

Classification issues of drained organic soils in relation to selected features of soil water regime: A case study from central Poland

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ABSTRACT

Organic soils constitute a major terrestrial carbon reservoir and play a key role in regulating climate, biodiversity, and water balance. In Poland, organic soils – mainly of peat origin – cover approximately 1.3 million hectares (4.3%), of which about 85% have been drained or hydrologically altered. Drainage modifies their water regime, leading to a drop in the groundwater table (GWT), typically oscillating between 0.3 and 1.0 m below the surface, depending on land use and drainage intensity. The lowered GWT enhances aeration and activates a cascade of transformations collectively referred to as the *mursh-forming process*. This permanent drainage creates practical problems related to the identification of organic material, which, according to the Polish Soils Classification, must meet the criterion of water saturation for more than 30 days per year (on average over a multi-year period), even after drainage. Therefore, the aim of the study was to assess the fulfillment of this criterion in *thin murshic soils* used for agricultural purposes. The research was conducted on soils within the “Racot” subirrigation facility in central Wielkopolska, Poland. Continuous measurements of GWT depth and soil moisture were carried out in 2019–2020. The murshic horizon developed in these soils had an average thickness of 33–35 cm, underlain by sandy material. Mean GWT depths ranged from 0.80 to 0.83 m below surface, with the most frequent range between 0.5 and 1.1 m. During the study period, the GWT never reached the upper boundary of the murshic horizon; only for short periods (6–9 days) did it rise to 0.3–0.4 m below the surface. The degree of water saturation (f) in the murshic horizon typically ranged between 0.60 and 0.70 $\text{m}^3 \cdot \text{m}^{-3}$, never attaining full saturation ($f=1$). Multiple linear regression revealed that GWT depth was the dominant factor controlling degree of water saturation, while precipitation and air temperature had secondary, statistically weaker effects. The results demonstrate that drained murshic horizons are not water-saturated for more than 30 days per year. In light of the research conducted, it seems reasonable to remove the obligatory criterion of water saturation (>30 days) in identifying organic material in the next edition of the Polish Soil Classification.

Keywords: drainage, organic soil, murshic horizon, organic material, degree of saturation, Polish Soil Classification.

INTRODUCTION

Organic soils constitute one of the principal reservoirs of organic carbon within terrestrial ecosystems and play a crucial role in the regulation of climate, biodiversity, and water retention

processes. These soils predominantly develop from peat deposits and, less frequently, from organic mud or gyttja (Łachacz et al., 2023). Their formation occurs under conditions of excessive soil moisture, an environmental state in which limited oxygen availability inhibits or slows

down the microbial decomposition of organic debris, primarily of plant origin (Systematyka Gleb Polski – SGP, 2019). Although peatlands cover only about 4% of the Earth's terrestrial surface, they store nearly 30% of the global soil organic carbon (Joosten and Clarke, 2002; Xu et al., 2018; IPCC, 2023). The most recent National Inventory Report for Poland (Bebkiewicz et al., 2022) indicates that organic soils, mainly of peat origin, occupy about 1.3 mln ha, corresponding to roughly 4.3% of Poland's land surface. It is estimated that approximately 84–86% of these organic soils have been drained or hydrologically altered, mainly for agricultural use, leading to substantial losses of organic carbon and peat degradation (Joosten et al., 2012; Kotowski et al., 2017; Bebkiewicz et al., 2022). Such drainage alters their water regime, understood as the entirety of periodic variations in soil moisture conditions, including water retention capacity, the dynamics of water flow within the soil profile, and fluctuations in the groundwater table (GWT) (Bouma, 1983; Yaalon, 1983; Soil Science Division Staff, 2017). After drainage, GWT depths in these soils typically range between 0.3 and 1.0 m below the surface, depending on land use type and drainage intensity (Paavilainen and Päivänen, 1995; Holden et al., 2004; Evans et al., 2021). The lowering of the GWT enhances aeration within the soil profile, initiating a series of processes that profoundly transform the properties of organic soils, known as the mursh-forming process (Łachacz et al., 2023; SGP, 2019).

Modern soil classification systems are regarded as dynamic representations of the current state of knowledge concerning soil genesis, properties, and functions, and are continuously modified in response to changing environmental conditions and advances in soil science (Krasilnikov et al., 2009; Buol et al., 2011; SGP, 2019). Climate change, land use transformations, intensification of anthropogenic activities, and ongoing degradation processes affect both the course of pedogenic processes and the variability of diagnostic properties employed in classification systems.

In the SGP2019, organic soils – similarly to those in other widely applied classification systems (IUSS Working Group (WRB), 2022; Soil Survey Staff (SST), 2022) – are identified based on the presence of a diagnostic organic material that must meet specific quantitative criteria. According to SGP (2019), organic materials such as peat, gytja, organic mud, or mursh must not only contain

a minimum organic carbon (OC) content of more than 12%, but must also meet the criterion of being water-saturated for at least 30 days per year (on average over a multi-year period), even after drainage. In contrast, the SST (2022) classification applies this temporal saturation requirement only to undrained organic materials, while the fourth edition of WRB (2022) has completely abandoned this criterion, despite its long-term application in previous editions. Considering the drainage of organic soils in Poland, it seems reasonable to check whether these soils are characterized by organic material that meets the quantitative criteria of SGP (2019). Therefore, the objective of this study was to assess the fulfillment of the 30-day water-saturation criterion based on selected elements of the water regime in thin murshic soils used for agriculture in central Poland.

