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The occurrence of organic soils in the Middle Noteć River Valley, Poland – comparison of the current state with the divisions on the soil-agricultural map

Tomasz Kaczmarek[1]*, Waldemar Spychalski[1], Bartłomiej Glina[1]

[1] Poznań University of Life Sciences, Department of Soil Science and Microbiology, Szydłowska 50, 60-656 Poznań, Poland

* Corresponding author: PhD, Tomasz Kaczmarek, tomasz.kaczmarek@up.poznan.pl, ORCID iD: https://orcid.org/0000-0002-1441-7179

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Abstract

In recent years, soil-agricultural maps created between the mid-1960s and 1980s have been converted to digital formats and are regarded as valuable sources of information on the suitability and diversity of soils used for agricultural purposes in Poland. However, in the case of peatland areas, especially those that have been under intensive agricultural use since the 1950s and 1970s, these soil-agricultural maps may have lost some of their relevance. Peatland drainage adversely affects the physical, chemical, and biological properties of organic soils, as the reduced moisture content in the topsoil horizons and increased oxygenation trigger the mursh-forming process. In extreme cases, this process can even lead to the complete disappearance of organic soils. The research was conducted in selected areas of agriculturally used fen peatlands located in the Middle Noteć River Valley, one of the largest fen peatland complex in Poland. This study aimed to verify the current occurrence of organic soils for selected areas of the Middle Noteć Valley based on soil profiles compared to the archival soil-agricultural map and own research. Comparison of the current state of soil cover with data included in soil-agricultural maps for the study area showed some changes in the occurring soil types, as the effect of agricultural use (mainly grasslands) in the last 50–60 years.

1. Introduction

The general soil classification carried out in 1956–1967 was a significant achievement of Polish soil scientists and soil classifiers (Smreczak and Łachacz, 2019). As a result of this work, detailed data were collected on, among others: spatial distribution of soils used for agriculture in Poland, soil texture, water conditions, pH, water erosion risk, and other additional information useful for agricultural management (Wężyk et al., 2012). Archival soil-agricultural maps with accompanying studies are considered as a valuable source of information on the spatial diversity of soils in Poland (Strzemski et al., 1973; Jadczyszyn and Smreczak, 2017). Among the distinguished contours of mineral soils, the occurrence of organic soils is also marked on soil-agricultural maps. According to Tanneberger et al. (2017) there are approximately 14 950 km^2 of peatlands in Poland, of which 90% are covered by fen peatlands, as a result of climatic conditions (Ilnicki and Żurek, 1996). As a result of anthropopressure and the progressive soil organic matter (SOM) mineralization, natural peat soils are transformed into peat-mursh or mursh soils, and ultimately into mineral soils, which results in the disappearance of organic soils (Okruszko, 1992; Sykuła, 2020). Particularly organic soils located in the Middle Noteć River Valley, which have been transformed, as a result of intense drainage in the last 50–60 years. Thus, the soil-agricultural maps that were developed for this region in the 1960s and 1970s may have become outdated. Especially if intensive peatland utilization in Poland began immediately after the period of preparation of soil-agricultural maps, as mentioned by Gotkiewicz et al. (1996), Siuta and Żukowski (2009), Kucharzyk and Szary (2012). In recent years, soil-agricultural maps of selected voivodeships in Poland have been updated to digital versions, which is significant progress, because previously these maps were in most cases available only in analogue forms. It is also worth noting that, over the past 50 years, only a few studies on organic soils in the Middle Noteć River Valley have been published (i.e., Marcinek, 1960; Ilnicki, 1979; Dzierżek, 1997; Ratajczak-Szczerba, 2011). Additionally, the Middle Noteć River Valley is one of the largest fen peatlands in Poland (Sołtys-Lelek and Gruszka, 2020), primarily used for agriculture (Lipka and Stabryła, 2012), making it crucial to improve knowledge about the current state of soils in this region.

Supplementary materials are available at https://www.soilsa.com/SuppFile/203732/1/

The aim of the study was to verify the current occurrence of organic soils in selected areas of the Middle Noteć River Valley. Based on the comparison of the obtained results with the data contained in the soil-agricultural map at a scale of 1:5000, and correlation with a recent Polish Soil Classification (PSC) (2019), as proposed by Świtoniak et al. (2019) and Witek (1973), an attempt was made to answer the following question: Did the intensive peatland drainage in the 1960s and 1970s, and following agriculture use significantly influence the occurrence of organic soils in the Middle Noteć River Valley? The results of this study will significantly enhance current knowledge regarding the occurrence and degree of degradation of organic soils within one of Europe's largest complexes of agriculturally used fen peatlands of temperate climate zone.

2. Materials and methods

2.1. Study area

The study area (Middle Noteć River Valley) is located in the Greater Poland Voivodeship, central Poland (Fig. 1). The mean annual air temperature throughout the year is approximately 9.3°C. The coldest month of the year is January (–0.9°C), while the warmest is July (19.4°C). Precipitation in the study area is approximately 650 mm per year (website 1).

