POLISH JOURNAL OF SOIL SCIENCE
VOL. XLVIII/1 2015 PL ISSN 0079-2985

DOI: 10.17951/pjss/2015.48.1.65

Soil Chemistry

MACIEJ MARKIEWICZ, ŁUKASZ MENDYK, SŁAWOMIR S. GONET*

SOIL ORGANIC MATTER STATUS IN AGRICULTURAL SOIL SEQUENCE OF FORMER SHORELINE OF DISAPPEARING SUMOWSKIE LAKES, NORTH-EASTERN POLAND

Abstract. The aim of the study has been to define the stocks and the basic properties of soil organic matter in agricultural-used soil sequence located in the former shoreline of disappearing lakes. The study area is located in the catchment of the Sumowskie Lakes, the Brodnica Lake District, North-Eastern Poland. The investigations involved preparation of five soil pits located in the south-western part of the former Sumowskie Lake bottom and on the southern slope of the adjacent kame hill. The greatest soil transformation is reflected in the quality and quantity of the soil organic matter. Indexes of organic matter quality and TOC stocks are significantly changing along the studied transect. The strongly humidified organic matter is found in mursh horizons. Gyttja layers above the groundwater level have a medium humification index. Horizons saturated with water are very low humidified. TOC stocks drop along the analysed soil sequence from the biogenic plain to the top of the kame hill.

The process of lakes disappearing occurs worldwide and is caused by both natural factors and human activities. At a certain stage of evolution, the dwindling lakes act as wetlands which are rated among the most important natural resources on earth. They cover about 5% of the land surface. They provide a potential sink for atmospheric carbon. Drainage and cultivation of wetlands increase the soil aeration and reverse the carbon flux into net carbon dioxide (CO_2) emissions. Thus, the soil organic carbon (SOC) changes in wetlands are closely related to climate change.

Soils are considered as a very good and relatively fast indicator of any environmental change. The changes affect not only those soils which are closely

* M. Markiewicz, DSc., Ł. Mendyk, Prof. S. Gonet, DSc., Department of Soil Science and Landscape Management, Nicolaus Copernicus University in Toruń, Lwowska 1, 87-100 Toruń, Poland.

linked to a high level of groundwater, but also mineral soils occurring in the immediate vicinity of those water bodies. Many of these changes are adverse, which leads to both physical and chemical degradation of soils, and consequently also decrease their value-in-use [4]. These are also the areas with completely new soils, originating from the exposed lacustrine sediments, which also undergo further evolution dependent on their dehydration. The existence and development of specific soils within the area of the bottom of the former Sumowskie Lake is confirmed by the studies of i.a. [10, 17, 19, 20].

The aim of this paper has been to define the stocks and the basic properties of soil organic matter in the agricultural-used soil sequence located in the former shoreline of the disappearing Sumowskie Lakes.

MATERIALS AND METHODS

The study area was located in the catchment of the Sumowskie Lakes, the Brodnica Lake District, Northern Poland (Fig. 1). The water level of the former Sumowskie Lake, which in 1860–1874 was still a single water body [10], has lowered due to natural and anthropogenic processes, forming two separate water bodies (about 15.1 ha and 10.3 ha) connected with each other by a ditch. Since 1860, the surface area of this lake has decreased by 72.6% [10]. The hydrographic network in the direct catchment of the Sumowskie Lakes is very well developed. However, this results mostly from the conducted drainage work.

The investigations involved preparation of five soil pits located in the south-western part of the former Sumowskie Lake bottom and on the southern slope of the adjacent kame hill (Fig. 1 and 2). This soil sequence in catena is the typical one for the undulated young glacial landscape of north-eastern Poland.

The samples for laboratory analysis were taken from all the genetic horizons and layers and the following soil analysis was conducted [2, 27]: bulk density by the oven-dry method, solid particle density was calculated by the Marcinek and Spychalski equation [14], porosity was calculated by the equation [2], hygroscopic water content – by measn of the oven-dry method, loss of ignition at a temperature of 550° for 3 hours, organic carbon content − by oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4, total nitrogen content − Kjeldahl method, $CaCO_3$ content − Scheibler volumetric method, particle-size distribution − by the sieve method and the hydrometer (Bouyoucos aerometric) method; pH of the soil-to-solution ratio of 1:2.5 using 1 M KCl and H_2O as the suspension medium. In addition, the index of humidification (the degree of transformation of dead organic debris in humic substances) was performed by means of the Springer method [16] in post lacustrine soils located at the former bottom of the Sumowskie Lake and in the soil at the foothill of the slope.

