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DISTRIBUTION OF ELEMENTS IN SOILS OF MORAINE LANDSCAPE IN MASURIAN LAKELAND*

S³awomir Smólczyñski, Miros³aw Orzechowski

Chair of Soil Science and Soil Protection
University of Warmia and Mazury in Olsztyn

Abstract

The research was carried out in three catenas, in which the soils made a typical toposequence of the moraine landscape in Masurian Lakeland, i.e. eroded soils, deluvial soils, mucky soils as well as slightly and strongly silted peat-muck soils. The total content of Ca, Mg, K, P, Na, Fe, Mn, Zn and Cu was analyzed in these soils. The amounts of soil organic matter and measured elements showed catenal variation. Mucky soils had the highest content of Mg, K, Fe and Na whereas strongly and slightly silted peat-muck soils contained the highest amounts of P, Mn, Ca and Cu. The content of Ca was positively correlated with organic matter content. The amount of Mg, K, Cu and Mn was positively correlated with the amount of clay fraction. As the studied soils are located at the bottom of a slope, downwards water flow, where mineral compounds are accumulated in deposits or dissolved in water, mucky soils and silted peat-muck soils contain high amounts of the analyzed elements. Mucky soils and silted peat-muck soils play a role of biogeochemical barriers protecting wetlands against nutrients from surrounding moraine uplands.

Surface horizons of deluvial soils were depleted of the analyzed elements (excluding P) whereas AO horizons of mucky soils and Mt horizons of peat-muck soils were abundant in the measured elements (excluding Ca). Various amounts of the analyzed elements in the pedons of the catena sequences should be taken into consideration when planning land use in the moraine landscape, which has unique natural values.

Key words: macro- and microelements, moraine landscape, toposequence, eroded soils, deluvial soils, mucky soils, strongly and slightly silted peat-muck soils.

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dr in¿. S³awomir Smólczyñski, Chair of Soil Science and Soil Protection, University of Warmia and Mazury, 10-719 Olsztyn, Poland, phone: 089 5234846, e-mail: slawomir.smolczynski@uwm.edu.pl

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ROZMIESZCZENIE PIERWIASTKÓW W GLEBACH KRAJOBRAZU MORENOWEGO POJEZIERZA MAZURSKIEGO

Abstrakt

Badania przeprowadzono w 3 katenach, w których gleby tworzy³y typow¹ dla krajobrazu morenowego Pojezierza Mazurskiego toposekwencjê: gleb erodowanych, deluwialnych, namurszowych oraz gleb torfowo-murszowych silnie i s³abo zamulonych. W glebach oznaczono ca³kowit¹ zawartoœæ Ca, Mg, K, P, Na, Fe, Mn, Zn, Cu. Badane gleby wykazywa³y katenaln¹ zmiennoœæ zawartoœci materii organicznej i oznaczonych pierwiastków. Gleby namurszowe wyró¿nia³y siê najwy¿sz¹ zawartoœci¹ Mg, K, Fe, Na, a silnie i s³abo zamulone gleby torfowo-murszowe – P, Mn, Ca i Cu. Zawartoœæ wapnia by³a dodatnio skorelowana z iloœci¹ materii organicznej, natomiast zawartoœæ Mg, K, Cu, Mn z iloœci¹ frakcji ilastej. Stwierdzona najwiêksza zawartoœæ wiêkszoœci oznaczonych pierwiastków w glebach namurszowych i zamulonych glebach torfowo-murszowych jest uwarunkowana ich usytuowaniem u podnó¿a stoków, na drodze sp³ywów erozyjnych, gdzie nastêpuje akumulacja sk³adników mineralnych przemieszczanych wraz z mas¹ glebow¹ lub rozpuszczonych w wodzie. Gleby namurszowe i zamulone gleby torfowo-murszowe w krajobrazie morenowym pe³ni¹ funkcjê barier biogeochemicznych chroni¹cych siedliska mokrad³owe przed przenikaniem pierwiastków biogennych z otaczaj¹cych wysoczyzn.