MATERIALS AND METHODS

Study area

The study was conducted at the “Racot” sub-irrigation facility (52°03'47" N, 16°41'46" E), located in the lower section of the Wyskoć ditch, which is a right tributary of the Kościański Canal of the Odra River (Figure 1). Administratively, the Racot subirrigation facility is situated in the Wielkopolska Voivodeship, Kościan Municipality, approximately 4 km southeast of Kościan city of and about 1 km northwest of Racot village. According to the physiographic division by Solon et al. (2018), it is located within the Krzywiń Lakeland mesoregion of the Leszno Lakeland macroregion. In the studied area, thin organic materials occur, underlain by fluvial sands.

At the Racot subirrigation site, four experimental plots (Kw1, Kw2, Kw3, and Kw4) were delineated for the implementation of the IN-OMEL project (see Acknowledgements). Within these plots, systematic measurements of GWT depths and soil moisture were conducted during the period 2019–2020. The soils of the studied subirrigation site are used as a three-cut meadow equipped with a subsurface irrigation system that regulates the water regime in this area. This system is based on control weirs installed on ditches. These weirs allow for the regulation of water levels in the ditches and, consequently, control the GWT between them. For the purposes of this study, we present the results of stationary

measurements of soil organic material moisture and GWT depth in the experimental plots Kw3 (Rac 1) and Kw4 (Rac 2), carried out from January 1, 2019, to June 19, 2020 (Figure 1).

Soil sampling and measurements

At the beginning of the field research, soil diversity within the plots was determined using the scattered points method, which allowed for the selection of representative pedons for further hydrogeological measurements. These pedons were designated in the center of the plots (in the middle of the field), between ditches serving drainage and irrigation functions (Figure 1). The depth of the ditches ranged from 0.65 m to 0.85 m on average. Piezometers and soil moisture probes were installed in these pedons. GWT measurements were carried out using U20L-04 Hobo and 30001 LTC Solinst hydrostatic pressure recorders, while soil water content was measured using an ADCON SM 10 probe. These measurements were taken at hourly intervals, which were averaged over a 24-hour period for the purposes of this study. The morphological description of the soils and their taxonomic classification were determined on the basis of soil profiles. Monolithic soil samples with disturbed and undisturbed structures were taken from each soil horizon. The bulk density (BD) was determined in 100 cm³ sample (ISO 11272, 2017), and the particle density (PD) was determined using

the pycnometric method (ISO 11508, 2017). The total soil porosity (SP) was determined based on the relationship between BD and PD. Soil water retention curves (SWRC) up to 100 kPa were determined using Richards pressure chambers, and for lower matric potentials, by the vapor pressure method above sulfuric acid solution (Campbell and Gee, 1986; Klute, 1986). The SWRCs were fitted using the van Genuchten equation (van Genuchten et al., 1991) with the Mualem constraint $m = 1 - 1/n$, where m and n are model parameters. The general characteristics of soil retention properties were determined by identifying the water content at characteristic matric potentials: saturated water content Θ_c (m³ m⁻³) at 0 kPa, field capacity Θ_{FC} (m³ m⁻³) at -10 kPa, and permanent wilting point Θ_{WP} (m³ m⁻³) at -1500 kPa, and by calculating the drainage porosity AFP ($AFP = \Theta_c - \Theta_{FC}$). Saturated hydraulic conductivity (K_{sat}) was determined using the constant head method (Klute and Dirksen, 1986). Based on actual soil moisture (θ_a) in the 30 cm thick murshic horizon and θ_c , the degree of saturation index ($f = \theta_a / \theta_c$) was calculated, which equals 1 for a fully saturated soil, where all pores are filled with water and no air is present.

Meteorological conditions

The meteorological conditions for the analyzed area were determined based on data obtained from the Institute of Meteorology and

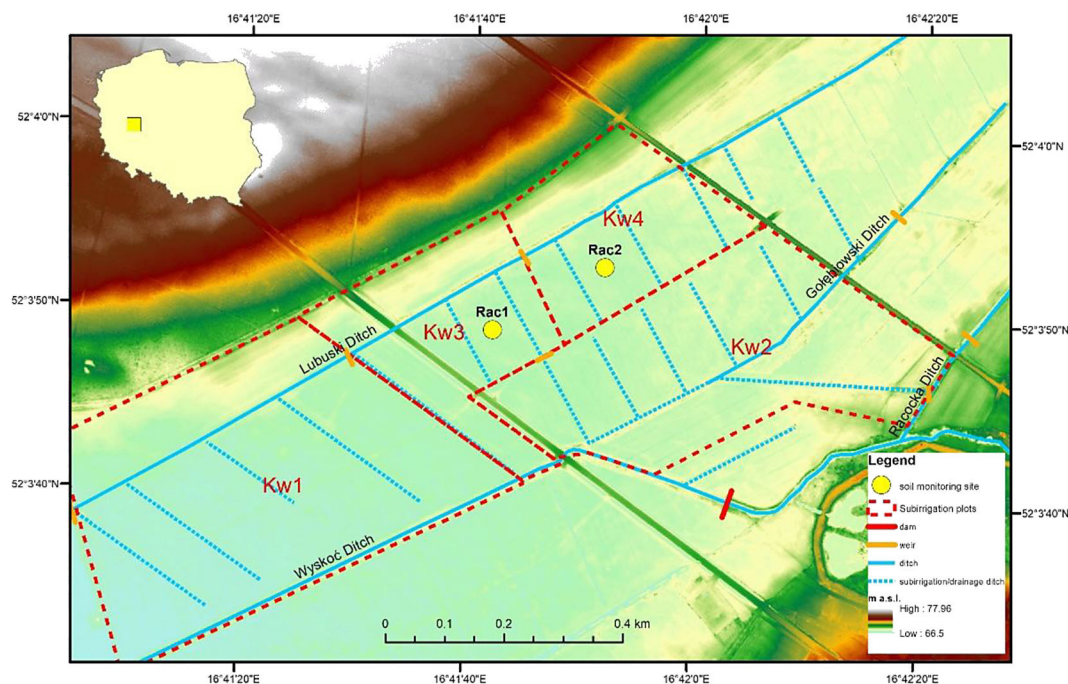


Figure 1. Location of study area

Water Management – National Research Institute (IMGW-PIB) from a meteorological station located in Kościan. This station is located 5 km from the Racot research plots.

