Journal of Elementology ISSN 1644-2296

Pawluczuk J., Stępień A., Alberski J. 2019.
Physical and chemical properties of organic soils in connection with habitat conditions and the land use in the Dolina Rzeki Pasłęki Natura 2000 site.
J. Elem., 24(2): 437-447. DOI: 10.5601/jelem.2018.23.3.1704

RECEIVED: 14 July 2018
ACCEPTED: 1 November 2018

ORIGINAL PAPER

PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC SOILS IN CONNECTION WITH HABITAT CONDITIONS AND THE LAND USE IN THE *DOLINA RZEKI PASŁĘKI* NATURA 2000 SITE*

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Abstract

A study was carried out in 2014-2016 at three comparable, representative areas of permanent grassland situated on organic soils within the Pasłęka River valley, in Kiewry (53°53′ N, 20°10′ E, Poland) near Olsztyn. Soil samples were collected during the growing season from selected objects located at a distance of 50 m, 150 m and 300 m from the Pasłęka River bank, which determined their use. Physicochemical properties were determined in the soil samples. The aim of the study was to assess the physicochemical properties of the soil in a selected area of the *Dolina Rzeki Pasłęki* Natura 2000 site depending on the habitat conditions and land use. The factors that determined the use of organic soils at the site were the prevailing habitat conditions. At a high level of groundwater, which caused high soil moisture, a given site was used as natural meadow. However, at a low level of groundwater, which was associated with low soil moisture, it was intensively used as grassland for hay harvest. Peat and muck soils of moderate moorshification in the uppermost layers, covered with a natural meadow (occasionally mown) and situated 50 m away from the Pasłęka River bank, were characterised by the highest total nitrogen and phosphorus content in all layers compared to the other objects. Correlational relationships between the current moisture content, soil air content and the soil abundance of general forms of macronutrients were determined by the location of a grassland in relation to the distance from the river and the depth of the organic layer within the soil profile. The results of the research obtained at the Natura 2000 Site called Dolina Rzeki Pasłęki (the Pasłęka River Valley) show that the land use variants do not affect the degradation of organic soils.

Keywords: protected area, organic soils, grassland.

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* This study was financed by funds allocated to the statutory research at the University of Warmia and Mazury in Olsztyn.

INTRODUCTION

Ecological assets of valuable natural areas are determined by the degree of transformation and the mode and intensity of their use, which is determined by habitat conditions (Piaścik et al. 2003, Verhoeven 2014). However, despite an obvious strong human impact on peatland ecosystems, we cannot exclude the climate variables (Glina et al. 2016b). There is growing interest in understanding and predicting how soil processes in peatlands respond to anthropogenic pressures, including land-use changes, resource extraction and global climate warming (Booth et al. 2012, Rezanezhad et al. 2016).

Organic soils are very labile soils, which is why the use of organic soils affects their properties and consequently they are mostly used in greenland. Most frequently, these are soils used for permanent meadows (Stępień, Pawluczuk 2011). The way of using organic soils is determined by the habitat conditions occurring in a given area (Gotkiewicz 1996).

The most unfavourable change in the environment of organic soil is the deterioration of water conditions, which depressed the water retaining capacity of the soil in the profile and decreases the groundwater penetration to the upper layers (Pawluczuk et al. 2009, Parzych et al. 2011, Kalisz et al. 2015). Due to the thus modified conditions of peat and muck soils, they become less useful for the development of multispecies, hygrophilous plant communities (Kiryluk 2008, Kalisz, Łachacz 2009, Ławniczak 2011, Stępień, Pawluczuk 2011). The water and air conditions in a habitat determine whether organic soils are either in the accumulation phase or the decession phase. In the decession phase, organic matter changes its physicochemical properties and organic soils transform into organic, mineral and eventually mineral soils (Pawluczuk, Stępień 2010, Jakubus et al. 2013, Tokarz et al. 2015). A low groundwater level, which may be caused by a small amount of precipitation, inadequate drainage, mining (Jakubus et al. 2013) or an unsuitable agricultural use (Kiryluk 2008) in the long run leads to the degradation of organic soils.

The aim of this study was to assess physicochemical properties of soil in a selected area of the Dolina Rzeki Pasłęki Natura 2000 site depending on the habitat conditions and land use.

MATERIAL AND METHODS

The study was conducted in 2014, in the village called Kiewry (53°53′ N, 20°10′ E, Poland) situated near Olsztyn, in the Olsztyn Lake District. The Olsztyn Lake District is a physico-geographical mesoregion in the Mazurian Lake District, which comprises the Pasłęka River in its western part. The landscape of the area under study was sculpted by the last glaciation, whose recession phases are discernable as moraine rampart arcs.