Poziomy powierzchniowe gleb deluwialnych wykazywa³y zubo¿enie w oznaczone pierwiastki (z wyj¹tkiem P), natomiast poziomy AO gleb namurszowych i Mt torfowo-murszowych wzbogacenie (z wyj¹tkiem Ca). Zró¿nicowanie zawartoœci pierwiastków w pedonach badanych katen powinno byæ uwzglêdniane podczas u¿ytkowania gleb w krajobrazie morenowym, który ma unikatowe walory przyrodnicze.

S³owa kluczowe: makro- i mikroelementy, krajobraz morenowy, toposekwencja, gleby erodowane, gleby deluwialne, gleby namurszowe, silnie i s³abo zamulone gleby torfowo-murszowe.

INTRODUCTION

The moraine landscape, shaped during the Vistula glaciation, is located in the middle of Masurian Lakeland and occupies the largest area (PIAŒCIK 1996a). In this landscape, the relief, soil cover and soil formations are diversified. The zone of moraine uplands is represented by hills and rolling ground moraines with numerous depressions filled with wetlands, which have unique natural values (PIAŒCIK, GOTKIEWICZ 2001). In the moraine landscape, which has diversified land relief, processes of translocation of soil formations from slopes and their accumulation at the foot of slopes, on the surface of organic formations filling depressions, are common. In consequence, certain toposequences of soils are found, e.g. eroded soils, deluvial soils along sloped and mucky soils, silted peat-muck soils in depressions (PIAŒCIK et al. 2001b, PIAŒCIK, SOWIÑSKI 2002).

In the moraine landscape, slope-related processes have great influence on the carbon cycle and content of mineral compounds (WOC£AWEK 1973, SMOLSKA et al. 1995, STEPA 1996, KRUK 2000, SOWIÑSKI at al. 2004), which locally, in young glacial areas, in soils of mid-moraine depressions, may reach dangerous levels (BIENIEK 1997, SMÓLCZYÑSKI et al. 2004). Deluvial and upper silted organic soils (mucky soils as well as slightly and strongly silted peat-muck soils) play an important role in the nutrient cycle (GOTKIEWICZ et al. 1990, SOWIÑSKI et al. 2004a,b). These soils were formed in the ecotone zones between wetlands and mineral soils of the surrounding slopes. HILLBRICHT--ILKOWSKA (2005) stressed that ecotone zones are a very typical element of the landscape of lakeland hills of north-eastern Poland and are particularly important for sustaining its stability and function.

The aim of this paper was to determine the total amount of elements in the examined soils and depict the distribution of the elements in soil profiles as well as in typical toposeqences of eroded soils, deluvial soils, mucky soils and slightly and strongly silted peat-muck soils of the moraine landscape of north-eastern Poland.

MATERIAL AND METHODS

The research was carried out in the zone of the moraine landscape shaped during Poznañ phase (Prusinowo site in Mr¹gowo Lakeland) and Pomeranian phase (Lutry I and Lutry II sites in Olsztyn Lakeland) of the Vistula glaciation. At the studied sites, along the transects, from the slope to the depression, soil profiles were made (in Prusinowo and Lutry II catenas – 7 soil profiles each, in Lutry I catena – 8 soil profiles). The following alternation of soils was found: eroded soils in the upper part of the slope, deluvial soil in the lower part, mucky soils at the bottom of the slope, slightly and strongly silted peat-muck soils in a depression. Eroded soils were developed from sandy loam and their parent material had loam texture. Deposits of deluvial soils had thickness of 40-110 cm and silty sandy loam or silty loam texture. In mucky soils of the studied sites, the surface layer of thickness of 30 cm was composed of mineral-organic deposit, which contained 10-20% of organic matter. In peat-muck soils, the thickness of muck horizons was 25-33 cm and the muck-forming process was medium advanced.