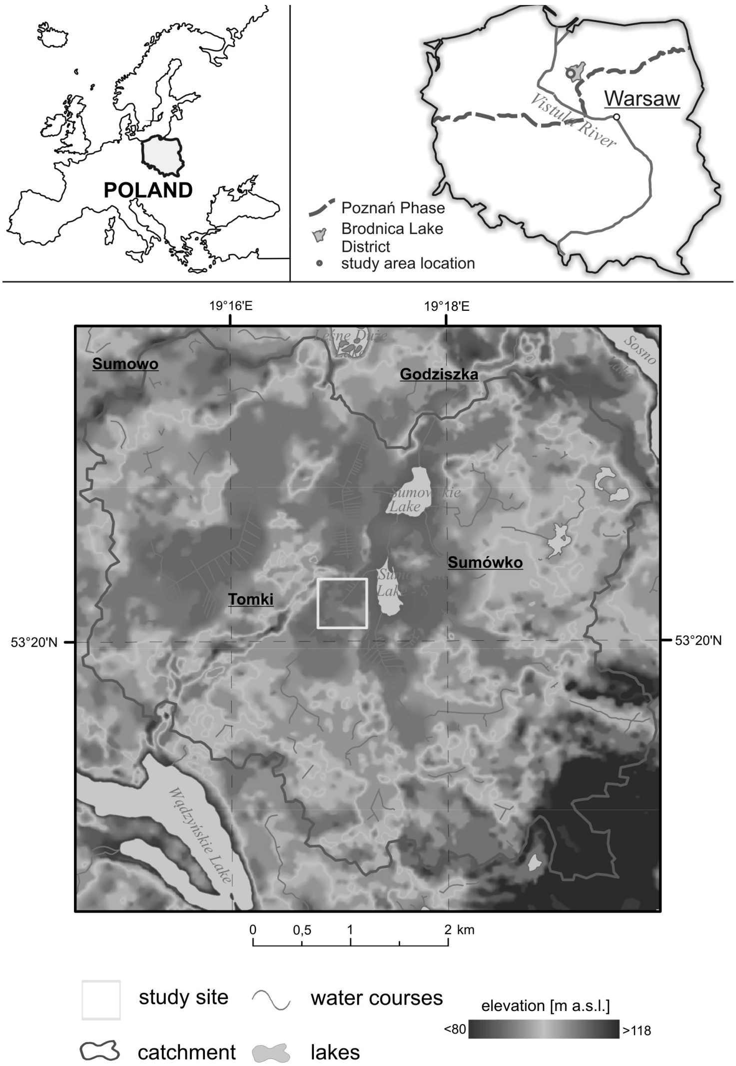

Fig. 1. Location of the study site.

The humidification degree may be defined as a degree of conversion of dead organic residues into humic substances. It is defined based on various indicators. In this study, the humidification index (HI) was used. The humidification index determines the percentage rate of organic matter that has passed into the solution (the samples were digested with a mixture of sodium hydroxide and sodium oxalate). The value of the humidification index is directly proportional to the degree of humidification of the test material [16]. This index is calculated according to the following formula:

$$HI = \frac{\%\ humic\ acids\ in\ sample}{\%\ LOI} \cdot 100 \qquad (1)$$

The characteristics of humic compounds are most often determined on the basis of the humic acids / fulvic acids ratio [16]. The indicator used in this case is the ratio of absorbance at a wavelength of 472 nm to 664 nm (modified by Sapek in: Matyka-Starzyńska and Sokołowska, [16]) – A_4:A_6. Matyka-Sarzyńska and Sokołowska [16] report after Kononowa that the ratio of the absorbances at wavelengths of 465 nm and 665 nm is <6 for humic acids and from 6 to 18.6 for fulvic acids.

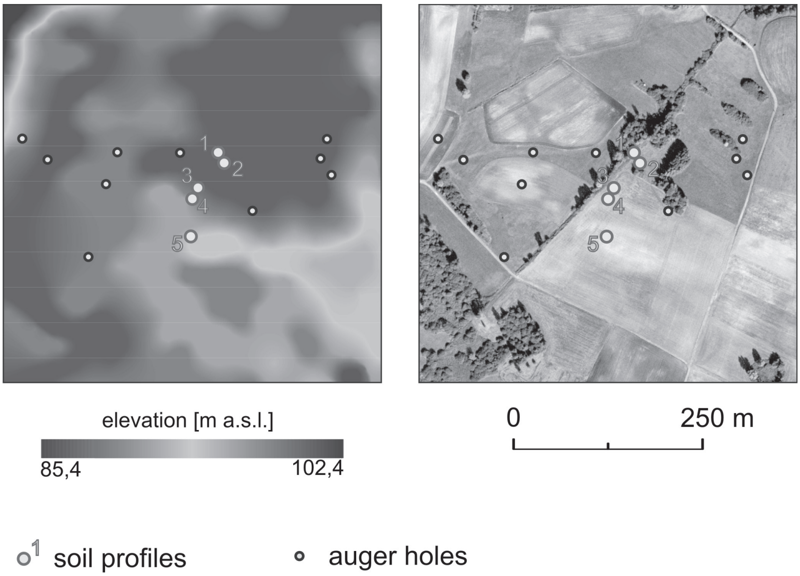

Fig. 2. Location of the soil profiles.

