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Current state of peatland soils as an effect of long-term drainage – preliminary results of peatland ecosystems investigation in the Grójecka Valley (central Poland)

Abstract: Understanding the effect of long-term drainage of peatland areas is helpful in future peatland management and regulations of water conditions. The aim of this work was to assess the current state of fen peatland soils in the Grójecka Valley (eastern part of the Wielkopolskie voivodeship, central Poland), affected by long-term agricultural use (pastures, meadows) since the 1960s and potentially by lignite open pit mining industry (KWB Konin) since 1980s. Field studies were carried out in 2015 in selected fen peatland areas. Soil material for laboratory analysis was collected from genetic horizons from four soil profiles. The surface horizons of studied organic and organo-mineral soils were built with well-developed moorsh material. They were classified as medium moorshiefied – MtII (profile 1, 3 and 4) and strongly moorshiefied – MtIII (profile 2). Obtained results of physical and physico-chemical analysis indicate that long-term peatland utilization connected with potential impact of the lignite mining, transformed mainly the upper horizons of studied organic and organo-mineral soils. However, despite obvious strong human impact on peatlands ecosystems, we cannot exclude the climate variables, what should be confirmed by long-term monitoring program. Furthermore, presented paper indicated that new subtype moorsh-muddy soils (in Polish: gleby murszowo-mułowe) within the type of gleyic soils should be implemented in the next version of Polish Soil Classification.

Keywords: soil transformation, fen peatlands, organic soils, dehydration, agricultural use

INTRODUCTION

Environmental conditions, especially hydrological conditions, play essential role in peatland functioning (Strack et al. 2008). In most cases the disturbances in water conditions of peatlands are the effect of strong human impact such as drainage for agricultural use (Limpens et al. 2008). Many peatlands, particularly after the Second World War, had been drained and converted to managed agro-ecosystems (Joosten and Couwenberg 2001), what caused harmful changes in peatlands hydrology (Ferrati et al. 2005). In Poland, the amelioration projects of river valleys, also including peatland areas, reached the highest intensity in the 1960s–1970s (Niewiarowski and Kot 2011), what is documented also in the case of Wielkopolskie voivodeship (Rząsa 1963). Changes of the groundwater table may also be caused by open pit lignite mining (Komisarek et al. 2011, Uzarowicz et al. 2014). Intensive dewatering lowers the hydrostatic pressure of usually confined aquifers, what causes disturbances in water management of areas in close vicinity of a mine (Jambrik and Bartha 2006). Lowering of water table accelerates the secondary transformation process of organic soils (Gawlik 2000), connected with mineralization of organic matter (Sokołowska et al. 2005), typical of moorsh-forming process occuring in topsoil horizons (Markiewicz et al. 2015, Łabaz and Kabała 2016). Noticeable changes are particularly observed in peat structure (Holden et al. 2004) and organic matter transformation for instance dissolved organic carbon (DOC) production (Strack et al. 2008).

The aim of this study was to assess the current state of fen peatland soils in the Grójecka Valley, where aggravation of local hydrological conditions was the result of agricultural use (pastures, meadows) since the 1960s (Mocek and Owczarzak 2003) and potentially of lignite open pit mining industry (KWB Konin) since 1980s (Owczarzak et al. 2003). Understanding the effects of long-term drainage of peatland areas will be helpful in the future management and regulations of water conditions. Additionally, a problems of organo-mineral soil classification, built of organic (moorsh) and organo-mineral (mud) materials was discussed and some propositions were given to improve the next edition of the Polish Soil Classification (PSC 2011).

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MATERIALS AND METHODS

Grójecka Valley is located in the eastern part of the Wielkopolskie voivodeship, central Poland (Gajewski et al. 2015). This area is mostly formed of the Riss-grey till covered by sandy sediments (Mocek et al. 2000). This kind of mineral bedrock created favorable conditions for peatlands formation, which cover significant area of the Grójecka Valley (Gajewski 2005). In the sampling year 2015, the mean annual air temperature was 10.5°C, whereas the annual sum of precipitation was 435 mm. The area of the Grójecka Valley has the highest negative water balance in Poland (Owczarzak and Mocek 2004).