Statistical analyses

For the purposes of this study, frequency analysis was applied to the measurement data of GWT depth as well as to the f . The measurement results of these elements of the soil water regime were also presented using boxplots. The relationship between the f values of the *murshic* horizon and GWT depth, precipitation (P), and temperature (T) was determined using multiple linear regression analysis (MLR). All statistical computations were performed using Statistica 13.0 (TIBCO Software Inc., Palo Alto, CA, USA).

RESULTS

Meteorological circumstances

In terms of monthly precipitation totals in 2019, there were extremely dry months (June), very dry months (April), dry months (January, July, October), normal (March, August, December), wet (May), very wet (September, November) and extremely wet (February) (Table 1). Also in 2020, individual months were characterized by varying precipitation conditions: extremely dry (April), very dry (November), dry (December), normal (January, March, June, July, September), wet (May, August) and extremely wet (February, October). In 2019, the month with the highest precipitation was May (75 mm), whereas in 2020 it was August (87 mm). In turn, the lowest monthly precipitation in 2019 was in June (9

mm), while in 2020 it was in April (1 mm). Despite differences in monthly precipitation totals between the analyzed years relative to the long-term monthly means, the annual precipitation in 2019 and 2020 did not differ significantly from the average for 1991–2020. The annual precipitation for the study area amounted to 495 mm in 2019 and 540 mm in 2020 (Table 1), representing 97% and 106%, respectively, of the mean annual precipitation for 1991–2020. Therefore, both analyzed years can be classified as normal in terms of precipitation conditions.

General soil properties

Within the “Racot” site, soils with a thin *murshic* horizon occur, with an average thickness of 33–35 cm (Table 2). In the irrigation plot Kw3, the *murshic* horizon is approximately 33 cm thick, while in Kw4 it is about 35 cm. This horizon is underlain by sandy material with a sand texture and distinct gleyic properties. In terms of taxonomy, considering only the criteria of organic carbon (OC) content required for distinguishing organic material and its thickness, the soils of the “Racot” site can be classified as thin *murshic* soils according to SGP (2019), as Eutric Histic Gleysols (Arenic, Drainic) according to WRB2022, and as Histic Humaquepts according to ST2022. The OC content in the surface organic material (*murshic* horizon) ranged from 204.7 to 315.1 g·kg⁻¹ and 282.9 to 336.3 g·kg⁻¹, respectively, in the soils of irrigation plots Kw3 (Rac 1) and Kw4 (Rac 2). In the underlying mineral horizons, the OC content was considerably lower (Table 2).

In the analyzed soils, bulk density (BD) values also showed distinct vertical differentiation (Table 3). The *murshic* horizons were characterized by

Table 1. Precipitation totals by month in 2019 and 2020 and total precipitation for the thirty-year period from 1990–2020 in Kościan meteorological station

Month	January	February	March	April	May	June	July	August	September	October	November	December	Sum
Monthly precipitation totals in 2019 (mm)	25	66	41	10	75	9	53	61	63	18	54	20	495
Monthly precipitation totals in 2020 (mm)	29	73	30	1	66	56	62	87	35	69	11	21	540
Average precipitation totals from the period of 1991–2020 (mm)	34	28	36	27	50	56	77	64	39	34	32	32	509

Table 2. Summary of texture, OC, BD, PD, SP, and pH in the analyzed soil profiles

Horizon*	Depth (cm)	Soil fraction (%)			Texture	OC	BD	PD	SP	Soil reaction
		2.0–0.05 mm	0.05–0.002 mm	<0.002 mm		g kg ⁻¹	Mg m ⁻³		m ³ m ⁻³	pH _{KCl}
Rac 1 (Kw3)										
Md1	0–20	-	-	-	-	315.1	0.452	1.918	0.764	7.04
M2	20–33	-	-	-	-	204.7	0.664	2.250	0.705	7.13
C/M	33–37	92	6	2	fS	13.0	1.478	2.605	0.432	7.28
Cgg	36–60	96	3	1	fS	2.5	1.639	2.641	0.380	7.46
G	60–95	94	4	2	fS	1.9	1.614	2.643	0.389	7.98
Rac 2 (Kw4)										
Md1	0–18	-	-	-	-	336.3	0.422	1.792	0.764	7.01
M2	18–35	-	-	-	-	282.9	0.366	1.889	0.806	7.08
MC	35–42	92	6	2	fS	77.1	0.822	2.388	0.656	7.22
Cgg	42–64	94	5	1	fS	2.8	1.598	2.639	0.394	7.63
G	64–90	95	4	1	fS	2.3	1.647	2.641	0.376	8.01

Note: * – soil horizon and suffix designation according to SGP (2019), OC – organic carbon, BD – bulk density, PD – particle density, SP – total soil porosity.

markedly lower BD values (0.366–0.664 Mg·m⁻³) compared with the mineral horizons (1.598–1.647 Mg·m⁻³). As a consequence of the vertical differentiation of OC content, clear differences were also observed in PD values. In the murshic horizon, PD ranged from 1.792 to 2.250 Mg·m⁻³, whereas in the underlying mineral horizons, it ranged between 2.639 and 2.643 Mg·m⁻³. An opposite trend to BD was observed for SP and AFP. In the murshic, SP and AFP values ranged from 0.705 to 0.806 m³·m⁻³ and from 0.174 to 0.180

m³·m⁻³, respectively. In the underlying sandy mineral horizons, these values were lower, ranging from 0.376 to 0.394 m³·m⁻³ and from 0.167 to 0.238 m³·m⁻³, respectively (Table 2, 3). In the identified transition horizons, SP and AFP values were also lower than in the surface horizon. In the case of Θ_c , Θ_{FC} , and Θ_{wp} , large differences in values were also noted between the murshic horizon and the underlying sandy mineral. In the murshic horizon, θ_{FC} ranged from 0.553 to 0.599 m³·m⁻³ and θ_{wp} from 0.231 to 0.288 m³·m⁻³, whereas in

