Contemporary Problems of Management and Environmental Protection
Vol. 1, 2009. Soils of Chosen Landscapes: 125-151

Chapter VIII

Mirosław Orzechowski

Sorptive Properties of Alluvial and Deluvial Soils in Various Landscapes of North-Eastern Poland

INTRODUCTION

North-eastern Poland is the region of young glacial area. It was shaped by the glacier and meltwater processes. The landscape was formed by the deposition of material from the glacier during Pleistocene and was finally shaped during Holocene. It is distinguished by parallel variation of geological structure, relief and soil cover. Spatial differentiation of the relief was the basis for distinguishing three morpholithogenetic zones: morainic hills and plains, lakeland uplands and outwash plains [KONDRACKI 1988, GOTKIEWICZ AND SMOŁUCHA 1996]. In a relief of young glacial landscape, ground moraine prevails. However, frontal moraines and numerous meltwater depressions are also considerable [BIAŁOUSZ 1978, KONDRACKI 1972, PIAŚCIK 1996, STASIAK 1971]. Concave forms, which accompany hills of various origin, play an important role in natural environment [KOC 1991]. They are the ecological niche for various species of flora and fauna, natural retention reservoirs and a specific filter in a cycle of nutrients. Land depressions are the places of accumulation of various soil formations: mineral deposits, peat, gyttja and mud, and therefore are very labile and under permanent modifications.

In northern Europe, during postglacial period, processes of natural and anthropogenic denudations occurred with various intensity. They contributed to the mosaic soil cover and heterogeneity of soil formations [BIAŁOUSZ 1978, FRIELINGHAUS, SCHMIDT 1991, PIAŚCIK 1996, SINKIEWICZ 1998]. Soil material was washed off, slipped from the slope and deposited in the depressions. Consequently, deluvial soils, mucky soils and silted peat-muck soils were formed during Holocene [BIENIEK 1997]. Deluvial soils, due to their location in a relief, between eroded soils and soils of depressions, are the first biogeochemical barrier for chemical compounds flowing along the slope. Similar role is played by alluvial soils which are formed by alluvial sediments in delta and riverine landscapes.

A measure of soil resistance to degradation are sorptive properties. Alluvial and deluvial soils are distinguished against the surrounding soils by generally higher buffering capacity and sorption capacity. These soils can accumulate more mineral compounds and are resistant to changes [BIENIEK, GOTKIEWICZ 1990, BIENIEK 1997, ORZECHOWSKI 2008, RYTELEWSKI 1969].

The aim of the paper was to examine sorptive ability and cation composition in sorption complex of alluvial and deluvial soils in various landscapes of north-eastern Poland as well as to evaluate the studied soils with regard to resistance to chemical degradation.

MATERIALS AND METHODS

Examination of sorptive properties in alluvial and deluvial soils was carried out in the following mesoregions of north-eastern Poland: Żuławy Wiślane, Staropruskie Coast, Sępopol Lowland as well as Olsztyn Lakeland and Mrągowo Lakeland (Fig. 1). Five soil catenas in the landscape of lakeland hummocks and landscape of lakeland hills and plains, three catenas in riverine landscape and six soil profiles in delta landscape were studied. One of many methods which are used to examine the intensity of erosion processes is the assessment of the length of formation period of deluvial deposits as well as their thickness. This method was applied by RENIGER [1950], UGGLA et al. [1968], STOCHLAK [1996], SMOLSKA [2005] and enables to evaluate the intensity of erosion processes in the past and predict them in the future. Therefore the studies of deluvial soils were carried out using the catena method. This method enables to determine the toposequence of soils and spatially examine their properties [MARCINEK et al. 1998, SOMMER, ACHLICHTING 1997]. To provide a complete description of slope deposits, type of depression ought to be regarded as well. In case of open depressions, the flow and deposition of fine-grained material occurs outside the depression. However, when a depression is closed, eroded deposits are silting and covering the soils in the depressions [KRUK 1987, ORZECHOWSKI 2004, UGGLA et al. 1968].

In the soils samples collected from the studied sites, the following laboratory analyses were carried out: texture by Bouyoucos-Cassagrande method modified by Prószynski, organic carbon by Tiurin method, soil reaction in H_2O and 1M KCl $\cdot$ dm^{-3} potentiometrically and the content of exchangeable cations extracted by ammonium acetate (1M $CH_3COONH_4 \cdot dm^{-3}$) at pH 7.0. Calcium and magnesium was determined with atomic absorption spectrometry using a Pye Unicam Solaar 969; potassium and sodium was determined with emission atomic spectrometry using FLAPHO 4. Hydrolitic acidity was determined by Kappen method, after extraction with sodium acetate (1M $CH_3COONa \cdot dm^{-3}$). Additionally, the age of deluvial deposits covering peatlands was determined by 14C radiocarbon dating method in Poznan Radiocarbon Laboratory.