As the textures of eroded soils and deluvial deposits were similar at the studied sites, an average content of the elements in the studied pedons at three catena sequences is shown in Tables 1 and 4. As bulk density of mineral and organic formation is different, the amount of the analyzed elements was expressed per dm^3 (calculated on the basis of bulk density) and is presented in Table 4.

The total content of Ca, Mg, K, P, Na, Fe, Mn, Zn and Cu was measured after digestion in a mixture of $HClO_4$ and HNO_3. Calcium, potassium and sodium was measured photometerically using a Jenway flame photometer, while phosphorous was measured colorimetrically using a Specol EK 1

Table 1

Mean content of elements in surface horizons of studied soils

Soil horizon	Value	Percentage of mineral fraction (diameter in mm)			Organic matter	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
		<0.02	0.02-0.002	<0.002	$g \cdot kg^{-1}$							$mg \cdot kg^{-1}$		
1 A	*X*	25.0	17.0	8.0	22.7	3.1	2.7	3.7	0.2	0.5	23.1	7.30	59.87	290.37
	S	7.5	4.6	3.5	8.4	1.9	1.2	1.4	0.1	0.1	18.8	4.04	40.01	71.05
	CV	30.0	27.1	43.8	37.0	61.3	44.4	37.8	50.0	20.0	81.4	55.3	66.8	24.5
2 Ad	*X*	29.7	20.5	9.2	28.9	5.1	3.0	3.0	0.3	0.5	15.0	8.15	36.97	298.78
	S	11.0	6.2	2.7	17.0	3.4	0.6	0.7	0.06	0.2	3.5	3.01	9.41	157.92
	CV	36.9	29.9	29.3	58.8	66.8	20.0	23.3	20.0	40.0	23.3	36.9	25.5	52.8
3 AO	*X*	37.1	30.0	7.1	185.2	12.2	4.7	3.7	0.4	0.8	24.0	12.06	52.36	456.46
	S	6.4	10.7	1.0	56.5	3.0	0.9	0.6	0.09	0.2	7.7	2.61	8.04	159.06
	CV	17.3	35.7	13.9	30.5	24.6	19.2	16.2	22.5	25.0	32.1	21.6	15.4	34.9
4 Mtsz	*X*				357.9	15.6	3.5	3.3	0.3	1.0	20.7	9.79	55.51	665.63
	S				93.5	0.9	0.4	0.6	0.05	0.2	2.9	3.29	23.13	301.14
	CV				26.1	5.8	11.4	18.2	16.7	20.0	14.0	33.6	41.7	45.2
5 Mtz	*X*				639.2	39.7	2.2	1.3	0.4	0.8	20.5	12.75	34.20	385.27
	S				76.3	16.5	0.6	0.9	0.01	0.5	12.4	2.87	16.10	176.40
	CV				11.9	41.6	27.3	69.2	2.5	62.5	60.5	22.5	47.1	45.8
Statistically significant differences $\alpha = 0.05$						2<3<4<5	2<3 3>4>5	2<3 4>5	1<2	2<3	2<3	2<3	1>2 2<3	2<3

Explanations: A – humus horizon of eroded soils; Ad – humus horizon of deluvial soils; AO – humus horizon of mucky soils, Mtsz – strongly silted muck, Mtz – slightly silted muck, *X* – mean, *S* – standard deviation, *CV* – coefficient of variation
< – statistically significant differences between studied soil horizons

spectrocolorimeter and magnesium was measured using an AAS 1 Zeiss Jena analyzer. The total content of Fe, Mn, Zn and Cu was measured applying the AAS techniques on a 30 Zeiss Jena analyzer.

Statistical calculations (mean, correlation coefficients, standard deviation) were conducted using Statistica 8.0.

RESULTS AND DISCUSSION

In the soils of the analyzed catena sequences, the content of organic matter, which is a criterion for classification of hydrogenic soil formations, increased towards the depression. Based on the criteria suggested by OKRUSZKO (1974), the surface formations of mucky soils containing on average 185.2 $g \cdot kg^{-1}$ of organic matter were classified as mineral-organic and muck formations as strongly silted mucks (357.9 $g \cdot kg^{-1}$ of organic matter) or slightly silted mucks (639.2 $g \cdot kg^{-1}$ of organic matter) – Table 1. Deluvial deposits were richer in clay fraction (<0.02 mm) and colloidal clay (<0.002 mm) than eroded soils (Table 1).