The study was conducted within four research transects, established on agricultural used (grasslands) fen peatlands: transects I and II were located within the border of Antoniny, Nałęcza and Józefowice villages, while transects III and IV were located in the Atanazyn village (Fig. 2 and Fig. 3). The research plots within the study area were selected based on the differences in drainage network density and ditch depth. Transects I and II were characterized by a less dense network and deeper ditches (up to 2 meters), while transects III and IV had a more dense drainage network, but the ditches were shallower (up to 0.40 meters).

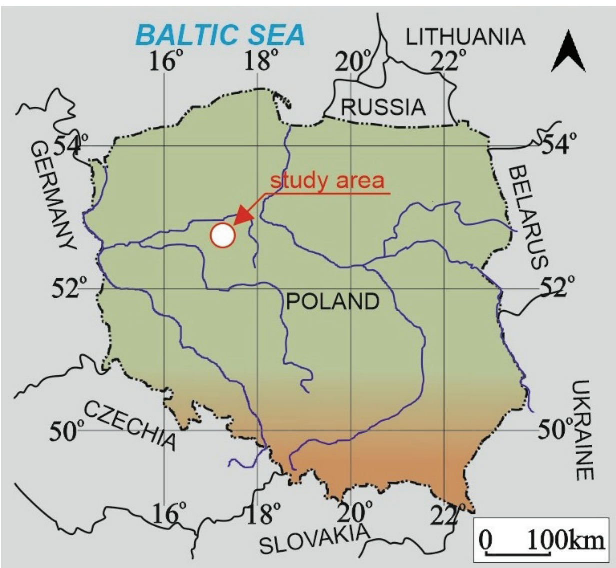

Fig. 1. Location of the study area

The Middle Noteć Valley has long been subjected to significant anthropopressure. As a result of a series of drainage measures carried out in the past, the area of agricultural land increased, and the river embankments limited its overflows, allowing for the expansion of field cultivation (Koczorowski, 1989). At the turn of the 1970s and 1980s, a large-scale investment project was carried out in this area, within the boundaries of the former village of Antoniny. The aim was to consolidate land and improve drainage systems, creating large parcels of approximately 50 hectares. Moreover, fish ponds were constructed in areas near the Noteć River. It is worth noting that, as reported by Warachowska and Zwoliński (2023), fish ponds, in addition to their role in irrigating agricultural areas, are also utilized in fish farming. The initial goal of the project was to regulate the water regime throughout the entire growing season, including both drainage and irrigation as needed. As a result, over the past centuries, this area was gradually drained, then deforested, and transformed into one of the largest complexes of meadows and pastures in Poland (Wiśniewski, 2015). In subsequent years, the subsidence of organic soils and the failure to maintain drainage systems resulted in spontaneous peatland rewetting which consequently slightly restored peat-forming processes in many parts of the valley (Krogulec and Wołczuk, 2014).

2.2. Field survey

Soil survey and sampling were carried out in the years 2016–2019. Soil samples for laboratory analysis were collected from 24 soil profiles (6 from each research transect) (Fig. 2 and Fig. 3). In total, 132 soil samples were collected from all identified soil horizons. Soil morphology was described in accordance with the field guide for soil description, annexed to the 6th edition of the Polish Soil Classification (Systematyka gleb Polski, 2019). The studied soil type was determined in accordance with the Polish Soil Classification (2019).

2.3. Laboratory analysis

In the laboratory soil properties necessary to classify the studied soils were conducted. At the first stage plant roots from the soil samples were removed, and the samples were then assigned to one of two groupings. In fresh material, the degree of peat decomposition (based on the fiber content after rubbing) was determined following the procedure (half-syringe method) proposed by Lynn et al. (1974). Meanwhile, the second part of the samples were air-dried and crushed in a mortar to obtain homogenized soil material. The following properties were determined in dry samples: pH in distilled water (soil to water w/v ratio 1:2.5) potentiometrically, total carbon (TC) and total nitrogen (TN) by using the VarioMAX CNS Elementar Analyzer and calcium carbonates equivalent by volumetric Scheibler method (Van Reeuwijk, 2002). TC values were adjusted (inorganic carbon content was subtracted from TC content) and expressed as total organic carbon (TOC) content if inorganic carbon (as carbonates) was present. Based on TOC and TN content the TOC/TN ratio was calculated. The undisturbed soil samples collected to stainless steel rings (100 cm^3) were used for the bulk density determination by weigh-drying method.