Soil survey and sampling were carried out in 2015 in the selected peatland areas located within the Grójecka Valley (Fig. 1). Soil material (peat, moorsh, mud) for laboratory analysis was collected from four soil profiles (in total 19 mean samples). Before the sampling procedure, soil morphology was described according to Guidelines for Soil Description (Jahn et al. 2006). The degree of peat decomposition was determined in the field, using the von Post method (1922). Undisturbed soil samples were collected to stainless steel rings (100 cm^3) for the bulk density determination. Before laboratory analysis each soil sample was divided into two parts. In fresh material the state of secondary transformation of soils was estimated by the water-holding capacity index W_1 (Gawlik 2000) and soil pH in distilled water, potentiometrically, at soil:solution ratio of 1:2.5 (v/v). The remaining parts of the soil samples were dried, mixed and plant remains were removed. The following properties, were determined in dry samples: ash content after placing dried samples for 5 h in a muffle furnace at 550°C as described by Heiri et al. (2001); total organic carbon (TOC) and total nitrogen (TN) on a VarioMax analyzer; content of calcium carbonate using a Scheibler volumetric method (Van Reeuwijk 1992). The concentration of hot water extractable carbon (HWC) was measured in soil extracts obtained by using the incubation method at 70°C for 18 h (Sparling et al. 1998). Cold water carbon (CWC) was determined in soil extracts obtained by shaking 10 g of soil samples with 10 ml of deionized water at 180 rev min^{-1} for 24 h and then centrifugation at 4000 rpm for 10 minutes (Landgraf et al. 2006). The HWC and CWC quantities in soil samples were measured using VarioMax analyzer, after the filtration via Whatman 0.45 μm membrane filters. Based on the morphological features and physico-chemical properties, soils were classified according to PSC (2011) and FAO-WRB (IUSS Working Group WRB 2015).

TABLE 1. Soil morphology, basic characteristic and soil classification

Soil horizon	Depth (cm)	Color (moist)	Structure	Soil moisture	$CaCO_3$	Horizon boundary
Profile 1 gleba organiczna saprowo-murszowa (PSC 2011), Eutric Murshic Sapric Histosol (WRB 2015)						
M1	0–18	10YR 3/2	GR	dry	+	G
M2	18–30	10YR 2/2	GR	slightly moist	+	G
M/Oa	30–43	10YR 3/2	GR/A	moist	+	G
Oa	43–73	10YR 2/1	A-F	moist	+	G
C	>73	10YR 6/4	SB	wet	+	–
Profile 2 gleba organiczna fibrowo-murszowa (PSC 2011), Eutric Drainic Hemic Fibric Histosol (WRB 2015)						
M1	0–20	10YR 3/1	GR	slightly moist	–	G
M2	20–35	10YR 3/2	GR	slightly moist	–	G
Oe	35–45	10YR 3/3	A-F	moist	–	C,W
Oi	45–70	10YR 3/4	F	wet	–	C,W
C	>70	10YR 6/3	SB	wet	–	–
Profile 3 gleba murszowo-glejowa (PSC 2011), Eutric Histic Gleysol (Drainic, Limnic) (WRB 2015)						
M1	0–15	10YR 2/2	GR	dry	+	G
M2	15–30	10YR 2/1	GR	slightly moist	+	G
Lc1	30–38	10YR 3/1	A	moist	+	C,W
Lc2	38–60	10YR 2/1	A	wet	+	C,W
Cg	>60	10YR 5/2	M	wet	+	–
Profile 4 gleba murszowo-glejowa (PSC 2011), Eutric Histic Gleysol (Drainic, Limnic) (WRB 2015)						
M1	0–15	10YR 2/3	GR	slightly moist	–	G
M2	15–25	10YR 3/1	GR	slightly moist	–	G
Lc1	25–47	10YR 4/1	A	moist	–	G
Lc2	47–70	10YR 4/2	A	wet	–	G
Lc3	70–110	10YR 3/2	A	wet	–	G
Lc4	110–130	10YR 5/1	A	very wet	–	–

Explanation. Structures: AB – subangular blocky, A – amorphous, GR – granular, F – fibrous, M – massive; Horizon boundaries: G – gradual, C – clear, W – wavy.