Among all the analyzed elements, calcium and iron were predominant in the soils. In the surface horizons, the average content of calcium increased towards the depression and when the amount of organic matter increased from 3.1 $g \cdot kg^{-1}$ in the humus horizons of eroded soils to 39.7 $g \cdot kg^{-1}$ in slightly silted mucks (Table 1). The differences in the content of these elements proved to be statistically significant between deluvial deposits, surface horizons of mucky soils and slightly and strongly silted mucks. The positive relationship between the amounts of calcium and organic matter is proved by high values of correlation coefficients (Table 2) as well as the results of studies on soils in other landscapes (PIAŒCIK et al. 2001a). According to BIENIEK (1997), compounds of calcium are dissolved in water and translocated during erosion. In hydrogenic soils, calcium occurs mainly in an exchangeable form and its accumulation in peat-muck soils is connected with high cation exchange capacity (PIAŒCIK 1977). The calculated coefficients, shown in Table 3, indicate that the content of calcium in surface horizons of the examined soils was lower than in deeper layers of the soil profile. Considerabledepletion of Ca was reported for mucky and peat-muck soils. It suggests that the process of decalcitation, reported in the literature, takes place (PIAŒCIK 1977, 1996b, PIAŒCIK et al. 1998, 2001a).

The smallest content of iron was recorded in deluvial soils (on average 15.0 $g \cdot kg^{-1}$) – Table 1. In mineral-organic formations of mucky soils, the average content of this element was statistically significantly higher (24.0 $g \cdot kg^{-1}$). Similar amounts were reported in humus horizons of eroded soils (on average 23.1 $g \cdot kg^{-1}$). In muck horizons, the average content of iron was not related to the degree of silting (Table 1) and reached

Table 2

Correlation coefficients for analysed elements in the surface layers

Specification	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
Organic matter	0.863*	-0.030	-0.428*	0.443*	0.558*	0.308*	0.498*	0.089	0.408*
<0.02	0.464*	0.606*	0.622*	0.129	0.375*	0.304	0.615*	-0.022	0.802*
0.02-0.002	0.514*	0.488*	0.407*	0.092	0.585*	0.175	0.276	0.120	0.496*
<0.002	-0.272	0.294	0.295	-0.041	0.420*	-0.063	0.001	-0.261	0.070
Ca		-0.089	-0.363*	0.385*	0.518*	0.326*	0.408*	0.042	0.190
Mg			0.474*	0.411*	0.214	0.395*	0.527*	0.275	0.364
K				0.003	0.160	0.083	0.029	0.226	0.201
Na					0.382	0.310	0.532*	0.165	0.176
P						0.360	0.396*	0.209	0.400*
Fe							0.488*	0.721*	0.391
Cu								0.122	0.526*
Zn									0.148

*significance level at α=0.05

20.5-20.7 $g \cdot kg^{-1}$. Iron was accumulated in surface layers of all the soils except deluvial ones (Tab. 3). As compared to calcium, distribution of iron in the soil profile was different. Solubility and mobility of this element depended on the oxidation and reduction processes and Fe was accumulated in aerobic zone of the soil profile. In muck horizons, iron is released during mineralisation as well as is precipitated from groundwater in the form of hydroxides (PIAŒCIK, BIENIEK 2001).

The content of magnesium was the highest in mineral-organic mucky soils (AO), reaching 4.7 $g \cdot kg^{-1}$ (Table 1). In deluvial deposits as well as in slightly and strongly silted mucks, the amount of this element was significantly lower.