The soils were classified according to WRB [11]. Descriptions of horizons are given after the Guidelines for Soil Description [8].

RESULTS AND DISCUSSION

Morphology and physical properties

The soil cover of the Sumowskie Lakes catchment area is characterised by a very high diversity. The soils originated from lacustrine sediments are exposed as a result of human activities, i.e. drainage. This phenomenon is common in areas of northern Poland and north-western Germany [i.e. 5, 13, 26]. In the immediate vicinity of the former lake bottom, there are such mineral-organic and mineral soils as Gleysols, Umbrisols, Phaeozems, Luvisols and Arenosols [10, 18]. They developed from sandy sediments near kame hills and esker near Tomki Village, as well as from basal till of ground moraine that surrounds the Sumowskie Lakes catchment (Fig. 1).

All of the studied soils were characterised by the morphological features connected with human impact. Starting with post lacustrine soils, less dehydrated ones, with a shallower groundwater level had thicker mursh horizons (60 cm in Profile No. 1 and 30 cm in Profile No. 2) as compared to more dehydrated, buried soil in profile 3 (15 cm). Small thickness of the mursh horizon in profile No. 3 may be caused by ploughing of the mursh into the cover of colluvium and deposition of this material into the wedges and cracks that represent another morphological feature resulting from dryness and vertical cracking of gyttja [17]. These cracks are clearly visible even on the surface of the colluvium that covers the buried soil in profile No. 3 (Fig. 4).

Texture of the soil studied was very diversified. The mineral gyttja was characterised by fine texture of silty clay loam and silt loam. The mineral formations below the gyttja were silty clay loam, loam and loamy sands. The surface horizon (Ah) in profile No. 1 with texture of loamy sand could be a result of mixing mursh with a colluvium from the surrounding kame hills or mineral material from ditch cleaning (Tab. 1; Fig. 3). A similar situation was reported by Smólczyński and Orzechowski [23]. The Limnic Histosols on the Gązwa gyttja land (Northern Poland) and in the vicinity of Lutry (Olsztyńskie Lakeland) were characterised by a high content of mineral parts (up to ca. 70%) within the surface horizons up to 10 cm.

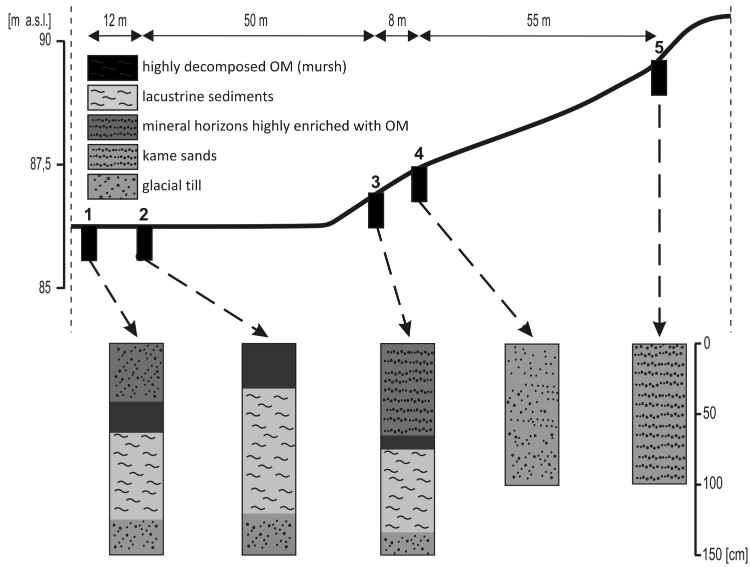

Fig. 3. Analysed soil sequence.