Table 3. Water retention and hydraulic properties of the analyzed soil

Horizon	Depth (cm)	Θ_c	Θ_r	α	n	k_{sat}	Θ_{FC}	Θ_{wp}	AFP
		$m^3\ m^{-3}$		-	-	$m\ d^{-1}$	$m^3\ m^{-3}$		
Rac 1 (Kw3)									
Md1	0–20	0.751	0.000	0.0648	1.1391	5.250	0.571	0.288	0.180
M2	20–33	0.727	0.000	0.0397	1.1791	5.089	0.553	0.231	0.174
C/M	33–37	0.417	0.000	0.0180	1.2845	3.544	0.324	0.085	0.093
Cgg	37–60	0.379	0.007	0.0316	1.7295	6.309	0.159	0.011	0.220
G	60–95	0.367	0.010	0.0181	1.8459	7.494	0.200	0.013	0.167
Rac 2 (Kw4)									
Md1	0–18	0.759	0.000	0.0511	1.1651	5.477	0.568	0.253	0.190
M2	18–35	0.778	0.000	0.0336	1.1873	8.700	0.599	0.242	0.178
CM	35–42	0.584	0.000	0.4826	1.1200	3.413	0.366	0.201	0.218
Cgg	42–64	0.384	0.007	0.0516	1.5909	5.968	0.147	0.015	0.238
G	64–90	0.367	0.000	0.0291	1.6115	7.742	0.180	0.009	0.188

Note: Θ_c – saturated water content, Θ_r – residual water content, α – van Genuchten equation parameter related to the inverse of the air entry suction, n – van Genuchten equation parameter related to the measure of the pore-size distribution, k_{sat} – saturated hydraulic conductivity, Θ_{FC} – field capacity, Θ_{wp} – permanent wilting point, AFP – drainage porosity.

the sandy subsurface horizons these values were considerably lower, ranging from 0.147 to 0.200 $\text{m}^3 \cdot \text{m}^{-3}$ and 0.009 to 0.015 $\text{m}^3 \cdot \text{m}^{-3}$ for θ_{FC} and θ_{WP} , respectively (Table 3).

Groundwater and soil moisture condition

The temporal dynamics of GWT depth in the investigated soils are presented in Figure 2. In 2019, the highest GWTs were recorded during January–February, mostly at a depth of 0.4–0.5 m b.s.l. The shallowest GWT depths were observed in the third decade of January, both in the Rac 2 (Kw4) (0.32 m b.s.l.) and in Rac 1 (Kw3) (0.35 m b.s.l.), reaching only the lower part of the murshic horizon. Subsequently, a clear decrease in GWT was recorded until May. May was characterized by wet precipitation conditions, which caused a rise in GWT to about 0.4 m b.s.l. Thereafter, a systematic decrease in GWT occurred until the third decade of August, when the lowest GWTs were recorded at approximately 1.20 m b.s.l. in both Rac 1 (Kw3) and Rac 2 (Kw4) soils. From August 2019 to March 2020, GWT regeneration was observed. In the first decade of March 2020, the shallowest GWT depths for that year occurred, averaging about 0.55 m b.s.l., not extending into the murshic horizon. These shallow GWTs were a result of high precipitation in the third decade of February, classified as extremely wet. After this period, a gradual lowering of the GWT depth was again recorded. Figure 3 shows

the frequency distribution of GWT depths in the analyzed soils. The data indicate that, during the entire monitoring period, the GWT never fully reached the entire murshic horizon. Only in March 2019 were the groundwater tables (GWTs) within the lower parts of this horizon. In soil Rac 1 (Kw3), the GWT depths ranged from 0.3 to 0.4 m b.s.l. and persisted for only 6 days, whereas in soil Rac 2 (Kw4) they remained for 9 days. Throughout the entire study period, GWT depths most frequently ranged from 0.5 to 1.1 m b.s.l. in soil Rac 1 (Kw3), and from 0.4 to 1.1 m b.s.l. in soil Rac 2 (Kw4). The mean GWT depths during the measurement period did not differ significantly between the analyzed soils and amounted to 0.83 and 0.80 m b.s.l. for Rac 1 (Kw3) and Rac 2 (Kw4), respectively (Figure 4).

Figure 5 presents the temporal variations of the water saturation in the murshic horizon. The data indicate that in 2019, the highest f values occurred during the third decade of January, reaching approximately 0.8 $\text{m}^3 \cdot \text{m}^{-3}$ in both soil Rac 1 (Kw3) and Rac 2 (Kw4). Subsequently, a pronounced decrease in the f was observed until May, when a substantial amount of precipitation caused a short-term increase in GWT and f values. Thereafter, a systematic decline in f continued until the first decade of July. Between the first decade of July and the second decade of August, the lowest f values in 2019 were recorded, generally ranging from 0.46 to 0.52 $\text{m}^3 \cdot \text{m}^{-3}$. In the following