RESULTS AND DISCUSSION

Morphology and classification of the studied soils

Surface soil horizons in studied soil profiles were built with well-developed moorsh material, noticeable effect of the long-term peatland drainage. The thickness of the granular structured moorsh horizons varied from 25 cm (profile 4) to 35 cm (profile 2) (Table 1),

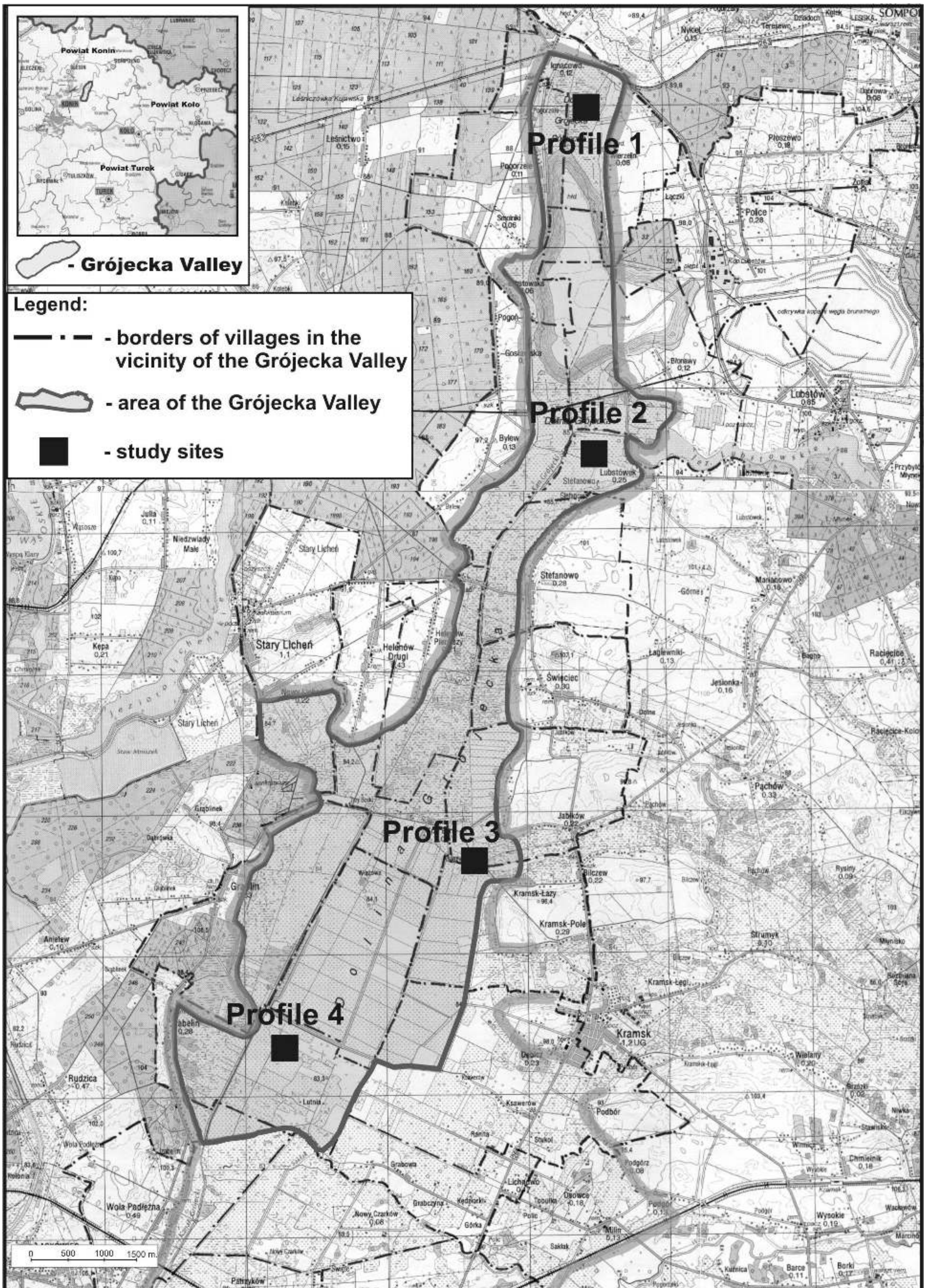

FIGURE 1. Location of the study sites within the Grójecka Valley

what allowed to classify these soils as medium moorshiefied – MtII (profile 1, 3 and 4) and strongly moorshiefied – MtIII (profile 2) according to classification proposed by Okruszko (1993). Fen peatland soils in the Grójecka Valley in accordance with FAO-WRB classification (IUSS Working Group, 2015) belonged to Histosols (Profile 1 and 2) and Histic Gleysols (Profile 3 and 4) reference groups, with addition of various principal and supplementary qualifiers (Table 1). According to the PSC (2011), profiles 1 and 2 were classified as sapric-moorsh organic soil (in Polish: gleba organiczna saprowo-murszowa) and fibric-moorsh organic soil (in Polish: gleba organiczna fibrowo-murszowa), respectively. Soil profiles 3 and 4 consisted of organic moorsh material over the telmatic mud (organo-mineral sediments of the Warta flooding) were problematic for classification according to PSC (2011). Due to low TOC content in the mud material (below 12%) mentioned soil profiles do not meet criteria for limnic-moorsh organic soils (in Polish: gleby organiczne limnowo-murszowe). In this situation, such heterogeneous soils had to be classified as moorsh-gleyic soils (in Polish: gleby murszowo-glejowe), what did not fully reflect the genesis of these soils. The peat material which was transformed into moorsh due to drainage was accumulated here on the telmatic mud – results of the Warta river flooding. In this case authors proposed to create a new soil subtype: moorsh-muddy soils (in Polish: gleby murszowo-mułowe) in which the mud material contains from 10 to 20% of soil organic matter. This is the next proposal to extend the type of gleyic soils with a new soil subtype. In previously published works by Kalisz and Łachacz (2008), Roj-Rojewski (2009), Roj-Rojewski and Walasek (2013) and Mendyk et al. (2015) muddy soils or muddy-gleyic soils subtypes were proposed for implementation to the next PSC update, what indicates that in many parts of Poland soils derived from organo-mineral alluvial muddy materials occurs.