The highest average content of potassium was reported in humus horizons of eroded and mucky soils (Table 1). In muck formations, the content of potassium decreased together with the degree of silting. Distribution of magnesium and potassium in the studied soil profiles was similar (Table 3). The humus horizons of eroded and deluvial soils was poor in Mg and K, which were largely accumulated in surface horizons of mucky soils and peat-muck soils (Table 3). The content of magnesium and potassium was positively correlated with the <0.02 mm and 0.02-0.002 mm fractions (Table 2). According to CHODAK et al. (2005), magnesium is subjected to translocation with the soil solid phase and potassium partly with the soil solution.

The mean content of sodium oscillated between 0.2 $g \cdot kg^{-1}$ in the humus horizons of deluvial soils and 0.4 $g \cdot kg^{-1}$ in the mineral-organic forma-

Table 3

Coefficients enrichment or impoverishment in elements for the surface layers (5-10 cm) in relation to deeper horizons 30-40 cm (I) and 50-60 cm (II)

Soil unit		Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
Eroded soils	I	0.87 0.62-1.06	0.74^{-} 0.48-0.91	0.93 0.55-1.30	0.96 0.83-1.04	1.50^{+} 1.00-2.00	1.45^{+} 0.87-2.27	1.00 0.53-1.54	1.53^{+} 1.03-2.29	1.26^{+} 0.90-1.46
	II	0.33^{---} 0.20-0.58	0.49^{---} 0.32-0.61	0.77^{+} 0.57-1.15	0.67^{--} 0.43-0.87	1.42^{+} 0.75-2.00	1.25^{+} 0.36-2.37	0.75^{-} 0.47-1.23	1.75^{+} 0.82-2.74	1.03 0.98-1.11
Deluvial soils*	I	0.93 0.71-1.11	0.82^{-} 0.66-1.00	0.93 0.72-1.14	0.86 0.67-1.00	1.28^{+} 0.67-2.00	0.83^{-} 0.59-1.02	0.80^{-} 0.52-1.26	0.82^{-} 0.64-1.07	0.88 0.54-1.14
	II	0.81^{-} 0.30-1.13	0.93 0.71-1.11	1.21^{+} 0.83-1.65	0.91 0.77-1.20	1.60^{+} 1.00-2.00	0.86 0.66-1.09	1.01 0.56-1.51	0.92 0.54-1.09	1.29^{+} 0.65-2.70
Mucky soil with mineral-organic layer in the top horizon*	I	0.59^{--} 0.28-1.20	1.31^{+} 0.67-2.62	1.41^{+} 0.84-2.06	0.94 0.69-1.14	1.11 0.80-1.25	1.39^{+} 0.94-2.54	1.04 0.57-1.79	2.19^{++} 1.26-4.17	2.27^{++} 1.08-3.42
	II	0.38^{---} 0.14-0.64	3.91^{++} 1.21-10.83	3.32^{++} 1.10-5.00	0.63^{--} 0.11-1.45	2.32^{++} 0.83-4.00	10.38^{+++} 1.16-21.40	1.92^{+} 1.02-2.97	6.92^{+++} 1.34-11.52	11.51^{+++} 1.08-33.14
Peat – muck soils* strongly silted	I	0.70^{--} 0.36-0.90	1.41^{+} 0.79-3.08	2.75^{++} 0.77-3.30	1.51^{+} 0.58-2.70	1.17 0.71-2.20	3.22^{++} 0.36-6.54	1.30^{+} 0.66-1.82	3.25^{++} 1.12-7.98	1.77^{+} 1.08-3.07
	II	0.24^{---} 0.22-0.29	3.96^{++} 2.62-5.29	3.87^{++} 3.30-4.13	0.89 0.77-1.00	3.25^{++} 1.50-5.00	2.58^{++} 1.20-3.39	0.91 0.37-2.28	8.89^{+++} 5.98-9.22	7.62^{+++} 0.82-14.41
Peat – muck soils*, slightly silted	I	0.74^{-} 0.70-0.77	3.00^{++} 1.67-4.33	2.32^{++} 2.30-2.33	0.67^{--} 0.58-0.75	1.15 1.00-1.30	4.88^{++} 2.25-7.51	2.21^{++} 0.92-3.49	5.44^{+++} 2.88-8.00	4.94^{++} 4.20-5.67
	II	0.73^{-} 0.57-0.90	2.40^{++} 1.54-3.25	2.31^{++} 2.30-2.33	1.20^{+} 0.88-1.52	0.69^{--} 0.50-0.88	2.51^{++} 1.62-3.40	2.05^{++} 1.43-2.66	3.61 2.77-4.45	4.95^{++} 3.36-6.53