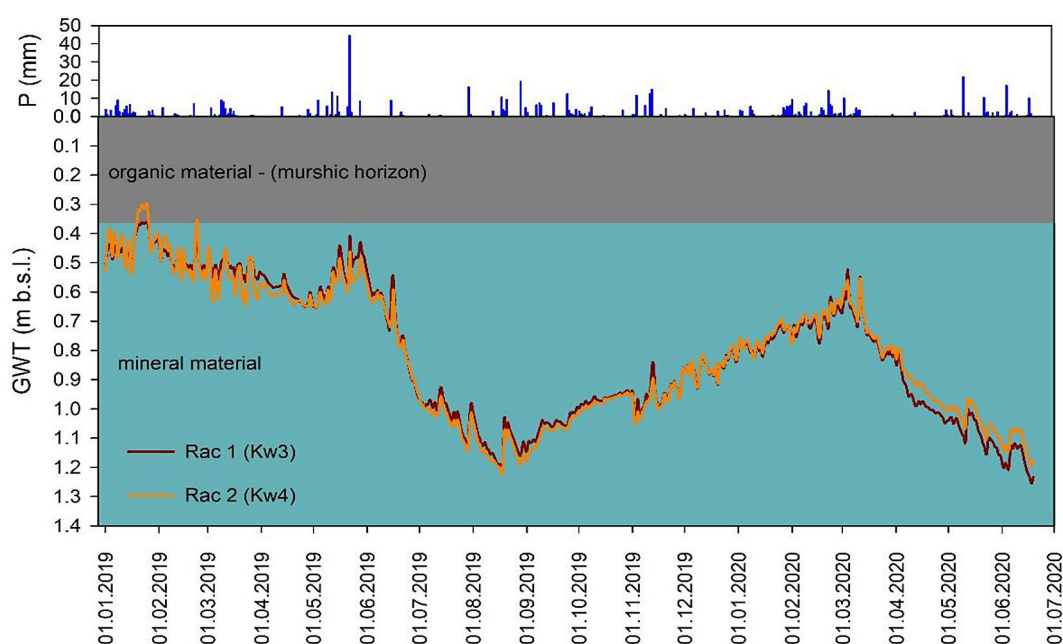


Figure 2. Groundwater table dynamics (GWT) in the analyzed soils against precipitation (P)

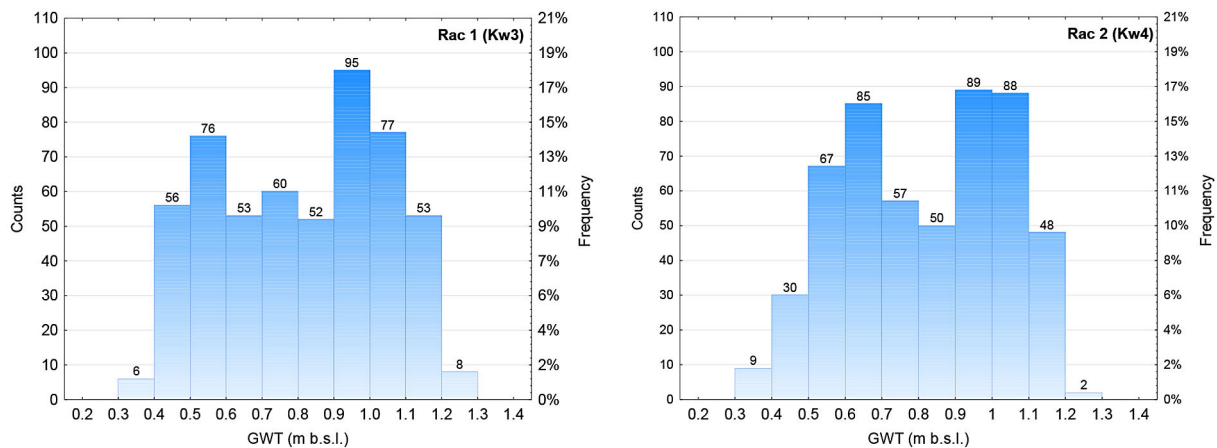


Figure 3. Frequency of GWT depths in the analyzed soils of the “Racot” irrigation facility

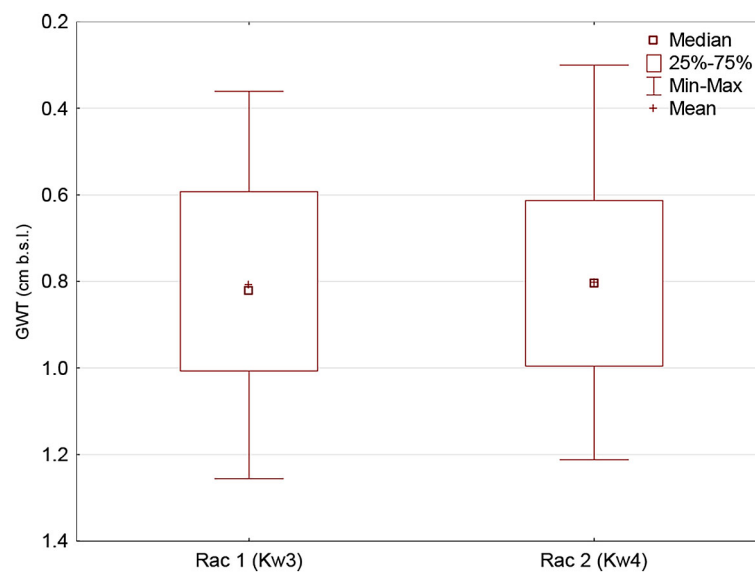


Figure 4. Average and median GWT depths in the analyzed soils of the “Racot” irrigation facility