Current state of organic matter transformations in the studied soils

The TOC content in studied soils was in the range of 19.6–431 g·kg^{-1} and the lowest was recorded in the telmatic mud layers (Lc1, Lc2 in profile 3 and Lc1–Lc4 in profile 4) with the highest admixture of mineral material – ash content >70% (Table 2 and 3). Similar situation was observed with content of TN. The highest amounts of TN were determined in the organic horizons (15.4–29.6 g·kg^{-1}), whereas the lowest amounts were recorded in the organo-mineral horizons (1.31–6.41). The calculated TOC/TN ratio (Table 3), which is an indicator of the mineralization of organic matter, showed that studied soils were subject to intensive mineralization process, as TOC/TN ratio was from 13.1 to 20.2. The lowest TOC/TN ratios (< 15) were observed primarily in moorsh topsoil horizons, what indicates that the most intense mineralization of organic matter occurred in the surficial soil layers. Narrow TOC/TN ratios (< 15) may indicate the low susceptibility of organic matter for further transformations (Bieniek et al. 2007) and intense mineralization process (Sokołowska et al. 2005).

The determined values of W_1 index in the organic horizons of investigated soils ranged from 0.43 to 0.92 (Table 2). The peat horizons in the profile 2 were assigned to initial class of secondary transformation. The highest state of secondary transformation (extreme and strong) was observed in the moorsh topsoil horizons in profiles 1, 2 and 4. Obtained values of W_1 index in agriculturally used fen peatland soils are similar to those reported for degraded peatlands in the Great Mazurian Lakeland (Kalisz et al. 2015) or in the Biebrza River valley (Gawlik and Harkot 2000, Sokołowska et al. 2005). Mentioned authors described the complete degradation or strong secondary transformation in the topsoil moorsh horizons of drained peatland soils, used as grasslands for a long time.