The obtained results were analysed statistically by applying correlation analysis, analysis of variance and Duncan's significance tests. The analyses were conducted using Statistica 8.0.

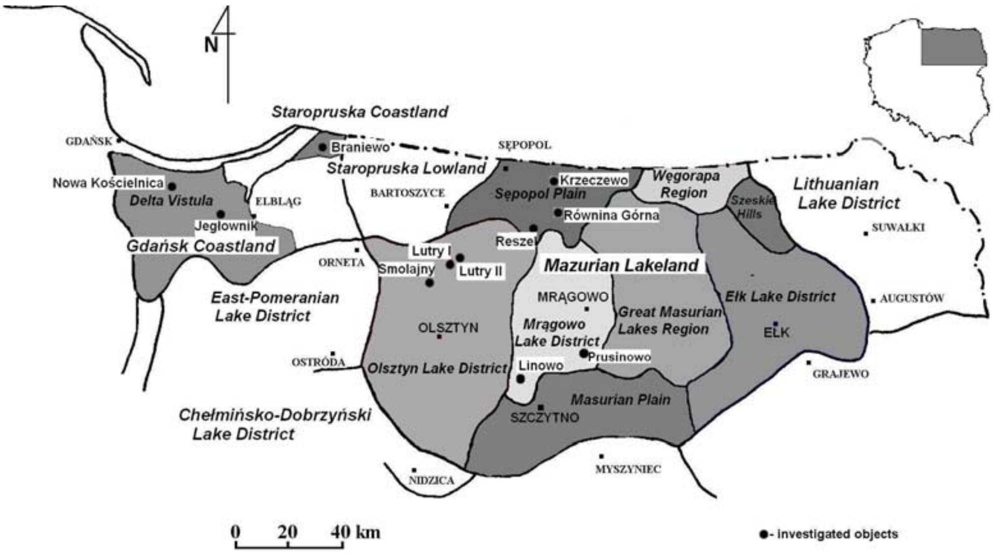


Fig. 1. Location of investigated sites with reference to physico-geografical regionalization of Poland

DESCRIPTION OF THE STUDIED SITES

Landscape of lakeland hills

This type of landscape is most common in north-eastern Poland and covers 50% of the area of Masurian Lakeland. GOTKIEWICZ AND SMOŁUCHA [1996], regarding lithological features of this young glacial landscape, termed it a zone of morainic uplands. Land level differences ranged from 5 m to 10 m and a slope gradient exceeded 7°. A typical feature of the relief is a variety of convex forms such as hummocks and hills as well as depressions of various origin. Most of them are small mid-moraine depressions such as small water bodies or larger areas of meltwater occupied by lakes and wetlands [STASIAK 1971]. According to SOLARSKI and NOWICKI [1990], there are approximately 84000 small water bodies in the area of Masurian Lakeland. Among closed depressions, KRUK [1987] and KLOSS [1987] distinguished: land depressions without wetlands, land depressions with natural wetlands and with drained wetlands. The slopes of the depressions are usually short with various gradient, shape and texture [SMOLSKA 2005, UGGLA 1956, UGGLA et al. 1967, 1968]. In this landscape, the soil cover is particularly diverse. Brown soils, rusty soils, lessive soils, podzol soils, pararendzinas and post-bog soils prevail. Alluvial and deluvial soils occupy the area of 100.39 thousand ha, i.e. 7.6% of the area of Masurian Lakeland [PIAŚCIK et al. 1996].

Four sites were chosen: Lutry I and Lutry II in the area of Pomeranian phase of Vistulianum Glaciation as well as Linowo and Prusinowo in the area of older, Poznań phase of glaciation [KONDRACKI 1972]. The processes of denudation contributed to the separation of soil cover into chains of various sequences. Depending on the intensity of denudation, the soils in the catenas can be variously transformed or new soils may be formed [BIENIEK, GOTKIEWICZ 1990, KOĆMIT et al. 2001]. In the catenas: Lutry I, Lutry II and Prusinowo, a typical toposequence of soils occurring in morainic landscape was found. It consisted of eroded lessive soils and pararendzinas which turned into shallow, medium deep and deep deluvial soils and brown soils in the middle and lower parts of the slope. At the bottom of the slope and in the depressions, shallow humous deluvial soils on peats, mucky soils and differently silted peat-muck soils were formed. The depressions are closed, with peatlands drained with open ditches. Prusinowo catena is situated in a pristine bay of Nawiady Lake, which now occupies the area of 120 ha. Other cross-sections comprise the depressions of pristine lakes which were entirely drained. Moderately and strongly decomposed (R_2 and R_3) alder and reed peats occured in the depressions. The thickness of peat layer amounted to 190 cm. Organic, calcareous and clay gyttja lay underneath. The thickness of the gyttja deposits amounted to 5 m (Lutry I).