months, an increase in f values was observed in the murshic horizon. In the first decade of March, the highest f values in 2020 were recorded; however, as in 2019, they remained below 1. This indicates that the murshic horizon was not fully saturated with water. From March 2020, a distinct decrease in f values was again observed. During the entire measurement period, f values most frequently ranged between 0.60 and 0.70 $\text{m}^3 \text{m}^{-3}$ in both soils Rac 1 (Kw3) and Rac 2 (Kw4) (Figure 6). No moisture states corresponding to the saturated water content (θ_c), where f would equal 1, were recorded. The highest f values, ranging from 0.80 to 0.75 $\text{m}^3 \text{m}^{-3}$ occurred for 8 days in soil Rac 1 (Kw3). In soil Rac 2 (Kw4), f values within the range of 0.85–0.80 $\text{m}^3 \text{m}^{-3}$ were observed for only 3 days, while values between 0.80 and 0.75 m^3

m^{-3} for 16 days. The mean f values in the murshic horizon did not differ significantly between the soils of the analyzed plots. In the organic material of soil Rac 1 (Kw3), the mean f value during the measurement period was 0.61 $\text{m}^3 \text{m}^{-3}$, whereas in soil Rac 2 (Kw4) it was 0.62 $\text{m}^3 \text{m}^{-3}$ (Figure 7).

The moisture state and the associated degree of saturation of the murshic horizon in the soils of the “Racot” irrigation site are closely related to the depth of the GWT. Table 4 presents the results of a multiple regression analysis conducted to examine the relationships between the f of the murshic horizon in the analyzed soils and precipitation, temperature, and GWT depths. For both soils Rac 1 (Kw3) and Rac 2 (Kw4), a significant relationship was found between f and GWT depth as well as temperature. The values of the

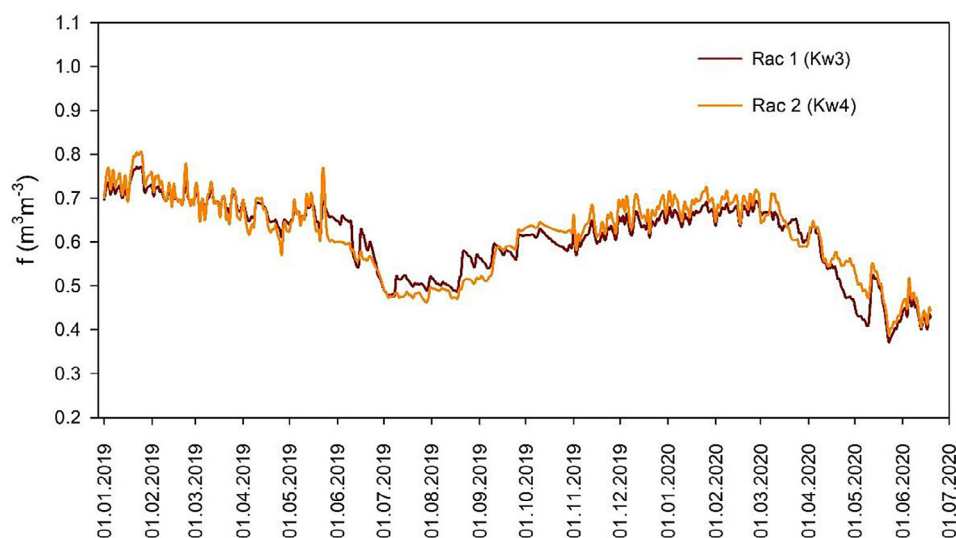


Figure 5. Temporary changes in the degree of water saturation (f) of the murshic horizon in the analyzed soils of the “Racot” irrigation facility

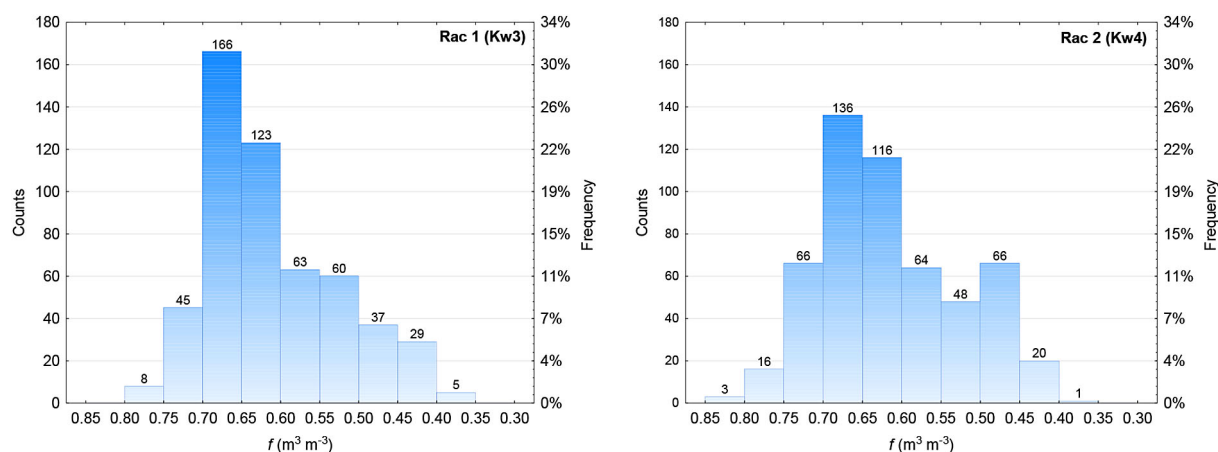


Figure 6. Frequency of the degree of water saturation (f) of the murshic horizon in the analyzed soils of the “Racot” irrigation facility