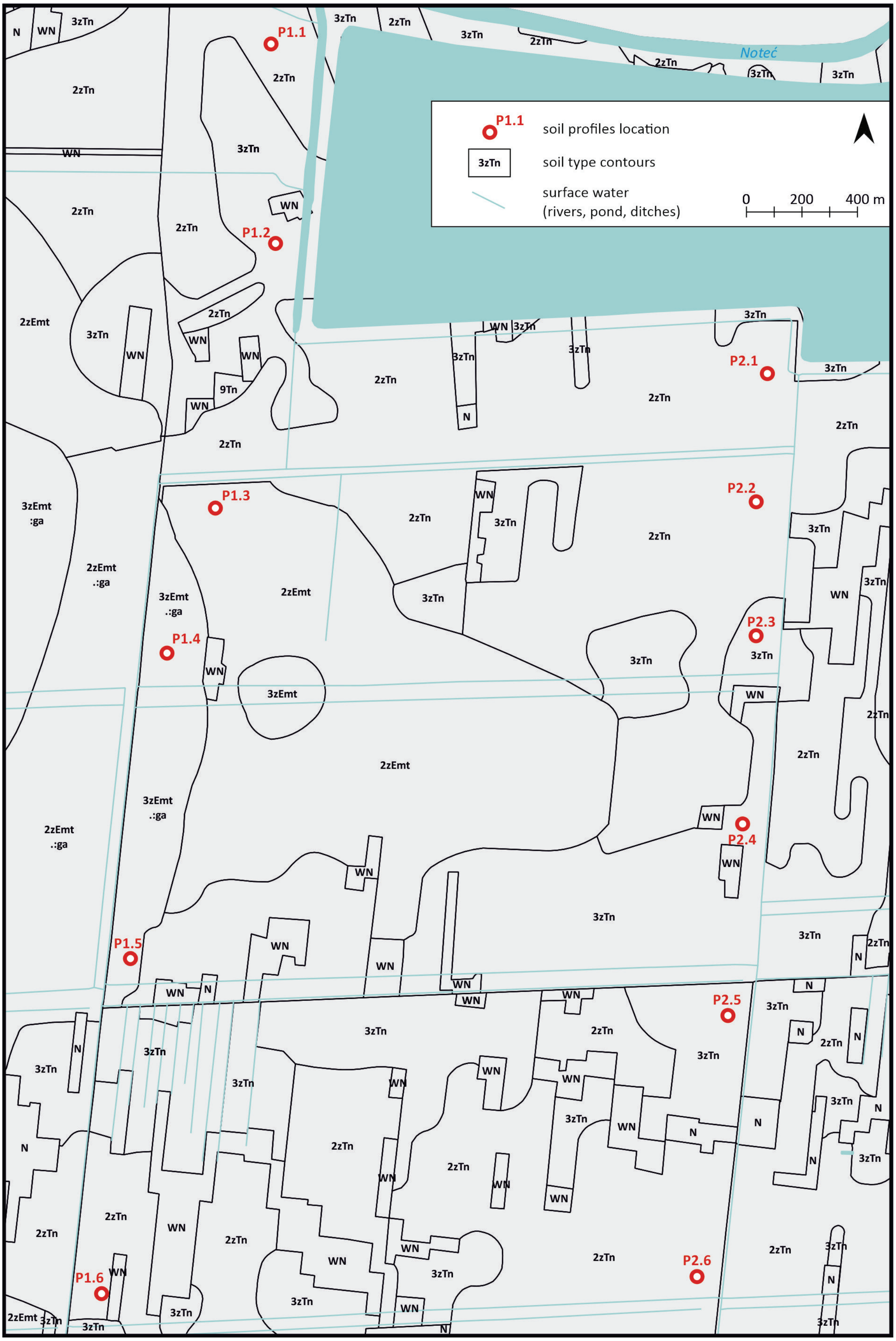

Fig. 2. Location of research transects no. 1 and 2 within the soil types contours of soil-agricultural map (MGR 1:5000; WN – water wasteland, N – wasteland, rest of the contour designations as in the Table 2) and surface waters from the Topographic Objects Database (BDOT10k)

Fig. 3. Location of research transects no. 3 and 4 within the soil types contours of soil-agricultural map (MGR 1:5000; WN – water wasteland, N – wasteland, rest of the contour designations as in the Table 2.) and surface waters from the Topographic Objects Database (BDOT10k)

3. Results

3.1. Morphology and classification

According to the Polish Soil Classification (2019) all soils represent organic soils order. Among the studied soil profiles, the most common soil types were: peat soils – 9 profiles, and murshic soils – 7 profiles, followed by 6 profiles classified as gyttja soils, and 2 as earth-covered peat soils (Table 1).

In general (except for earth-covered peat soils) the surface soil horizons of the studied soils were built with a well-developed mursh material, a noticeable effect of the long-term peatland drainage. The thickness of the granular structured mursh horizons varied from 14.3 cm to 32.8 cm. The smallest thickness of the mursh layers was observed in the peat soils from transects III and IV, while the greatest thickness was recorded in the murshic soils from transects I and II (Table 1). Peat soils in the research area were composed mainly of amorphous and

Table 1
Physical and chemical properties of the studied soils (mean values for each soil horizons)