The hot water carbon (HWC) contents were in the range 0.50–3.11 g·kg^{-1} (Table 3). The highest HWC content was found in moorsh horizons of profile 4, whereas the lowest was determined in organo-mineral mud layers in profiles 3 and 4. The cold water carbon (CWC) contents were decidedly lower than HWC and

TABLE 2. Physical properties of the soils studied (mean values)

Profile	Soil horizon	Depth (cm)	Bulk density (g cm^{-3})	Ash content (%)	W_1 index	State of secondary transformation
1	M1	0–18	0.19	24.9	0.92	extreme
	M2	18–30	0.21	28.3	0.67	moderate
	M/Oa	30–43	0.23	35.0	0.68	moderate
	Oa	43–73	0.16	17.9	0.63	moderate
2	M1	0–20	0.18	21.3	0.86	strong
	M2	20–35	0.15	15.3	0.72	moderate
	Oe	35–45	0.17	19.7	0.45	initial
	Oi	45–70	0.17	18.8	0.43	initial
3	M1	0–15	0.30	52.7	0.75	moderate
	M2	15–30	0.27	43.5	0.64	moderate
	Lc1	30–38	0.39	74.2	–	–
	Lc2	38–60	0.42	81.2	–	–
4	M1	0–15	0.19	23.7	0.86	strong
	M2	15–25	0.18	20.8	0.76	moderate
	Lc1	25–47	0.40	77.3	–	–
	Lc2	47–70	0.46	92.4	–	–
	Lc3	70–110	0.45	88.9	–	–
	Lc4	110–130	0.45	90.2	–	–

TABLE 3. Chemical properties of the soils studied (mean values)

Profile	Soil horizon	Depth	pH	TOC	TN	HWC	CWC	$CaCO_3$	TOC/TN
		(cm)	H_2O			g·kg^{-1}			
1	M1	0–18	7.64	356	27.4	2.79	0.68	17.1	13.6
	M2	18–30	7.61	345	24.9	2.78	0.80	10.5	14.2
	M/Oa	30–43	7.69	325	21.5	2.37	0.58	6.40	15.5
	Oa	43–73	6.84	363	22.4	2.19	0.10	2.72	16.4
2	M1	0–20	6.17	378	27.1	2.70	1.25	–	13.9
	M2	20–35	5.61	431	29.0	2.61	1.08	–	14.9
	Oe	35–45	5.79	403	22.8	2.34	0.17	–	17.6
	Oi	45–70	5.92	422	20.9	1.54	0.15	–	20.2
3	M1	0–15	5.56	203	15.4	2.53	0.78	4.27	13.4
	M2	15–30	5.67	250	17.7	2.48	0.61	4.27	14.4
	Lc1	30–38	6.34	111	6.41	1.54	0.02	1.52	17.5
	Lc2	38–60	6.44	83.1	5.38	1.57	0.03	1.81	15.8
4	M1	0–15	5.66	389	29.6	3.11	0.92	–	13.1
	M2	15–25	6.02	399	28.7	3.00	1.17	–	13.9
	Lc1	25–47	6.43	76.8	4.87	1.18	0.07	–	15.5
	Lc2	47–70	7.02	19.6	1.31	0.50	0.01	–	14.9
	Lc3	70–110	6.62	58.6	4.01	0.77	0.03	–	14.4
	Lc4	110–130	6.46	57.4	340	0.50	0.02	–	14.4

Explanation: TOC – total organic carbon; TN – total nitrogen; HWC – hot water extractable carbon, CWC – cold water extractable carbon.

ranged between 0.01 and 1.25 g·kg^{-1} (Table 3). The mean HWC and CWC quantity in the examined soil profiles showed similar tendencies. Both parameters had the highest concentrations in the topsoil horizons, what indicates stronger microbial activity in these layers, responsible for organic matter transformations (Kalisz et al. 2010). The concentration of HWC in organic layers of investigated soils represents ca. 1% of TOC, what is similarly to findings reported by Kalisz et al. (2010, 2015) based on the research conducted on peatlands in northeastern Poland.