TABLE 1. PHYSICAL PROPERTIES OF SOILS

Horizon	Depth [cm] 2.0 – 0.05	Particle size distribution [%]			BD [g·cm^{-3}]	PD [g cm^{-3}] [% by weight]	Actual moisture		P [%]	W_h[%]
		0.05 – 0.002	< 0.002				[% by volume]			
Profile 1 – Endocalcaric Histic Gleysol (Epiarenic, Bathyloamic, Drainic, Hyperhumic, Endolimnic, Nechic, Novic)										
Ah	0–40	88	10	2	0.68	2.35	93.8	63.8	71.1	3.9
Ha	40–60	n.d.	n.d.	n.d.	n.d.	1.69	n.d.	n.d.	n.d.	9.9
Lm	60–120	n.d.	n.d.	n.d.	n.d.	2.22	n.d.	n.d.	n.d.	4.3
C	120-(140)	48	32	20	n.d.	2.63	n.d.	n.d.	n.d.	1.0
Profile 2 – Calcaric Histic Gleysol (Loamic, Drainic, Hyperhumic, Limnic)										
Ha	0–30	n.d.	n.d.	n.d.	0.48	1.97	184.8	88.8	75.6	8.4
L	30–100	34	57	9	0.59	2.47	125.3	74.3	76.1	1.6
C2	120-(140)	13	49	38	n.d.	2.60	n.d.	n.d.	n.d.	2.4
Profile 3 – Colluvic Regosol (Loamic, Aric, Humic, Greyic) over Calcaric Histic Gleysol (Drainic, Hyperhumic, Limnic)										
Ap1	0–30	58	24	18	1.31	2.53	23.0	30.1	71.0	1.3
Ap2	30–60	60	27	13	1.26	2.49	26.3	33.2	49.4	3.1
Hab	60–75	n.d.	n.d.	n.d.	0.55	2.00	93.3	51.2	72.5	10.7
Lc1	75–80	n.d.	n.d.	n.d.	0.40	1.81	170.0	68.5	77.9	9.5
Lc2	80–90	n.d.	n.d.	n.d.	0.29	1.78	212.9	61.3	83.7	11.6
Lm1	90–102	18	60	22	0.69	2.48	96.2	66.7	72.2	2.8
Lm2	102–125	27	58	15	0.73	2.47	99.3	72.0	70.4	2.8
C1	125–140	85	12	3	n.d.	2.60	n.d.	n.d.	n.d.	0.3
C2	140-(160)	8	53	39	0.90	2.60	76.4	68.7	65.4	3.0

TABLE 1. CONTINUATION

Profile 4 – Calcaric Gleyic Phaeozem (Geoabruptic, Aric)										
Ap	0–28	60	23	17	1.67	2.58	17.5	29.2	35.3	0.8
Bl (loam)	28-(60)	42	33	25	1.76	2.76	3.76	4.76	5.8	6.8
Bl (sand)	28-(60)	91	4	5						
Profile 5 – Calcaric Stagnosol (Endoarenic, Aric, Inclinic, Nechic, Ochric)										
Ap	0–24	80	8	12	1.45	2.63	10.5	15.2	44.8	0.4
C1	24–40	86	6	8	1.44	2.65	6.0	8.6	45.7	0.5
C2	40–45	75	15	10	n.d.	n.d.	n.d.	n.d.	n.d.	0.6
Cg1	45–65	87	7	6	1.57	2.65	5.8	9.1	40.8	0.2
Cg2	65–80	87	7	6	1.64	2.65	5.1	8.4	38.1	0.3
Cg3	80-(95)	98	2	0	1.53	2.65	5.6	8.6	42.1	0.1

BD – bulk density, PD – particle density, P – porosity, W_h – hygroscopic water content.

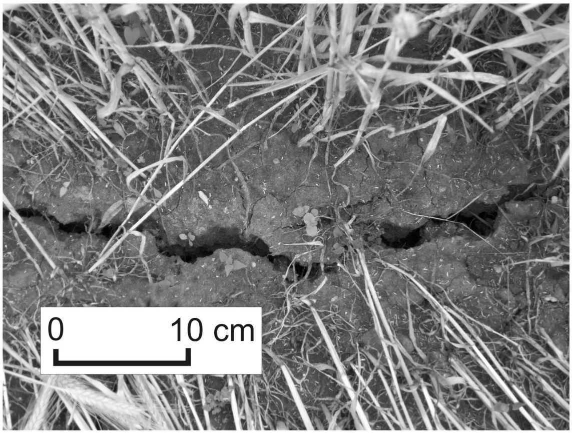

Fig. 4. Cracks on the surface of the colluvium in profile 3.

The mineral soils located on the kame hill slope were formed from the mixture of sandy and loamy sediments that were characteristic of these landforms (profiles 3–5). The colluvial horizons covering the organic soil in profile 3 had texture of sandy loam. This material consists of former humus horizons of soils located in the central part of the slope, which were displaced by gravity due to human-induced erosion (Fig. 2). This was evidenced by the texture of sandy loam in the Ap horizon in profile No. 4. The agricultural use of the kame hill and the area of the ground moraine caused blurring of characteristic morphological features in the profiles [25]. This is related to the intensification of the agricultural use of the early post-glacial areas of northern Poland from the Middle Ages (at most 1000 years ago) [12].