	Soil type	Soil horizon	Mursh thickness	FC	Bulk density	TOC	TN	TOC/TN	$CaCO_3$
			(cm)	%	(g cm^{-3})	%			%
Transects I and II	peat soil	M	24.8	N/A	0.70±0.17*	13.1±0.99*	1.19±0.18*	11±1.09*	8.81±7.00*
		Oa		9.71±5.31*	0.19±0.07*	52.2±3.41*	3.71±0.51*	14±2.14*	1.64±0.62*
		Oe		20.8±5.22*	0.17±0.04*	52.3±2.54*	3.59±0.60*	15±2.55*	3.75±1.68*
		OaLcca		12,0**	0.28**	31.4**	1.91**	16**	31.5**
		OeLcca		20.0±2.00*	0.26±0.03*	30.6±1.46*	2.09±0.34*	15±2.31*	31.8±5.30*
		OiLcca		42.0**	0.21**	33.7**	2.37**	14**	30.7**
		OiLc		42.0**	0.21**	40.3**	2.92**	14**	16.9**
		Lcca		N/A	0.24±0.03*	25.3±6.58*	2.05±0.17*	12±2.12*	40.0±15.6*
	murshic soil	M	32.8	N/A	0.55±0.26*	27.8±11.6*	2.30±0.92*	12±1.89*	1.95±1.79*
		Oa		9.00±3.37*	0.18±0.01*	50.0±4.90*	3.18±0.35*	16±0.96*	0.30±0.15*
		Oe		19.0±1.47*	0.20±0.05*	49.3±5.60*	3.31±0.29*	15±1.96*	5.00±1.39*
		Oi		43.5±2.12*	0.14±0.01*	54.7±0.35*	3.28±0.12*	17±0.71*	–
	earth-covered peat soil	Au	N/A	N/A	0.97±0.30*	6.40±2.35*	0.69±0.24*	9±0.55*	5.00±3.66*
		Oa		8.00**	0.18**	48.4**	3.30**	15**	–
		Oe		21.0±1.73*	0.20±0.04*	44.5±9.35*	2.98±1.14*	15±3.21*	–
		Oi		50.0**	0.14**	48.2**	3.95**	12**	1.95**
		OiLcca		46.0±4.24*	0.22±0.01*	38.5±0.71*	3.06±0.06*	13±0.71*	24.5±1.13*
Transects III and IV	peat soil	M	14.3	N/A	0.37±0.08*	18.8±3.74*	1.88±0.35*	10±0.00*	28.2±24.8*
		Oa		3.00±0.00*	0.20±0.01*	42.9±6.62*	3.38±0.67*	13±0.58*	11.7±17.0*
		Oe		23.0±10.0*	0.18±0.04*	46.8±3.92*	3.73±0.68*	13±1.71*	–
		OaLcca		9.00±5.96*	0.22±0.02*	26.7±6.97*	1.92±0.30*	14±2.17*	43.6±11.2*
		OeLcca		26.0±6.11*	0.24±0.07*	31.3±4.59*	2.29±0.24*	14±1.52*	35.2±6.66*
		Lcca		N/A	0.20**	25.4**	1.54**	16**	24.5**
	murshic soil	M	30.0	N/A	0.37±0.11*	28.8±15.7*	2.80±1.41*	10±0.50*	34.7±29.3*
		Oa		3.00±0.00*	0.22±0.02*	49.2±0.47*	3.69±.0.41*	13±1.73*	–
		Oe		23.5±9.19*	0.15±0.01*	52.1±0.00*	3.57±0.02*	15±0.00*	0.20±0.14*
		Lcca		N/A	0.26±0.01*	25.5±9.97*	2.10±0.86*	12±0.00*	39.4±18.5*
	gyttja soil	M	18.7	N/A	0.51±0.09*	14.2±1.79*	1.33±0.34*	11±1.79*	42.9±11.3*
		Oe		17.0±0.00*	0.28±0.17*	38.4±15.4*	2.68±1.18*	14±1.15*	8.90±1.31*
		LccaOa		8.00±5.70*	0.30±0.09*	25.1±5.27*	1.93±0.30*	13±1.07*	47.2±9.48*
		LccaOe		19.0±1.26*	0.22±0.02*	24.1±6.91*	1.75±0.36*	14±1.05*	50.5±14.4*
		Lcca		N/A	0.38±0.15*	17.1±4.70*	1.44±0.36*	12±1.72*	52.4±13.1*

Explanation: N/A – not analyzed, FC – fiber content after rubbing, TOC – total organic carbon TN – total nitrogen, * – average values for the genetic horizon within a given soil type, ** – parameter value amorphous-fibrous structured peat. In some peat horizons, a substantial admixture of calcareous gyttja was recorded (Table 1). The uppermost layers of earth-covered peat soils consisted of mineral semimurshic (in Polish: murszowaty) material, underlined by differently decomposed (from sapric to fibric) peat materials. The last recognized soil type – gyttja soils, occurred only in the transects III and IV, were composed mainly of calcareous gyttja with an admixture of hemic and sapric peat. This material was covered with mursh horizon, characterized by a granular structure and thickness of ca. 19 cm (Table 1). Additionally, according to Witek (1973) 13 soil profiles (9 profiles in transects I and II, and 4 profiles in transects III and IV) of the study area were classified as peat soils and peat-murshic soils (Tn), while the remaining 11 soil profiles (3 profiles in transects I and II, and 8 profiles in transects III and IV were classified as peaty mud soils (Emt).