The height of moraines in this area does not exceed 200 m A.S.L. Currently, the rivers in this area flow in postglacial valleys, whereas peatbogs are mainly found in basin-shaped areas, in the vicinity of which mineral formations are most often deposited (Piaścik 1996).

The study objects were located in the area of the Dolina Rzeki Pasłęki Natura 2000 site. The Dolina Rzeki Pasłęki Natura 2000 site is a bird sanctuary of European significance. The sanctuary serves an important role in the protection of breeding populations of the black kite (*Milvus migrans*), white-tailed eagle (*Haliaeetus albicilla*), lesser spotted eagle (*Clanga pomarina*), grey-headed woodpecker (*Picus canus*), and the middle-spotted woodpecker (*Dendrocoptes medius*). The local populations of the above species make up over 1% of their domestic populations. Key species (more than 0.5% of the domestic population) include the European honey buzzard (*Pernis apivorus*), red kite (*Milvus milvus*), western marsh harrier (*Circus aeruginosus*), common kingfisher (*Alcedo atthis*), red-breasted flycatcher (*Ficedula parva*), gadwall (*Mareca strepera*), garganey (*Spatula querquedula*), common goldeneye (*Bucephala clangula*), goosander (*Mergus merganser*) and the green sandpiper (*Tringa ochropus*) – Polish Regional Directorate for Environmental Protection – RDOŚ (2018).

The study area covered 12 ha of grassland located on organic soils. The study was carried out in three selected grasslands with different uses, representative of the entire object. The agricultural use of the meadows was determined by the habitat conditions prevailing within the area of the Pasłęka River valley. At a distance of approximately 50 m from the river bank, an occasionally mown natural meadow was situated. Further from the river, about 150 m from its bank, there was an extensively used, formerly mown grassland, while an intensively used, hay-growing and pasture area was found at about 300 m from the river (Figure 1).

Soil pits were dug on the representative stands, where the type of organic matter (type of lowland peat and the degree of its decomposition) was identified, genetic and diagnostic horizons were distinguished, and their main morphological features were characterised. Soil samples were collected in the soil pits from layers at a depth of 5-10, 15-20, 25-30 and 35-40 cm, using 100 cm^3 cylinders, in four replications. In the samples, collected with the soil structure undisturbed and in a fresh state, the basic physicochemical properties, i.e. moisture content, soil ash content, bulk density and porosity, were determined using methods developed by Sapek, Sapek (1997). The specific density of organic formations was calculated using a regression equation proposed by Okruszko (1971). Soil air content was measured and then determined according to the method developed by Malicki, Walczak (1983). The colour of organic and mineral-and-organic formation in the dry state, following the wetting and soaking up the excess water, as well as in the air-dry state, was determined using Munsell's tables (Oyama, Takehara 1992). After drying and grinding the soil samples, the following were determined: total nitrogen by the Kjeldahl method; total phosphorus by a spectrophoto-

Fig. 1. The location of the permanent grassland under study in the village Kiewry within the area of the *Dolina Rzeki Pasłęki* Natura 2000 site (www.google.pl/maps/place/Kiewry)

metric method after mineralization in sulfuric acid; potassium according to a lame photometry method after mineralization in sulfuric acid; magnesium in line with a flame atomic absorption spectrometry method after mineralization in sulfuric acid. The pH in H_2O and in 1 mole KCl dm^{-3} (weight ratio 1:10 soil to H_2O solution and KCl) was determined using the potentiometric method. Groundwater levels were measured in piezometers mounted in the vicinity of soil pits.

The study results were statistically processed with Statistica 13.0 software. The normality of data distribution was determined using the Shapiro-Wilk test at $p \leq 0.05$, and the Tukey's test was then applied and statistically homogeneous groups were identified. Relationships were identified between the current moisture content of the soil, the air content of the soil and the pH of the soil and total macronutrient content of the soil, expressed by the Pearson's correlation coefficient (r).

RESULTS AND DISCUSSION

Organic soils on the representative stands under study in the area of the Dolina Rzeki Pasłęki Natura 2000 site are located in various habitat conditions, which dcorrelated with the way the grassland was used (Table 1). The uppermost layers of the organic soils under study were developed ofrom peats differing in the degree of moorshification.