In the surface horizons the bulk density ranged from 0.48 $Mg \cdot m^{-3}$ in profile 2 to 1.67 $Mg \cdot m^{-3}$ in profile 4 (Tab. 1). Bulk density values in gyttja (L, Lc, Lm) ranged from 0.29 to 0.73 $Mg \cdot m^{-3}$ while the value of the solid particle density − from 1.78 to 2.48 $Mg \cdot m^3$ (organic gyttja < carbonate gyttja < mineral gyttja). The highest values of the solid particle density in the soils formed from the lacustrine sediments were obtained for the Ah horizon (profile No. 1) and for the C horizons (Profiles 1–3) underlying the gyttja and ranged from 2.35 to 2.63 $Mg \cdot m^{-3}$.

A specific feature of the studied soils is the compaction of the top sections of gyttja lying immediately beneath the mursh. This is clearly exemplified in profile 4, which is probably caused by agro-technical practices [3].

In general bulk and solid particle density increased with depth of the profile in the soils developed in the foothills and on the slope of the kame hill, which results from the decrease in the organic matter content. Phaeozem (profile No. 3) represents an exception, where the bulk and the solid particle density were higher in the surface Ap1 horizon and amounted to 1.31 $Mg \cdot m^{-3}$ and 2.53 $Mg \cdot m^{-3}$, respectively, as compared to the lower Ap2 horizon – 1.26 and 2.49 $Mg \cdot m^{-3}$.

This is because of ploughing of the buried Ha horizon into the Ap2 horizon, which was previously located on the surface.

Chemical properties

In the post lacustrine soils (Profiles 1, 2 and buried soil in Profile No. 3), pH was slightly and moderately alkaline (pH in H_2O 6.0–8.6) (Tab. 2). This reaction is closely related to the presence of calcium carbonate (Tab. 2) which is one of the components building the gyttja sediments. The higher acidity of the mursh horizons results from the fact that the mursh substrate developed from coarse detrital gyttja or peat. The pH (H_2O) of the soils located on the kame hill slope varied from 7.4 in the Colluvic Regosol (profile No. 3) to 8.8 in the Calcaric Stagnosol (profile No. 5). In general the pH values of the mineral soils raised up from to foothill to the top of the kame hill.

The total organic carbon (TOC) content in soils of the biogenic plain was characteristic of large variability. It is connected to the original diversity of the limnic and telmatic sediments as well as the human influence. In two cases, the organic carbon content of the surface horizon was lower than in the morphological horizon below. The former is associated with anthropogenic enrichment of the mursh horizon with sand in profile No. 1. In profile No. 3, the lower organic carbon content in the Hab horizon compared to the underlying limnic horizons is probably related to diagenesis processes that take place in the buried soil [1] and mineralisation process during the previous exposure of this soil.

In the profiles located on the kame hill, the highest TOC content occurred in the colluvial horizons of the soil located at the foot of the kame (profile 3) – 34.4 $g \cdot kg^{-1}$ and 47.6 $g \cdot kg^{-1}$. This is due to both, the erosion of the material rich in humus from the soils lying in higher sections of the slopes as well as a high level of groundwater affecting the decrease in the rate of decomposition of the organic matter.

Among all the studied soils, the TOC content was the lowest in Stagnosol (profile No. 5) situated at the kame hill (4.3 $g \cdot kg^{-1}$ in the Ap horizon, 0.3 $g \cdot kg^{-1}$ in the lowest bedrock horizon). Such low contents are related to the constant aeration of the highly permeable sandy formations, leading to the rapid mineralization of the organic matter in this profile. Nonetheless, the main factor is the agricultural use of the soil. It leads directly to the loss of the carbon eliminated in the form of crops, and indirectly to the displacement of the humus horizons down the slope as a result of anthropogenic denudation [21, 24, 25]. Organic carbon content decreases along the transect starting on the former lake bottom and ending at the top of the kame hill in opposite to the pH values.