3.2. Soil physical and chemical properties

Based on fiber content (FC), the peat materials were classified as strongly (sapric), moderately (hemic), and slightly (fibric) decomposed. Among 83 peat samples, the most abundant were sapric peat (55.4%), followed by hemic (36.1%) and fibric (8.50%) peat. The mean values of bulk density in the surface horizons (mursh in particular) ranged from 0.37 to 0.55 g cm^{-3} (Table 1). In the subsurface horizons, the mean values of bulk density ranged from 0.14 to 0.28 g cm^{-3} in peat materials, 0.20 to 0.38 g cm^{-3} in gyttja materials, and from 0.21 to 0.30 g cm^{-3} in mixed (peat-gyttja) materials (Table 1).

The mean TOC content in soil samples collected from transects I and II ranged from 6.40% to 54.7%, with the lowest TOC content observed in the semimurshic material of earth-covered peat soils, and the highest in soil horizons consist of fibric peat – Oi (Table 1). In the case of soil profiles from transects III and IV, the lowest TOC content (14.2–18.8%) was recorded in the mursh horizons, while the highest (46.8–52.1%) in the hemic peat horizons (Oe). In the horizons consisting exclusively of calcareous gyttja, the mean TOC content ranged from 17.1% to 25.5% (Table 1). The TN content in the studied soils ranged from 0.69% to 3.95%. In general, the lowest TN content was observed in the semimurshic horizons (Au) of earth-covered peat soils, while the highest in soil horizons consisted of fibric peat – Oi (Table 1). In the mursh horizons, the mean TN content was between 1.19 to 2.80%, while in the gyttja horizons its value ranged from 1.44 to 2.10%. The calculated TOC/TN ratio was within a narrow range of values, with the lowest (9.00–10.0) in the uppermost soil horizons (Au and M), and the highest (12.0–17.0) in hemic (Oe) and fibric (Oi) peat horizons (Table 1). Overall, the study soils in transects III and IV had a higher content of $CaCO_3$, than soils within transects I and II (Table 1). Definitely, the highest $CaCO_3$ content was recorded in soil horizons built of calcareous gyttja (24.5–52.4%) and gyttja horizons with an admixture of peat material (47.2–50.5%). The lowest mean $CaCO_3$ content (0.30–11.7%) was observed in sapric peat horizons (Table 1).

3.3. Analysis of soil-agricultural map

Based on the soil-agricultural map of the study area, the above-described soil profiles were located in 15 contours marked as Tn (10 contours) and Emt (5 contours) (Table 2). The contours on the soil-agricultural map marked as Tn represent the fen peat soils (in Polish: gleby torfowe torfowisk niskich). According to the legend for soil-agricultural map, the symbol T was used to mark peat and mursh-peat soils. In peat soils the mursh layer (if present) has less than 20 cm, if it has more and underneath there is a peat layer – then it is classified as mursh-peat soil (Instrukcja w sprawie wykonywania map glebowo-rolniczych, 1965; Witek, 1973). The contours marked with the symbol E on the soil-agricultural map belonged to the group of muddy-peat soils and peaty mud soils. These soils consist of peat and mud layers in various combinations and proportions. The Emt symbol on soil-agricultural map indicates soils with a predominance of mud material over peat material (in Polish: gleby mułowo-torfowe).

3.4. Comparison of soil-agricultural map data with the current state of soil cover

In the transect I of the study area, 3 soil profiles were located in the contours of fen peat soils and 3 in peaty mud soils, however these soils according to Polish Soil Classification (2019) represent the peat soils (profiles 1, 4, 5), murshic soils (profile 2) and earth-covered peat soils (profiles 3 and 6) types (Table 2). Peat soils in the study area were characterized by a murshic horizon thickness of less than 30 cm and with at least 50 cm of peat to a depth of 100 cm. Murshic soils were classified according to the granular mursh horizon with a thickness of ≥30 cm and earth-covered peat soils were characterized by the presence of a layer of deposited mineral material with a thickness of ≥10 cm on the surface of the organic soil. In the transect II all soil profiles were located in the Tn contours. According to Polish Soil Classification (2019), these soils have been classified as murshic (profiles 2, 3, 5, and 6) and peat (profiles 1 and 4) soils (Table 2). The situation was different in the case of transect III, where 2 of the 6 profiles were located in the contours of fen peat soils (Tn), and the remaining ones were in peaty mud soils (Emt), however according to Polish Soil Classification (2019) the soils were represented by murshic (profiles 1 and 6), peat (profile 2) and gyttja soils (profiles 3, 4 and 5). In the case of the transect IV, fen peat soil occurred only in the location of soil profiles 1 and 4, while the remaining soil profiles were found in the Emt contours (Table 2), which according to PSC (2019) represents peat (profiles 1, 2 and 3) and gyttja soils (profiles 4, 5 and 6). It is worth noting that across the entire study area, soil profiles located on the soil-agricultural map in the contours Tn (fen peat soil) and Emt (peaty mud soil) in the proposal after Witek (1973) were classified as Tn (peat soil and peat-mursh soil) and Emt (peaty mud soil), respectively (Table 2).