Table 1

Objects in the lithological zones of morainic uplands

Distance from the river (m)	Groundwater level (cm)	Soil (PKWG, THZ, PHSW)*	Types of land use of the grassland
50	0-10	peat – muck soils $MtIc_{pl180}$ PKWG – wet THZ – pressure, fluwiogenous PHSW – pressure, wet	Natural meadow
150	20-25	peat – muck soils $MtIIc_{pl160}$ PKWG – wet THZ – run-off PHSW – run-off and wet	Extensively used formerly mown grassland
300	30-45	peat – muck soils $MtIIc_{pl140}$ PKWG –drying THZ – run-off -topogenic PHSW – run-off and dryling	Intensively used hay-growing grassland

* PKWG – prognostic moisture – soil complex, THZ – type of the hydrological feeding, PHSW – potential hydrogenic moisture habitat

The natural meadow at a distance of 50 m from the river bank was situated on slightly moorshified organic soil ($MtIc_{pl180}$) made of lowmoor peat deposited at a depth of 180 cm on loose sand (Polsh Soil Classification 2011). This is a peat and muck soil, slightly moorshified, made of lowmoor sedge peat with a low degree of decomposition (R1). Organic soils under the natural meadow at the study object were characterised by the fluviogenic type of hydrological supply (Okruszko 2000), which involves flooding with the Pasłęka River water. Due to this type of habitat supply, a high level of groundwater (0-10 cm) was maintained in organic soils under the meadow at the study object, which determined its occasional mowing. There is a lower rate of transformation of the soil and floristic composition of meadows on very wet soils (Wasilewski 2013, 2015).

The grassland situated 150 m from the river was extensively used. It developed on a medium moorshified organic soil made of lowmoor sedge peat with a medium degree of decomposition (R2). At this study object, a run-off type of hydrological supply was predominant. Groundwater was maintained at a level of 20-25 cm.

The soil under the intensively used grassland is located in close proximity to moraine elevations (300 m from the river). Within the profile of this soil, loose sand is deposited under organic formations at a depth of 140 cm. Peat and muck soils (POLISH SOIL CLASSIFICATION 1989) of the study object are characterised by run-off and topogenic type of hydrological supply (300 m from the river). This mode of supply of organic soils, associated with a low level of groundwater (30-45 cm), allowed the grassland to be mowed 2 to 3 times a year. Dried habitats predominate here, occupied by various, transformed phytocenoses (STOSIK 2014).

Within the Pasłęka River valley, in the area of the analysed Natura 2000 site, medium deep organic soils are predominant (Table 2). Within the floodplain, in organic soils, the peat earth was only found in the uppermost layers (5-10 cm), while at an increasing distance from the river bed, the moorshification process affected deeper organic layers (5-20 cm). The soil ash content of the peat earth layers, irrespective of the distance from the river bank, was high and did not differ between the study objects. In the peat earth layer, the high content of mineral parts (soil ash content) at the object situated closest to the river can be mainly attributed to the alluvial process, while further away from the river bed, it can be attributed to the process of mineralisation of organic nitrogen compounds. In the organic soil layers, the soil ash content was lower and decreased down the soil profile. Similarly to the soil ash content, the bulk density of the soil at the study objects

Table 2

Physical and chemical properties of organic soils

Layer (cm)	Genetic horizon	Depth (cm)	Ash content (%)	Volume density (g dm^{-3})	Specific density (g dm^{-3})	Total porosity (%)	pH in H_2O	pH in 1M KCl	Munsell colour notation	
									wet	dry
50 m ($MtIc_{pl180}$)										
5–10	Mt	5-10	16.3	0.29	1.58	82.8	7.13	6.98	7,5YR2/2	7,5 YR 3/1
15–20	Ot_{nituR1}	15-20	13.8	0.22	1.61	86.3	7.15	7.00	10YR2/1	10 YR 3/1
25–30	Ot_{nituR1}	25-30	13.2	0.20	1.60	87.5	7.14	6.98	10YR2/3	10 YR 3/2
35–40	Ot_{nituR1}	35-40	12.9	0.19	1.59	88.1	6.96	6.65	10YR2/3	10 YR 3/2
150 m ($MtIIc_{pl160}$)										
5–10	Mt	5-10	15.9	0.28	1.53	83.3	6.98	6.95	7,5YR2/2	7,5 YR 3/2
15–20	Mt	15-20	14.9	0.25	1.62	84.2	6.95	6.90	7,5YR2/3	7,5 YR 3/3
25–30	Ot_{nituR2}	25-30	11.9	0.15	1.58	90.5	6.99	6.94	10YR3/2	7,5 YR ¾
35–40	Ot_{nituR2}	35-40	11.9	0.14	1.57	91.4	6.87	6.79	10YR3/4	7,5 YR 3/2
300 m ($MtIIc_{pl140}$)										
5–10	Mt	5-10	16.1	0.28	1.63	82.8	7.18	7.10	7,5YR2/2	7,5 YR 3/1
15–20	Mt	15-20	15.7	0.27	1.63	83.7	7.45	7.38	7,5YR2/2	7,5 YR 3/1
25–30	Ot_{nituR3}	25-30	13.4	0.21	1.60	87.5	7.15	7.10	10YR2/2	10 YR 3/1
35–40	Ot_{niszR2}	35-40	12.4	0.17	1.59	89.3	7.12	6.89	10YR2/2	10 YR 3/1