Explanations: 1.20-2.00 – evident enrichment (+); 2.01-5.00 – strong enrichment (++); > 5.00 very strong enrichment (+++); 0.85-0.71 – evident impoverishment (–); 0.70-0.51 – strong impoverishment (– –); <0.50 very strong impoverishment – – –).

*according to Polish Soils Classification System (1989) tions of mucky soils and slightly silted mucks (Table 1). The distribution of sodium in the soil profile was variable, which has been manifested by the varied values of coefficients presented in Table 3.

The smallest content of phosphorous was reported in eroded soils and deluvial soils (0.5 $g \cdot kg^{-1}$) – Table 1. In AO horizons of mucky soils and in muck formations, the amount of this element was significantly higher and oscillated between 0.8 $g \cdot kg^{-1}$ and 1 $g \cdot kg^{-1}$. In the analyzed soils, phosphorous was accumulated in surface layers (5-10 cm) of the soil profile (Table 3), which was also noted by SAPEK et al. (1991) and PIAŒCIK et al. (2001a).

Copper was largely accumulated in surface layers of peat-muck soils and mucky soils (Table 3), and its content (9.8-12.8 $g \cdot kg^{-1}$) – Table 1 was higher than in eroded soils and deluvial soils (7.3-8.2 $g \cdot kg^{-1}$). The content of this element was positively correlated with the content of organic matter and <0.02 mm fraction (Table 2).

The average content of zinc was the highest in A horizons of eroded soils (59.9 $g \cdot kg^{-1}$) – Table 1. In deluvial soils, its content was significantly lower (37.0 $g \cdot kg^{-1}$) and increased in AO horizons of mucky soils (54 $g \cdot kg^{-1}$) as well as in strongly silted mucks (55.5 $g \cdot kg^{-1}$) – Table 1.

The content of manganese increased from 290.4 $g \cdot kg^{-1}$ in A horizons of eroded soils to 665.6 $g \cdot kg^{-1}$ in strongly silted mucks (Table 1). The amount of this element was positively correlated with the amount of organic matter and clay fraction (<0.02 mm) – Table 2. In the soil profile, manganese is mobile and precipitated at the point of changes in the redox potential (SAPEK et al. 1991). The distribution of Mn in the soil profile was similar to the zinc distribution. Peat-muck soils and mucky soils showed considerable enrichment of surface layers whereas eroded soils demonstrated impoverishment in the analyzed elements (Table 3).

According to the data in Table 4, the content of the measured elements, except calcium, was higher in deluvial soils and mucky soils than in peat-muck soils. This can be explained by a 2-4-fold higher degree of silting of mineral and mineral-organic formations in comparison to mucks. However, SAPEK et al. (1991) stressed that due to high soil exchange capacity and low density, peat soils may be contaminated on the surface with heavy metals. A statistically significant decrease in the analyzed elements in muck formations as compared to humus horizons (AO) of mucky soils (Table 3) is typical. It distinguished mucky soils and is an argument in favour of classifying them as a separate soil unit in the soil classification system. In the moraine landscape, mucky soils are a pedo-ecotone between and deluvial soils and hydrogenic soils.

