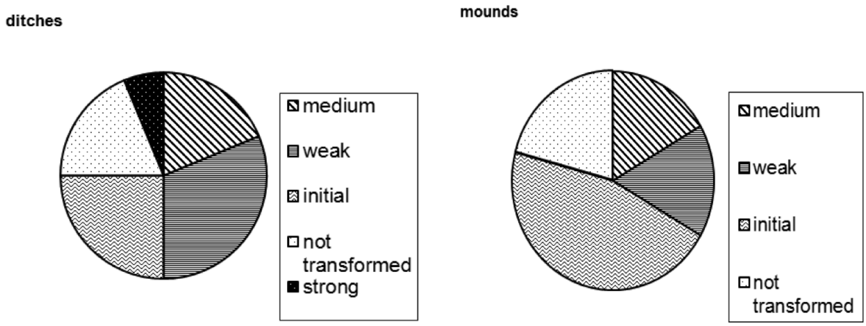

Fig. 5. State of secondary transformation of the organic soils horizons
a) ditches and b) mounds

CONCLUSIONS

1. The old drainage system has changed the soil morphology and increased the diversity of soil horizons, especially on a drier area.
2. Peatland forestry has transformed organic horizons more in drainage ditches than in parts called mounds.
3. The development of several centimeters of litter *folic* horizons may indicate the inhibition of peat forming process in the dry part of peatland.
4. Shallow Histosols and Histic Gleysols showed a greater trophy status in soil horizons from old drainage ditches than in the mounds.

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