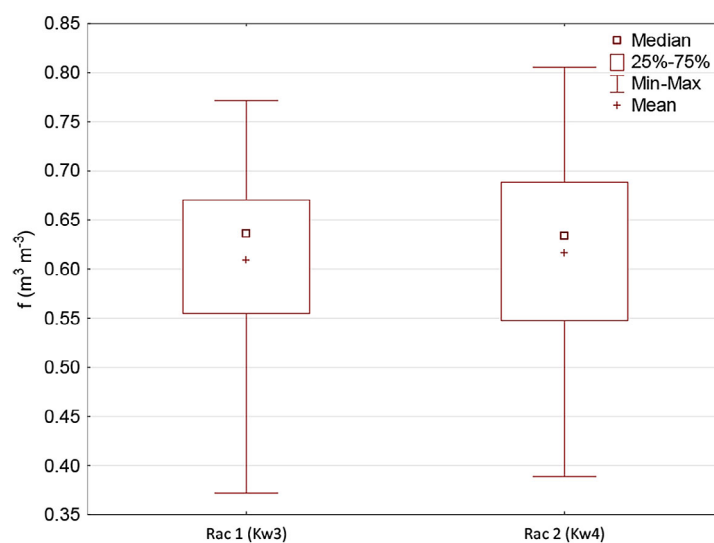


Figure 7. Average and median degree of water saturation of organic material in the analyzed soils of the “Racot” irrigation facility

standardized regression coefficients indicate that GWT depth had the greatest impact on moisture content and, consequently, on the degree of water saturation of the murshic horizon. With increasing GWT depth, f values decreased. Temperature also significantly affected f , and this relationship was likewise negatively correlated. A positive correlation was observed between precipitation and the f of the murshic horizon; however, this relationship was not statistically significant during the analyzed period.

DISCUSSION

Soil degradation and classification

The soils of the Racot subirrigation facility constitute a characteristic part of the soil cover of the Racocki basin of the Obra River valley. At the end of the 18th century, this area was described as shallow lakes overgrown with reeds, as well as swamps and marshes. Between 1979 and 1806, a series of drainage works were carried out in the valley with the aim of draining the soil and gradually incorporating it into agricultural production (Marcinek and Spsychalski, 1998). The most intensive period of drainage activity in Poland occurred during the in the 1960s and 1970s (Oleszczuk et al., 2022). As a result, the organic material in these soils underwent significant drainage-related transformations known as the mursh-forming process (Łachacz et al., 2023; SGP, 2019; WRB, 2022). The mursh-forming

process is inherently related to the mineralization of soil organic matter and leads to a reduction of soil organic carbon, resulting in a drop in the thickness of the organic layer and subsidence of the organic deposit surface (Dawson et al. 2010; Leifeld et al. 2011; Glina et al., 2016; Oleszczuk et al., 2021, 2022; Ma et al. 2022). This sometimes leads to the disappearance of organic soils and their transformation into mineral soils (Lipka et al., 2017; Kabała et al., 2022; Łachacz 2021, Łachacz et al., 2023, 2024). It seems that the soils analyzed in the “Racot” facility have undergone significant changes due to drainage. The thickness of the murshic horizon in these soils currently does not exceed 35 cm, while on the 1:5000 soil-agricultural map, drawn up in the 1970s, these soils were designated as Tn. According to Witek (1973), the soil map unit Tn refers to peat soil and peat-mursh soil, in which the thickness of organic material is at least 150 cm.

The analyzed soils, based solely on the criteria of organic carbon (OC) content and the thickness of the organic material, were classified according to the Polish Soil Classification, 6th edition (SGP, 2019), as thin murshic soils. According to the World Reference Base for Soil Resources (WRB, 2022), due to the thickness of the organic material being less than 40 cm, these soils were identified as Eutric Histic Gleysols (Arenic, Drainic), while in the Soil Taxonomy (SST, 2022), they correspond to Histic Humaquepts. The diagnostic murshic horizon developed in the analyzed soils (according to the SGP (2019) classification) has no direct equivalent in the WRB (2022)

Table 4. Results of multiple linear regression estimation of the murshic horizon water saturation (f) in the analyzed soils (Rac 1 and Rac 2)

Explanatory variable	Regression summary for dependent variable f for Rac 1 soil $r=0.86$ $r^2=0.74$					
	b^*	Std. Err. of b^*	b	Std. Err. of b	$t(532)$	p-value
(constant)			2.349	0.055	42.581	0.000
Rac 1 GWT	-0.914	0.029	-2.479	0.079	-31.309	0.000
P	0.022	0.023	0.002	0.002	0.970	0.484
T	-0.166	0.031	-0.005	0.001	-2.951	0.003
Explanatory variable	Regression summary for dependent variable f for Rac 2 soil $r=0.81$ $r^2=0.66$					
	b^*	Std. Err. of b^*	b	Std. Err. of b	$t(532)$	p-value
(constant)			2.360	0.074	32.035	0.000
Rac 2 GWT	-0.957	0.040	-2.421	0.102	-23.656	0.000
P	0.026	0.025	0.002	0.002	1.032	0.303
T	-0.193	0.040	-0.006	0.001	-4.769	0.000

Note: P – precipitation, T – temperature, Rac 1 GWT – groundwater table depth in Rac 1 soil, Rac 2 GWT – groundwater table depth in Rac 2 soil, b^* – standardized regression coefficients, b – raw regression coefficients.

classification, in which its identification is based on criteria similar to those for the histic horizon, with additional requirements corresponding to the murshic principal qualifier (refers to histic degradation due to drainage and further pedogenic transformation with structure development). Unfortunately, the murshic principal qualifier can only be used to the Histosols Reference Soil Group. The results of our study indicate that the murshic principal qualifier should also be added to the Gleysols Reference Soil Group.