TABLE 2. CHEMICAL PROPERTIES OF SOILS

Horizon	Depth [cm]	TOC [g·kg^{-1}]	TN [g·kg^{-1}]	C:N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Profile 1 – Endocalcaric Histic Gleysol (Epiarenic, Bathyloamic, Drainic, Hyperhumic, Endolimnic, Nechic, Novic)							
Ah	0–40	96.6	5.62	17	6.3	6.1	n.d.
Ha	40–60	423	26.8	16	6.0	5.7	n.d.
Lm	60–120	144	10.2	14	8.0	7.8	490
C	120-(140)	6.59	0.44	15	7.8	7.3	125
Profile 2 –Calcaric Histic Gleysol (Loamic, Drainic, Hyperhumic, Limnic)							
Ha	0–30	255	17.1	15	6.4	6.2	n.d.
L	30–100	53.4	3.99	13	7.9	7.6	225
C2	120-(140)	13.3	0.91	15	7.8	7.3	164
Profile 3 – Colluvic Regosol (Loamic, Aric, Humic, Greyic) over Calcaric Histic Gleysol (Drainic, Hyperhumic, Limnic)							
Ap1	0–30	34.4	2.85	12	7.5	7.0	16
Ap2	30–60	47.6	3.72	13	7.4	6.9	4
Hab	60–75	243	15.7	15	7.6	7.2	4
Lc1	75–80	347	21.5	16	7.5	7.0	3
Lc2	80–90	365	23.9	15	7.4	6.9	8
Lm1	90–102	51.7	3.58	14	8.6	7.4	241
Lm2	102–125	53.0	3.72	14	7.8	7.4	394
C1	125–140	13.6	0.87	16	8.0	7.8	131
C2	140-(160)	14.4	0.94	15	7.5	7.2	95
Profile 4 – Calcaric Gleyic Phaeozem (Geoabruptic, Aric)							
Ap	0–28	19.7	1.63	12	7.8	7.2	59
Bl (loam)	28-(60)	4.45	0.36	12	8.3	7.3	96
Bl (sand)	28-(60)	1.19	0.11	11	8.6	8.0	132
Profile 5 – Calcaric Stagnosol (Endoarenic, Aric, Inclinic, Nechic, Ochric)							
Ap	0–24	4.30	0.45	10	8.1	7.6	78
C1	24–40	0.73	0.06	12	8.7	7.9	94
C2	40–45	2.53	0.14	18	8.5	8.1	456
Cg1	45–65	0.64	0.07	9	8.6	7.9	159
Cg2	65–80	0.86	0.05	17	8.4	7.9	104
Cg3	80-(95)	0.30	0.02	15	8.8	8.1	62

Stock and properties of the organic matter

One of the basic index describing the quality of soil organic matter is the C:N ratio which reflects the conditions conducive to the processes of humidification and mineralization of organic matter and high biological activity. In the gyttja horizons, the C:N ratio values ranged from 15 to 16. The values ranging from 13 to 15 indicate a mixture of detrital building the organic part of gyttja, coming from both vascular plant debris and algae. It is representative of most of the lacustrine sediments [6, 7].

In the surface horizons C:N ratio obtained values were 15 and 17 in the post lacustrine soils (Profiles 1–3) and from 10 to 12 – in the minerals ones.

The lowest value of A_4:A_6 ratio (4.8) was obtained for buried horizon with high content of organic matter (Hab in profile 3, Tab. 3). It is caused by transformation of humic acids into more stable forms when buried [1]. The relatively low value of this (4.7) ratio observed in Ap2 horizon in profile 3, is the result of the aforementioned ploughing of the surface horizon into cover of the colluvium.

TABLE 3. PROPERTIES OF ORGANIC MATTER IN POST LACUSTRINE SOILS

Profile No.	Genetic horizon	Depth [cm]	LOI	A4:A6	HI	% HA
1	Ah	0–40	19.0	6.0	32	5.99
	Ha	40–60	84.3	6.9	31	26.1
	Lm	60–120	27.3	5.3	6	1.70
2	Ha	0–30	46.4	6.1	39	18.2
3	Ap1	0–30	8.1	7.1	33	2.65
	Ap2	30–60	11.3	4.7	50	5.69
	Hab	60–75	44.5	4.8	60	26.6
	Lc1	75–80	69.9	5.9	17	11.6
	Lc2	80–90	71.9	6.0	22	16.0
	Lm1	90–102	10.5	5.2	11	1.15
	Lm2	102–125	10.0	5.9	10	1.01

LOI – loss of ignition, HI – humification index, %HA – humic substances in solution.

Based on the results it may be concluded that the strongly humidified organic matter among the studied soils is found in the muck horizons (Ha and Ah) – HI values of 31 and 60 (Tab. 3). The high HI value (50) in the Ap horizon (profile 3) most likely results from ploughing of the underlying Ha horizon (60) when the layer of colluvium in this profile was thinner. Another important fact is the sequestration of carbon in buried organic material [22]. The average humidification degree (HI 17–22) was specific to top organic horizons in buried Histic Gleysol (profile 3). The intensive humidification results from the fact that these horizons are less affected by groundwater as compared to other horizons within a given profile. The lowest HI values (6–11) were determined in highly hydrated organic horizons derived from the limnic material.