Above described results indicates that long-term peatland agricultural use, connected with intensive drainage transformed primarily upper horizons of the organic and organo-mineral soils studied. This is in line with the findings reported by other researchers (Sokołowska et al. 2005, Strack et al. 2008, Glina 2014, Kalisz et al. 2010, 2015). The present paper provides new challenges for future peatland monitoring program, which will allow to answer what is the main factor responsible for peatland degradation in the Grójecka Valley: is it the combined effect of agricultural use and lignite open pit mining industry in the vicinity, as was reported by Owczarzak et al. (2003) and Komisarek et al. (2011) or the climatic factors? Although strong human impact on peatlands ecosystems is obvious, we cannot exclude the climate variables influencing peat soils in the area studied. Particularly, when the Grójecka Valley is located in the zone of the most unfavorable weather conditions in terms of precipitation in Poland (Owczarzak and Mocek 2004). Described problem confirms the validity and necessity of the peatlands monitoring in the Grójecka Valley. Only long-term interdisciplinary monitoring program will give an answer for the mentioned unknowns.

CONCLUSIONS

1. Agricultural use of peatlands, combined with potential influence of lignite open pit mining industry since 1980s caused severe degradation of the soil cover in the Grójecka Valley.
2. Effect of long-term drainage observed in soil morphology (well-developed moorsh horizons) was confirmed by the soil physical and physicochemical properties (e.g., W_1 index, TOC/TN ratio and dissolved organic carbon content).
3. For precise determination of main factor responsible for peatland soil degradation in the Grójecka Valley, several years of interdisciplinary monitoring program of these ecosystems is required.
4. Implementation of a new subtype moorsh-muddy soils (in Polish: gleby murszowo-mułowe) within the type of gleyic soils should be considered in the next edition of the Polish Soils Classification.

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Aktualny stan gleb torfowisk niskich jako efekt długoletniego drenażu – wstępne wyniki badań ekosystemów torfowiskowych Doliny Grójeckiej

Streszczenie: Celem pracy było rozpoznanie aktualnego stanu pokrywy glebowej torfowisk niskich z obszaru Doliny Grójeckiej (wschodnia część województwa wielkopolskiego). Gleby te były użytkowane rolniczo (pastwiska, łąki) od 1960 roku oraz znajdowały się pod wpływem potencjalnego oddziaływania odkrywkowego górnictwa węgla brunatnego (KWB Konin) od roku 1980. Prace terenowe przeprowadzono w 2015 roku na wybranych obszarach torfowisk niskich. Materiał glebowy do badań laboratoryjnych pobrano z wydzielonych w terenie poziomów genetycznych z czterech profili glebowych. Powierzchniowe poziomy badanych gleb organicznych i organiczno-mineralnych były zbudowane z dobrze wykształconego materiału murszowego. Zaklasyfikowano je jako średnio zmurszałe – MtII (profil 1, 3 i 4) oraz silnie zmurszałe – MtIII (profil 2). Uzyskane wyniki analiz właściwości fizycznych i fizykochemicznych wskazały, że w wyniku długotrwałego użytkowania torfowisk, połączonego z intensywnym drenażem przekształcone zostały głównie powierzchniowe poziomy badanych gleb. Obserwowana sytuacja jest efektem długoletniego użytkowania rolniczego oraz może być potencjalnie skutkiem działalności górnictwa węgla brunatnego w bezpośrednim sąsiedztwie badanego obszaru. Jednakże nawet jeśli silny wpływ antropopresji na ekosystemy torfowiskowe jest oczywisty, nie można wykluczyć roli zmiennych czynników klimatycznych. Zasadne wydaje się być przeprowadzenie interdyscyplinarnych wieloletnich badań na podstawie sieci stałego monitoringu ekosystemów torfowiskowych Doliny Grójeckiej. Mogą one pomóc w udzieleniu jednoznacznej odpowiedzi, który z czynników w głównej mierze wpływa na przekształcenia tych obszarów. Morfologia i geneza niektórych z badanych gleb wskazują na konieczność podjęcia dyskusji nad celowością wprowadzenia do Systematyki Gleb Polski nowego podtypu gleb murszowo-mułowych, w obrębie typu gleb glejowych.

Słowa kluczowe: przeobrażenia gleb, torfowiska niskie, gleby organiczne, odwodnienia, użytkowanie torfowisk