In the examined catena sequences, the content of the analyzed elements in eroded soils and deluvial soils is parallel to the amounts in similar soils of Masurian Lakeland examined by BIENIEK (1997). However the muck formations contained more magnesium and potassium than unsilted peat-muck soils of Masurian Lakeland (PIAŒCIK 1977). The content of zinc and copper

Table 4

Mean content of elements in surface horizons of studied soils (expressed per dm^3 of dry soil)

Soil horizon	Value	Ca	Mg	K	Na	P	Fe	Cu	Zn	Mn
		$g \cdot dm^{-3}$							$mg \cdot dm^{-3}$	
1 A	*X*	4.8	4.1	5.7	0.3	0.8	35.4	11.20	91.43	440.71
	S	3.0	1.9	2.4	0.1	0.2	29.2	6.57	62.49	114.57
	CV	62.5	39.6	42.1	33.3	25.0	82.5	58.7	68.4	26.0
2 Ad	*X*	7.1	4.2	4.2	0.4	0.7	20.9	11.27	52.05	415.65
	S	4.65	0.90	0.89	0.08	0.28	4.38	3.42	8.96	213.90
	CV	65.5	21.4	21.2	22.0	40.0	20.9	30.4	17.2	52.7
3 AO	*X*	10.2	4.0	3.3	0.3	0.7	19.7	10.09	42.55	405.84
	S	2.37	0.68	1.31	0.08	0.19	3.45	1.82	13.17	201.89
	CV	23.2	17.0	39.7	26.7	27.2	17.6	18.1	31.0	49.8
4 Mtsz	*X*	7.8	1.7	1.7	0.16	0.5	10.9	4.61	27.34	308.9
	S	1.88	0.51	0.57	0.06	0.17	1.81	1.01	132.12	98.31
	CV	24.1	29.7	34.6	37.5	32.7	16.6	22.0	48.3	31.2
5 Mt	*X*	14.6	0.8	0.5	0.13	0.3	6.9	4.59	11.81	135.12
	S	6.06	0.24	0.43	0.01	0.23	3.54	0.79	4.29	53.30
	CV	41.7	29.6	86.0	7.7	74.2	5.1	17.3	36.4	39.5
Statistically significant differences $\alpha = 0.05$		3>4>5*	3>4>5	1>2>3>4>5	2>3>4	3>4	1>2 3>4	3>4	1>2>3>4>5	4>5

Explanations as in Table 1

was at a natural level (KABATA-PENDIAS et al. 1993), although locally, in mid-moraine depressions of Masurian Lakeland, the soils contained increased levels of some heavy metals (SMÓLCZYÑSKI et al. 2004). As the studied soils are located at the bottom of a slope, downwards water flow, where mineral compounds are accumulated in deposits or are dissolved in water, mucky soils and silted peat-muck soils contain the highest amounts of the analyzed elements (expressed as percentages). This verifies the role of these soils as geochemical barriers for nutrients in moraine landscapes. Similar relationships were reported by OKRUSZKO and CHRUSKA (1998) in grassland soils. Among all the soil formations these authors studied, the most abundant in macro- and microelements were silted organic and mineral-organic formations, especially at sites enriched in mineral compounds with surface flow from surrounding fields. Another study, carried out in an agricultural catchment area of young glacial landscape, proved that land relief was the main determinant of nutrient concentration (Ca, Mg, Na) in both groundwater (SZYMCZYK, CYMES 2005) and mid-field water bodies (CYMES, SZYMCZYK 2005).

CONCLUSIONS

1. The content of elements in the studied toposequences, typical for the moraine landscape of Masurian Lakeland, of eroded soils, deluvial soils, mucky soils as well as slightly and strongly silted peat-muck soils varied in a catena sequence.

2. The highest amounts of Mg, K, Fe, Na were reported in mucky soils, P and Mn in strongly silted peat-muck soils, Ca and Cu in slightly silted peat-muck soils.

3. Surface horizons of deluvial soils were poor in the analyzed elements (excluding P). The measured elements (excluding Ca) were largely accumulated in surface horizons of mucky soils and peat-muck soils.

4. In the moraine landscape, mucky soils and silted peat-muck soils play a role as geochemical barriers protecting wetlands against nutrients from surrounding uplands.

5. Various content of elements in the pedons of the examined toposequences should be taken into consideration when planning land use in the moraine landscape, which has unique natural values.

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