The SOM stocks of surface horizons (Tab. 4) are closely related to the genesis of the parent material, soil moisture and pedogenetic processes [9, 15]. Undoubtedly the way of land use plays an important role. The soils located on the biogenic plain are used as a pasture. Profiles 1 and 2 exhibit the highest stocks of both organic carbon and nitrogen. TOC stocks in the surface layer (0–40 cm) of the soil in profile No. 2 are nearly 40 $kg \cdot m^{-2}$. With the lowering of the ground water level the decrease of soil moisture and the stocks of organic matter is noted. It is connected also with the cultivation practices as these soils are used as arable land. TOC stocks drop from about 26 $kg \cdot m^{-2}$ to less than 2 along the transect (profile No. 1 < profile No. 2 > profile No. 3 > profile No. 4 > profile No. 5)

TABLE 4. TOC AND TN STOCKS (0–20, 0–40 CM) IN SOILS

Profile No.	Depth [cm]	TOC	TN
		kg /m²	
1	0–20	13.1	0.76
	20–40	13.1	0.76
2	0–20	24.5	1.64
	20–40	15.4	1.06
3	0–20	9.0	0.75
	20–40	10.5	0.84
4	0–20	6.58	0.54
	20–40	3.57	0.29
5	0–20	1.25	0.13
	20–40	0.42	0.04

CONCLUSIONS

1. The human impact is the main factor determining the current development of the soil cover in the entire catchment of the Sumowskie Lakes. It is manifested in the form of the drainage network draining the vast kettle holes and in the human-induced erosion taking place within the surrounding slopes of the forms used for agricultural purposes. Human activity within the area has led to the exposure of lacustrine sediments that have turned into the parent material for newly developed soils.

2. The shoreline of the former lake is characteristic of great variability of the soil cover. On the edge of the former lake basin, Histosols and Gleysols are buried and covered with Colluvic Regosols, developed due to the phenomenon

of human-induced erosion where forms surrounding the lake basin were used for agricultural purposes. It leads to a gradual erosion of the surface horizons of the soil occurring on the slopes of the forms surrounding the basin of the Sumowskie Lakes.

3. The greatest soil transformation is reflected in the quality and quantity of the soil organic matter. Indexes of organic matter quality and TOC stocks are significantly changing along the studied transect. The strongly humidified organic matter is found in mursh horizons. Gyttja layers above the groundwater level have a medium humification index. Horizons saturated with water are very low humidified. TOC stocks drop along the analysed soil sequence from the biogenic plain to the top of the kame hill.

Acknowledgements

This study was financed by the National Science Centre (NCN) of Poland in the form of project No. N N305 283337.

REFERENCES

[1] Bednarek, R.: Diagenetic changes in sandy buried soils. In: Manikowska, B., Konecka-Betley K., Bednarek, R. (Eds.): Paleopedology problems in Poland. Łódzkie Towarzystwo Naukowe, 47, 2002.
[2] Bednarek R., Dziadowiec H., Pokojska U., Prusinkiewicz Z.: Badania ekologiczno-gleboznawcze. PWN, Warszawa, 344,2004.
[3] Berglund K.: Int. Peat J., **6**, 5, 1995.
[4] Bogacz, A., Dzięcioł, D., Glina, B., Gersztyn, L.: Soil Sci. Ann., **63, 2**, 3, 2012.
[5] Chmieleski J., Zeitz J.: Gyttja-bearing soils in Northern Europe: formation and pedogenesis. [In:] Farrell and Feehan (Eds.): After Wise Use – The future of Peatlands. Proc.13th Int. Peat Congress, **2**, 5, 2008.
[6] Cieślewicz J.: Materia organiczna osadów dennych jezior. In: Gonet, S. Markiewicz, M. (Eds.): Rola materii organicznej w środowisku. PTSH, Wrocław, 2007.
[7] Cieślewicz J., Gonet S.S., Marszelewski W.: Soil Water Res., **3, 1**, 21, 2008.
[8] FAO: Guidelines for Soil Description. 4th Edition. FAO, Rome, 2006.
[9] Gonet S.S.: Ochrona zasobów materii organicznej gleb. [In]: Gonet S., Markiewicz M. (Eds.): Rola materii organicznej w **środowisku. PTSH, Wrocław, 7, 2007.**
[10] Gonet S., Markiewicz M., Marszelewski W., Dziamski A.: Limnological Review, **10(**3–4), 133, 2010.
[11] IUSS Working Group – FAO: WRB-World Reference Base for soil resources 2014. World Soil Resources Report No. 106. FAO, Rome, 181, 2014.
[12] Karasiewicz M.T., Hulisz P., Noryśkiewicz A.M., Krześlak I., Świtoniak M.: Quaternary Int., **328–329**, 264, 2014.
[13] Łachacz A., Nitkiewicz M., Pisarek W.: Soil conditions and vegetation on gyttja lands in the Masurian Lakeland. [In:] Łachacz A. (Ed.): Wetlands – their functions and protection. Department of Land Reclamation and Environmental Management, University of Warmia and Mazury in Olsztyn, 61, 2009
[14] Marcinek J., Spychalski M., Rocz. Akad. Roln., Poznań, **182**, 19, 1987
[15] Markiewicz M., Świtoniak M., Bednarek R., Gonet S.S.: Zasoby materii organicznej. [In:] Świtoniak M., Jankowski M., Bednarek R., (Eds.): Antropogeniczne przekształ-