Based on the proposed correlation of soil units distinguished on the soil-agricultural map (Świtoniak et al., 2019) and the study soil profiles, the correlation was confirmed for 6 of the 24 studied soil profiles. This situation occurred in the case of peat soils (5 profiles) and murshic soil (1 profile). Accordnig to Świtoniak et al. (2019) soils located on the soil-agricultural map in the Emt con-

Table 2
List of soil units from the soil-agricultural map and classification of studied soil profiles according to the proposal after Witek (1973) and Polish Soil Classification (2019)

Transect	Profile number	Systematic position and bonitation classification			
		Soil-agricultural map 1:5000	Proposal after Witek (1973)	Current systematic position of the study soils	
				PSC (2019)	Symbol
I	P 1	Tn – fen peat soil, 2z, Ł IV	Tn – peat soil and peat-mursh soil	hemic murshic peat soil	OThe
	P 2	Tn – fen peat soil, 3z, Ł V	Tn – peat soil and peat-mursh soil	hemic murshic soil	OMhe
	P 3	Emt – peaty mud soil, 2z, Ps IV	Emt – peaty mud soil	earth-covered fibric peat soil	OTnt
	P 4	Emt – peaty mud soil, :. ga – deeply underlayed with gyttja, 3z, Ł IV	Emt – peaty mud soil	hemic murshic peat soil	OThe
	P 5	Emt – peaty mud soil, :. ga – deeply underlayed with gyttja, 3z, Ł VI	Emt – peaty mud soil	hemic murshic peat soil	OThe
	P 6	Tn – fen peat soil, 2z, Ł IV	Tn – peat soil and peat-mursh soil	earth-covered hemic peat soil	OTnt
II	P 1	Tn – fen peat soil, 2z, Ps IV	Tn – peat soil and peat-mursh soil	fibric murshic peat soil	OTfi
	P 2	Tn – fen peat soil, 2z, Ł IV	Tn – peat soil and peat-mursh soil	hemic murshic soil	OMhe
	P 3	Tn – fen peat soil, 3z, Ł V	Tn – peat soil and peat-mursh soil	hemic murshic soil	OMhe
	P 4	Tn – fen peat soil, 3z, Ł V	Tn – peat soil and peat-mursh soil	sapric murshic peat soil	OTsa
	P 5	Tn – fen peat soil, 3z, Ł V	Tn – peat soil and peat-mursh soil	hemic murshic soil	OMhe
	P 6	Tn – fen peat soil, 2z, Ł IV	Tn – peat soil and peat-mursh soil	hemic murshic soil	OMhe
III	P 1	Tn – fen peat soil, :ga – medium-deeply underlayed with gyttja, 2z, Ł V	Tn – peat soil and peat-mursh soil	sapric murshic soil	OMsa
	P 2	Tn – fen peat soil, :ga – medium-deeply underlayed with gyttja, 3z, Ł V	Tn – peat soil and peat-mursh soil	sapric murshic peat soil	OTsa
	P 3	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	peaty murshic gyttja soil	OTgy
	P 4	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	peaty murshic gyttja soil	OTgy
	P 5	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	peaty murshic gyttja soil	OTgy
	P 6	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	hemic murshic soil	OMhe
IV	P 1	Tn – fen peat soil, :ga – medium-deeply underlayed with gyttja, 3z, Ł V	Tn – peat soil and peat-mursh soil	hemic murshic peat soil	OThe
	P 2	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	hemic murshic peat soil	OThe
	P 3	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	sapric murshic peat soil	OTsa
	P 4	Tn – fen peat soil, 3z, Ł V	Tn – peat soil and peat-mursh soil	peaty murshic gyttja soil	OTgy
	P 5	Emt – peaty mud soil, 3z, Ł V	Emt – peaty mud soil	peaty murshic gyttja soil	OTgy
	P 6	Emt – peaty mud soil, 2z, Ł IV	Emt – peaty mud soil	peaty murshic gyttja soil	OTgy

tour should represent peaty mud soils or sapric muddy peat soils. Based on the correlation table (Table 2), in most cases, soil profiles located in the transects III and IV in the Emt contours were represented by gyttja or murshic soils, while earth-covered peat soils are not included in the correlation propsed by Świtoniak et al. (2019). The correlation table, as intended by Świtoniak et al. (2019), is a proposal of equivalents for the soil units indicated in the map, reinterpreted on the basis of solely the information of the map. Moreover, it is worth mentioning that the reinterpretation of the soil-agricultural maps should be based on detailed field and laboratory analyses and annexes to the soil-agriculture maps.