decreased down the soil profile. In the study carried out in the area of Natura 2000 site called the Dolina Rzeki Pasłęki, the low level of groundwater in the soils MtIIcpl140 (Predictive moisture and soil complex, drying C) did not increase bulk density, which was not confirmed by KIRYLUK (2014) in his study on organic soils at a meadow object in the Supraśl River valley. The current research did not demonstrate changes in bulk density depending on different land use (determined by the distance from the river). KAMIŃSKI, CHRZANOWSKI (2007) demonstrated greater bulk density of soils in an object used as a pasture in relation to that used for hay-growing.

In soil $MtIIc_{pl140}$, situated in a drying habitat (Predictive moisture and soil complex, drying C), groundwater was at a level below 30 cm during the growing period, and was not available to meadow vegetation (Table 1). The moisture content of peat earths (5-10 and 15-20 cm in soils $MtIIc_{pl160}$ and $MtIIc_{pl140}$) was lower than that of organic layers (Table 3). This was due to

Table 3

Moisture, air content of peat-muck soils

Specification	Layer (cm)	Distance from the river (m)		
		50 m ($MtIc_{pl180}$)	150 m ($MtIIc_{pl160}$)	300 m ($MtIIc_{pl140}$)
Actually moisture (%)	5-10	91.4*a*	82.3*b*	77.2*b*
	15-20	89.6*a*	75.0*b*	69.5*b*
	25-30	92.4*a*	87.6*b*	80.6*c*
	35-40	93.9*a*	90.9*ab*	84.6*b*
Air content (%)	5-10	2.75*b*	5.63*ab*	9.14*a*
	15-20	3.95*b*	7.95*ab*	14.10*a*
	25-30	2.65*b*	2.85*b*	7.75*a*
	35-40	0.45*a*	2.40*a*	5.65*a*

a, *b*, *c*, … values with the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$)

the persisting low groundwater level. In the soil $MtIc_{pl180}$, where the groundwater level was high (0-10 cm), both peat earth layers and organic layers were characterised by high moisture content (ranging from 69.5 to 82.2%). The air content of these layers was high as well (5.63-14.10%). The moisture content of mineral and organic soils located at a distance of 50 m from the Pasłęka River was higher than that of soil layer located at a distance of 150 and 300 m from the river bank. Opposite relationships occurred for the air content of the soil.

The pH of the soils under study was neutral (pH in H_2O: 6.87-7.18; pH in 1M KCl: 6.65–7.10), with the exception of the soil located at a distance 300 m from the river in the layer of 15-20 cm, where it was alkaline (pH in H_2O: 7.45; pH in 1M KCl: 7.38). In studies by PAWLUCZUK et al. (2009) and PAWLUCZUK, STĘPIEŃ (2010), the pH value of soil, irrespective of its use, did not change in the uppermost layers. The pH value of the upper part

of the peat deposit was determined by the layer of groundwater, which was also demonstrated in a study by Tokarz et al. (2015). Jankowska-Huflejt et al. (2009) found that the acidity of soils (pH_{KCl}) under permanent grassland was above 5.7 on average, yet with significant fluctuations for particular types of land use. In their study, very acidic soils (pH above 4.5) were primarily those under meadows (20% of samples), with only 3% of samples for the soils under pastures. Acidic soils were predominant (up to pH_{KCl} 5.5) in 25% of samples of the soils from meadows and for 50% of the soils from pastures.

Soil $MtIc_{pl180}$, under natural meadow and situated 50 m away from the Pasłęka River bank, was characterised by the highest content of total nitrogen and phosphorus in all layers, compared to other objects (Table 4).