Water saturation of murshic horizon

Modern soil classification criteria, including those of SGP (2019), are based on precise, quantitatively defined diagnostic features of horizons, materials, and properties (WRB, 2022; SST, 2022). According to the SGP (2019) criteria, organic materials such as peat, gyttja, organic mud, or mursh, in addition to meeting the minimum OC content threshold ($\geq 12\%$), must also fulfill the condition of being water-saturated for at least 30 days per year (on average over a multi-year period), even after drainage. Our hydropedological research results for the Racot facility indicate that the murshic horizons in drained soils are not saturated with water for more than 30 days in an average year. This is associated with GWT occurring deeper than 0.3 m b.s.l. In the analyzed years (2019–2020), which were average in terms of meteorological conditions, no GWT depths covering the entire murshic horizon were observed. Only for some short period days (6–9 days) were GWT depths observed in the range of 0.3–0.4 m b.s.l., affecting only the lower part of the murshic horizon. The average GWT depths from the measurement period in the analyzed soils were approximately 0.80–0.83 m b.s.l., with the most frequent GWT depths ranging between 0.4(0.5)–1.1 m b.s.l. Similar observations were reported by Kiryluk (2020), Oleszczuk et al. (2021), Jarnuszewski et al. (2023) and Kocięcka et al. (2023a, 2023b), who found that in drained, agriculturally used organic soils, the GWT remains below the soil surface and does not encompass the full thickness of the organic material. Even the use of controlled drainage (CD) in such soils, which clearly affects the increase in GWT (Kocięcka et al., 2023a), does not result in GWT reaching the soil surface and lasting for >30 days. Not only the drained organic soils occurring in Poland, but also those developed under different climatic conditions, are characterized by GWT

depths significantly below the upper boundary of the organic material (Mäkelä et al. 2025; Tähtikarhu et al., 2025), particularly if they are deeply drained (Pierce et al., 2025).

The consequence of lowering the GWT, which usually ranges between 0.3 and 1.0 m b.s.l. after drainage, depending on the type of use and intensity of drainage (Paavilainen and Päivänen, 1995; Holden et al., 2004), is the moisture state of the upper parts of organic material. The results of the study indicate that the murshic horizons in the analyzed soils are not saturated with water for a period of >30 days. Degree of water saturation index (f) values lower than 1 confirm that the measured actual water contents (θ_a) were smaller than those corresponding to full saturation (θ_c). The highest f values were recorded in winter months, reaching 0.80–0.75 $\text{m}^3 \cdot \text{m}^{-3}$ in Rac1 soil and persisting for 8 days, while in Rac2 soil, a slightly higher range of maximum values (0.85–0.75 $\text{m}^3 \cdot \text{m}^{-3}$) was observed, persisting for 18 days. In contrast, during the summer months, the lowest f values were observed, indicating severe drying of the murshic horizon. The results presented in other studies (Oleszczuk et al., 2021; Kocięcka et al., 2023a; 2023b; Tähtikarhu et al., 2025) also do not indicate that the upper parts of drained organic soils are completely saturated with water for a longer period (>30 days). Our research results indicate that temporary changes in the f of the murshic horizons in organic soils are characterized by distinct seasonal variability mainly related to the dynamics of GWT depths. This is confirmed by the results of multiple linear regression analysis (Table 4), which are consistent with reports in the literature, that water content in surface organic horizons is directly determined by GWT depths (Tähtikarhu et al., 2025; Pierce et al., 2025).

Folik and histik classification issues

In light of the research results presented in this paper, it seems justified to remove the obligatory criterion of water saturation (>30 days) for identifying organic material in the revised edition of the Polish Soil Classification. This requirement may not be fulfilled by the majority of drained organic soils in Poland, which constitute approximately 84–86% (Joosten et al., 2012; Kotowski et al., 2017; Bebkiewicz et al., 2022.). In the WRB (2022), SST (2022), and SGP (2019) soil classifications, the quantitative criterion of water saturation (in most years) must be met for

the identification of the diagnostic horizons folic (folistic in SST (2022), folik in SGP (2019)) and histic (histik in SGP (2019)). In the case of the folic (folistic or folik) horizon, it must be saturated with water for < 30 consecutive days in most years and not drained, while the histic (or histik) horizon must be saturated with water for ≥ 30 consecutive days in most years or be drained. Therefore, the identification of diagnostic folic (folistic or folik) or histic (histik) horizons requires long-term measurements of their moisture content, which are not carried out in studies on organic soils. Consequently, in future editions of the Polish Soil Classification, it should be considered to remove such quantitative criteria and replace them with qualitative indicators related to the pedogenic conditions under which these organic horizons form – criteria that can be reliably determined during field soil description.

CONCLUSIONS

Within the Racot subirrigation facility, there are thin murshic soils, which are designated as Tn with thicker organic material on soil-agricultural maps. At present, the thickness of the organic material does not exceed 40 cm, which provides evidence of the permanent drainage-induced degradation of these soils. This degradation has led to a reduction in the original thickness of the organic deposit and its pedogenic transformation into mursh. Based on a two-year measurement period, no occurrence of GWT persistence exceeding 30 days within the murshic horizon was observed that would result in its full water saturation. The GWT was generally recorded at depths ranging from 0.4 to 1.1 m b.s.l., while only in the lower parts of the murshic horizon was a short-term GWT presence observed. As a consequence of the drainage of organic soils for agricultural purposes, the moisture content of the murshic horizon remains below the saturated water content. This is confirmed by the degree of saturation values, which during the analyzed period (2019–2020) were below 1, indicating at the same time the absence of a period of water saturation of the murshic horizon. According to the current moisture-based criterion for identifying organic material in the SGP (2019), the murshic horizon in the studied soils does not meet the required condition of being saturated with water for at least 30 consecutive days per year. Therefore, it seems

justified that in the next edition of the Polish Soil Classification, the moisture criterion for the identification of organic material should be removed. The results of our study indicate that the murshic principal qualifier should also be added to the Gleysols Reference Soil Group in the next edition of the WRB International Soil Classification.

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