4. Discussion

At the turn of the 1960s and 1970s, peatland ecosystems were intensively used, mainly for agricultural purposes in Poland (Oleszczuk et al., 2022). Additionally, the dynamic climate change (prolonged droughts) occurring and forecasted for Europe mainly result in increased evapotranspiration from the surface of peatlands, resulting in a gradual loss of water and ultimately, in the drying of the surface layers of organic soils (Gillooly et al., 2001; Zhaojun et al., 2011, Łachacz et al., 2023).

Murshic soils occurred in 7 of 24 studied soil profiles, 6 of them were located in the contours marked as Tn, and 1 as Emt (Table 2). According to Witek (1973) murshic-peat soils (in Polish: gleby murszowo-torfowe) were described as peat soils in which the process of peat formation is currently not occurring, and the peat mass has significantly decomposed (to a depth of over 20 cm). It is worth noting that in the peatlands of the Middle Noteć River Valley showed the occurrence of mursh horizons with a thickness of mursh horizons ≥30 cm.

It should also be pointed out that several mursh horizons of the analyzed soil profiles were made of organic materials in which the TOC content was minimally higher than 12%. Assuming the progressive mineralization of organic matter, these deposits soon will not meet the criteria for the organic materials (≥12% TOC) and will be transformed into mursh-like material (another stage of peat degradation), which will be reflected in determining the systematic position of the soils in this area. In addition to the changes presented above, it should also be pointed out very narrow TOC/TN ratios (10:1-12:1) in the mursh horizons, which confirms the intensive chemical transformations of these soils. According to Szajdak et al. (2021) TOC/TN ratios below 20 indicate an intensive process of mineralization of SOM caused by periodic drying as a result of long-term drainage. The lowest TOC/TN ratios in the analyzed research area were observed primarily in the surface horizons of soil profiles, which indicates intensive mineralization of organic matter in these soil horizons. Additionally, the bulk density of the studied soil samples, especially in the case of soils from transects I and II, are clearly higher than those published for mursh horizons in soils of permanent fen peatlands in other regions of Poland (e.g. Bieniek et al., 2011; Bieniek and Łachacz, 2012; Jaszczyński et al., 2013; Glina et al., 2019; Becher et al., 2023), which may confirm intensive soil transformation.

The peat soils were represented only by 5 soil profiles (among 13) located within the Tn contour, representing fen peat soils (Table 2). According to Witek (1973) peat soils were characterized as soils with actual peat forming process, or those where this process has recently been halted, but the peat mass has not been significantly decomposed. As studied soils are nowadays under mursh-forming process, only few of them represent peat soil type (Polish Soil Classification, 2019). Earth-covered peat soils occurred in the transect I, where located in the contour marked as Emt (profile 3), and in the Tn contour (profile 6), but earth-covered peat soils were not distinguished on soil-agricultural maps (Strzemski et al., 1973), and in the Polish Soil Classification (1974, 1989). Their presence in the study area is probably the effect of human activity, e.g. digging and renovating drainage ditches to adapt peatlands for agricultural purposes. Additionally, the topographic map 1:10 000 (PUWG1965) shows, that the profiles P3-P6 of transect I are located very close to a former ditch, moreover the profile P3 is located very close or even on the former field road of Antoniny village, that no longer exists.

Currently, in the studied area, 6 soil profiles have been classified according to the current Polish Soil Classification (2019) as gyttja soils, whose occurrence was not confirmed by the soil-agricultural map. This situation is due to the fact that, gyttja soils were first described in the 4th edition of the Polish Soil Classification (1989), while soil-agricultural maps were developed for the entire area of Poland in the 1960s and 1970s, which explains the absence of this soil type on maps. In the previous Polish Soil Classification (1974), these soils were named as mud soils, which Witek (1973) described as peaty mud soil as bi- or multi-layered soils where layers of silt and peat alternate. Additionally, the gyttja soils profiles in this study were found only in the contours of Emt – but without the gyttja material recorded in the map contour description. The likely explanation could be the different location of soil pits during this work and the works leading to soil maps creation. It is also possible, that during the soil-agricultural fieldworks the gyttja material was not recognized properly and described as mud. Currently, the Emt contours are characterized by various soil types: peat soils, murshic soils, gyttja soils, and earth-covered peat soils.