cenia pokrywy glebowej Brodnickiego Parku Krajobrazowego. Wyd. Nauk. UMK, Toruń, 129, 2014.
[16] M a t y k a - S a r z y ń s k a D., S o k o ł o w s k a Z.: Acta Agrophysica, **123**, 1, 2005.
[17] M e n d y k Ł., M a r k i e w i c z M.: Episteme, **18**(3), 321, 2013.
[18] M e n d y k Ł., M a r k i e w i c z M., Ś w i t o n i a k M., B e d n a r e k R.: Ecological Questions, **17**, 57, 2013
[19] M e n d y k Ł., M a r k i e w i c z M., J a n k o w s k i M., D e r d z i k o w s k i P.: Przekształcenia pokrywy glebowej wskutek odwodnienia. [In:] **Świtoniak** M., Jankowski M., Bednarek R. (Eds.): Antropogeniczne przekształcenia pokrywy glebowej Brodnickiego Parku Krajobrazowego. Wyd. Nauk. UMK, Toruń, 85, 2014.
[20] M e n d y k Ł., M a r k i e w i c z M., Ś w i t o n i a k M.: Catchments of disappearing lakes in glacial meltwater landscapes (Brodnica Lake District). [In:] Świtoniak M., Charzyński P., (Eds.): Soil Sequences Atlas. Wyd. Nauk. UMK, Toruń, 93, 2014.
[21] S i n k i e w i c z M.: Rozwój denudacji antropogenicznej w środkowej części Polski północnej. Wydawnictwo Naukowe UMK, Toruń, 103,1998.
[22] S m ó l c z y ń s k i S., K a l i s z B., O r z e c h o w s k i M.: Polish J. Envir. Stud., **20, 3**, 755, 2011.
[23] S m ó l c z y ń s k i S., O r z e c h o w s k i M.: Woda-Środowisko-Obszary Wiejskie, **9**(1/25), 141, 2009.
[24] S m ó l c z y ń s k i S., O r z e c h o w s k i M.: J. Elementol., **15, 1**, 177, 2010.
[25] Ś w i t o n i a k M.: Catena, **116**, 173, 2014.
[26] U g g l a H.: Soil Sci. Annual, **27**(2), 113, 1976.
[27] V a n R e e u v i j k L.P.: Procedures for Soil Analysis. 7th Edition. Technical Report 9, ISRIC-World Soil Information, Wageningen, Netherlands, 2006.

STAN GLEBOWEJ MATERII ORGANICZNEJ W ROLNICZO UŻYTKOWANEJ SEKWENCJI GLEB DAWNEJ STREFY BRZEGOWEJ ZANIKAJĄCYCH JEZIOR SUMOWSKICH (PÓŁNOCNO-WSCHODNIA POLSKA)

Celem badań było określenie zasobów i podstawowych właściwości materii organicznej sekwencji rolniczo użytkowanych gleb dawnej strefy brzegowej zanikających jezior. Obszar badań był zlokalizowany w zlewni jezior Sumowskich na Pojezierzu Brodnickim w Polsce północno-wschodniej. Analizowano transekt składający się z pięciu profili glebowych znajdujących się w pd.-zach. części dawnego Jeziora Sumowskiego. Obejmował on dno dawnego jeziora oraz przylegające wzgórze kemowe. Największe zróżnicowanie gleb dotyczyło ilości i jakości glebowej materii organicznej. Zarówno właściwości materii organicznej, jak i jej zasoby wyraźnie różnicują się w analizowanym transekcie. Materia organiczna poziomów murszowych gleb pojeziornych odznacza się najwyższym stopniem humifikacji, warstwy gytii, powyżej poziomu wód gruntowych, pośrednim, a poziomy nasycone wodą najniższym spośród analizowanych. Zasoby węgla organicznego zmniejszają się wzdłuż transektu od gleb pojeziornych do szczytu pagórka kemowego (pararędziny).