Table 4

Chemical properties of organic soils

Specification	Layer (cm)	Distance from the river (m)		
		50 m ($MtIc_{pl180}$)	150 m ($MtIIc_{pl160}$)	300 m ($MtIIc_{pl140}$)
N-total (g kg^{-1})	5-10	1.39*a*	1.27*ab*	0.61*b*
	35-40	1.73*a*	1.15*b*	1.23*b*
P- total (g kg^{-1})	5-10	2.66*a*	1.20*b*	0.71*c*
	35-40	1.74*a*	1.08*a*	0.87*a*
K- total (g kg^{-1})	5-10	1.00*a*	1.00*a*	1.00*a*
	35-40	0.83*a*	0.83*a*	0.83*a*
Mg- total (g kg^{-1})	5-10	1.33*b*	1.57*b*	2.05*a*
	35-40	1.27*a*	1.50*a*	1.87*a*

a, *b*, *c*, … values with the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$)

Total N content was associated with the low dynamics of the process of mineralisation of organic nitrogen compounds, which was limited by the high level of groundwater and the low content of soil air in all layers. Similar relationships between the nitrogen content of organic soils and the moisture content of soils was demonstrated by Ławniczak (2011).

Physical and chemical properties of organic soils are related to the level of groundwater, the abundance of minerals (Hill, Siegel 1991) and soil-forming processes (Todorova et al. 2005).

Glina et al. (2016*a*) showed that the amount of precipitation and actual soil moisture had a dominant impact on the N mineralisation process in organic soils. The dynamics of the moorshification process contributed to the release of mineral forms of both nitrogen and phosphorus which, in turn, is associated with the content of general forms of these elements in soil. Jankowska-Huflejt (2009) found that an average total N content was determined by the land use; in soil samples from meadows, it was 0.58%, i.e. higher than the N content of soil samples collected from pastures.

The total potassium content of organic soils at the study objects was low in all layers (0.83-1.00 g kg^{-1}). Similarly, the total magnesium content was low (1.27-2.05 g kg^{-1}).

The air and water properties (the current moisture content and the air content) of organic soils at the study object were mostly correlated with the content of total forms of macronutrients, i.e. N, P, K and Mg (Table 5).

Table 5

Relationships between the actual moisture, the air content of the soil and the total macronutrient content of the soil, expressed by the Pearson's correlation coefficient (r)

Specification	Layer (cm)	Actually moisture			Air content		
		50 m ($MtIc_{pl180}$)	150 m ($MtIIc_{pl160}$)	300 m ($MtIIc_{pl140}$)	50 m ($MtIc_{pl180}$)	150 m ($MtIIc_{pl160}$)	300 m ($MtIIc_{pl140}$)
N-total	5-10	0.384	0.532	-0.518*	-0.169	0.214	-0.313
	35-40	0.921*	-0.170	0.964*	0.999*	-0.146	0.959*
P- total	5-10	0.969*	-0.794*	-0.853*	0.951*	-0.953*	-0.948*
	35-40	-0.136	-0.867*	0.889*	-0.519*	-0.829*	0.997*
K- total	5-10	0.913*	0.913*	0.797*	0.989*	0.997*	0.912*
	35-40	-0.010	0.983*	-0.747*	-0.388	0.994*	-0.985*
Mg- total	5-10	0.999*	-0.172	-0.740*	0.818*	0.172	-0.872*
	35-40	0.364	0.999*	-0.680*	-0.036	0.993*	-0.964*

Correlational relationships, different in strength, between the studied features were determined by the location of grassland in relation to the distance from the river and the depth of the organic layer within the soil profile.

CONCLUSIONS

1. The factors determining the use of organic soils at the site called the Dolina Rzeki Pasłęki (the Pasłęka River Valley) were the prevailing habitat conditions.

2. At a high level of groundwater, which caused high moisture of the soils, the representative stand was under a natural meadow. However, at a low level of groundwater, which was associated with low moisture, it was used as a grassland intensively managed for hay-growing.

3. Peat and muck soil with a medium degree of moorshification of the uppermost layers, under a natural meadow (occasionally mown), situated 50 m away from the Pasłęka River bank, were characterised by the highest total nitrogen and phosphorus contents in all layers compared to other objects. The potassium content in soil did not depend on the distance from the river. The magnesium content grew, although not always statistically significantly, when sampled further away from the river bed. With respect

to the surface layer, it was significantly higher only in the soil located 300 m from the river bed.

4. Correlational relationships between the current moisture content, soil air content and the soil abundance of general forms of macronutrients were determined by the location of a grassland in relation to the distance from the river and the depth of the organic layer within the soil profile.

5. The results of the research obtained at the Natura 2000 Site called the Dolina Rzeki Pasłęki show that the land use methods applied did not affect the degradation of organic soils. However, the recommended method of land use in this area is natural meadow or extensively used, formerly mown grassland. They ensure beneficial properties of this protected object.

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