The problems with the reinterpretation of the legend of soil and agricultural maps have been known since the 1960s (Kabała et al., 2022). Similar issues were encountered during the implementation of presented research. These mainly resulted from the lack of access to archival appendices to soil-agricultural maps (annexes to the soil and agricultural map), making it impossible to relate current research results to archival data and fully answer the question of whether the intensive drainage of peatlands in the 1960s and 1970s, and following agriculture use significantly influence the evolution of organic soils in the Middle Noteć River Valley. In this study, difficulties were encountered when analyzing murshic soils. Their occurrence in the study area was confirmed based on field and laboratory work, mainly in the Tn contours. However, using the criteria of the soil-agricultural map provided by Witek (1973), they would still be classified as Tn (peat soils) on the map, without changing their type. Many authors (Glina et al., 2016; Kiryluk, 2020; Orzechowski and Smólczyński, 2021, Łachacz et al., 2023) confirm the relationships between the intensive drainage of peatlands and the degree of the mursh-forming process that took place in the study area. However, without the use of archival data, it cannot be fully confirmed that the well-developed murshic horizons existed were present in the the 1960s, despite the fact that their occurrence were reported for other parts of Noteć River Valley (Marcinek, 1960). Difficulties were also encountered when analyzing the Emt contours on the soil and agricultural map of the studied area, which, according to Świtoniak et al. (2019) in the PSC (2019), correspond to peaty mud soils, a subtype of limnic soils. However, due to the high dynamism and spatial variability of shallow or periodically flooded sedimentary environments, the Emt soil contours may also include sapric murshic peat soils (Świtoniak et al., 2019). In this study, in addition to peat soils, murshic soils and gyttja soils were also observed. It is worth noting that the interpretation of data contained in soil-agricultural maps in terms of determining the systematic position of soils in accordance with the criteria of PSC (2019) is possible using correlation tables in some cases. However, it should be emphasized that the proposed equivalents refer to the entries actually provided in the contours of the map and do not correct potential errors resulting from the generalization of soil information within the contour, incorrect interpretation of spatial structure of the soil cover or errors that occurred during the editing stage of the original soil-agricultural map or its numerical version, as highlighted by many authors

(Koćmit and Podlasiński 2002; Marcinek and Komisarek 2004; Eckes and Gołda 2007; Świtoniak et al., 2019).

The most favorable solution would be to prepare new soil-agricultural maps based on a completely new field survey. However, this would generally be impossible due to financial and logistical reasons (Kabała et al., 2022). In conclusion, it can be stated that soil-agricultural maps can be a valuable source of soil-cartographic data for new (reinterpreted) soil maps, and the key issue in the widespread use of soil-agricultural maps is the limited availability of the numerical version of the map and the soil profile database, which could support the reinterpretation of archival data.

5. Conclusions

Based on the presented research results, the following conclusions have been drawn:

1. The highest variability in the studied soil types (peat soils, murshic soils, gyttja soils, earth-covered peat soils) was observed in the case of the soils located within the contours of peaty mud soils (Emt) – research transects III and IV.
2. The actual soil classification system in Poland (PSC, 2019) allows for a much more detailed characterization of organic soils than the system used when the soil-agricultural maps were created. The presence of mursh or gyttja materials in the soil profile can now be identified at the level of soil type or subtype, which is important for an accurate description of the soil cover, especially in the river valleys.
3. The analysis of selected physical and chemical properties revealed significant degradation of the uppermost soil horizons. Therefore, it seems advisable to undertake actions aimed at preventing further degradation of the soil cover in the Middle Noteć River Valley.

Conflict of interest

The authors declare no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research did not involve human or animal subjects.

Author Contributions

Tomasz Kaczmarek – Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Waldemar Spychalski** – Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. **Bartłomiej Glina** – Conceptualization, Investigation, Supervision, Writing – review & editing. All authors read and approved the final manuscript.

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Występowanie gleb organicznych na obszarze Doliny Środkowej Noteci – porównanie stanu obecnego z wydzieleniami na mapie glebowo-rolniczej

Słowa kluczowe

Użytkowanie rolnicze
Polska Centralna
Torfowiska niskie
Łąki
Mursz
Torf

Streszczenie

Mapy glebowo-rolnicze tworzone od połowy lat 60. do 80. XX wieku stanowią bardzo cenne źródło danych o przydatności a także o przestrzennym zróżnicowaniu gleb użytkowanych rolniczo w Polsce. Jednak w wyniku intensywnego wykorzystania torfowisk niskich na przełomie lat 50. i 70. ubiegłego wieku głównie na cele rolnicze, mapy glebowo-rolnicze mogły stracić na aktualności na niektórych obszarach. Odwadnianie terenów torfowiskowych wpływa negatywnie na właściwości fizyczne, chemiczne i biologiczne gleb organicznych głównie ze względu na zmniejszenie wilgotności wierzchnich poziomów genetycznych, a także wzrostu natlenienia tych warstw gleby co przede wszystkim przyczynia się do zapoczątkowania procesu murszenia. W ekstremalnych przypadkach może nawet dojść do całkowitego zaniku gleb torfowiskowych. Badania w niniejszej pracy przeprowadzono na wybranych terenach rolniczo użytkowanych torfowiskach niskich, położonych w Dolinie Środkowej Noteci, która jest jednym z największych kompleksów torfowisk niskich w Polsce. Celem niniejszej pracy była weryfikacja aktualności występowania gleb organicznych na wybranym obszarze Doliny Środkowej Noteci na podstawie wykonanych profili glebowych, w porównaniu z mapą glebowo-rolniczą. Porównanie aktualnego stanu pokrywy glebowej z danymi zawartymi na mapach glebowo-rolniczych dla obszaru badań, wykazało istotne zmiany w typologii gleb występujących w obrębie analizowanych konturów, które są efektem użytkowania rolniczego (głównie użytków zielonych) w analizowanej części Doliny Środkowej Noteci w ostatnich 50–60 latach.