In the paper, the soil sequence at Lutry catena, which has coordinates 54°00′57.7″ N, 20°49′58.8″ E (Fig. 2), was presented. On eroded hills, “de-headed” lessive soils occured. They were formed from sandy loam lying on sandy clay loam. Shallow humus horizon with low OC content (8.5 $g \cdot kg^{-1}$) was lying directly on *argillic* horizon (Bt). Due to denudation processes and plowing, the eroded humus horizon was mixed with *luvic* horizon (Eet). Deluvial soils occupied a short section, approximately 22 m.

At Linowo catena, sequence of soils was different: typical proper brown soils – medium deep proper deluvial soils – meedium deep and shallow humous deluvial soils – muckous soils and strongly silted peat-muck soils (Fig. 3). On the top, proper brown soils occurred. They were formed from sandy loam. At Lutry I and Linowo catenas, lessive soils, brown soils and proper deluvial soils (at Linowo also humous deluvial soils) are used as ploughlands. Organic soils in the depressions, muckous soils and shallow humous deluvial soils at Lutry I catena are used as grasslands. The degrees of erosion threat of studied soils were moderate and medium [JÓZEFACIUK, JÓZEFACIUK 1992]. Slope gradient oscillated between 12.3% at Lutry I and 13.6% at Linowo (Figs. 2, 3). Deluvial soils at Linowo site, of older phase of Vistulanum Glaciation, occupied a section of 54 m.

Landscape of morainic hills and plains

This type of landscape comprises Sępopol Lowland and some areas in northern part of Masurian Lakeland. Depressions of ground moraine are extensive with land level differences up to 5 m, and small slope gradients amounting to 2-7°. The depressions are surrounded by ice-dammed and boulder formations. The landscape is hardly diversified. The Sępopol Lowland is distinguished from the Masurian Lakeland by the lithogenesis and morphogenesis. Sępopol Lowland forms an extensive basin without well-developed morainic forms and lakes. Land depressions are not very scattered as in Masurian Lakeland, and slope gradient as well as erosion threat are low [KONDRACKI 1988]. GOTKIEWICZ and SMOŁUCHA [1996] termed this area the zone of ice-dammed lake origin. Fertile brown soils and black earths prevail. The area of alluvial and deluvial soils is small and amounts to 1.6 thousands ha, i.e. 1.4% of the area of Sępopol Plain [PIAŚCIK et al. 1996]. In this landscape the soils were formed from loam and clay, which origin was associated with deglaciation of ice-dammed lake origin [KONDRACKI 1988; UGGLA, WITEK 1958].

For the research, a site located near Reszel, with coordinates 54°03′16.4″ N, 21°04′22.0″ E was chosen. The following soil sequence was noted: black earths – shallow proper deluvial soils – deep, medium deep and shallow humous deluvial soils on peat – mucky soils and peat-muck soils. Black earths were formed from loam. The land is drained with drainage pipes and the soils were used as ploughland. The soil erosion threat was lowand the slope gradient was up to 7% (Fig. 4). Deluvial soils occupied the longest section among all studied catenas – 120 m.

Riverine landscape

In the area of north-eastern Poland there are only few typical fluvial forms. In Masurian Lakeland, rivers used the postglacial gutters and lake depressions by connecting them with the gorges to carry waters flowing from morainic hills [KONDRACKI 1972, PIAŚCIK 1986[a,b]]. In this area, Łyna is the longest river and is flowing through Olsztyn Lakeland and Sępopol Lowland. In Olsztyn Lakeland, the river has a post-lacustrine character and the valley is as wide as from 100 m to 1600 m [PIAŚCIK 1986[a]]. Below Dobre Miasto, the river begins to meander. Fine-grained formations were deposited in wider parts of the valleys and in old-bows. PIAŚCIK [1986[b]] termed this part of the river the basin of formations of ice-dammed lake origin.

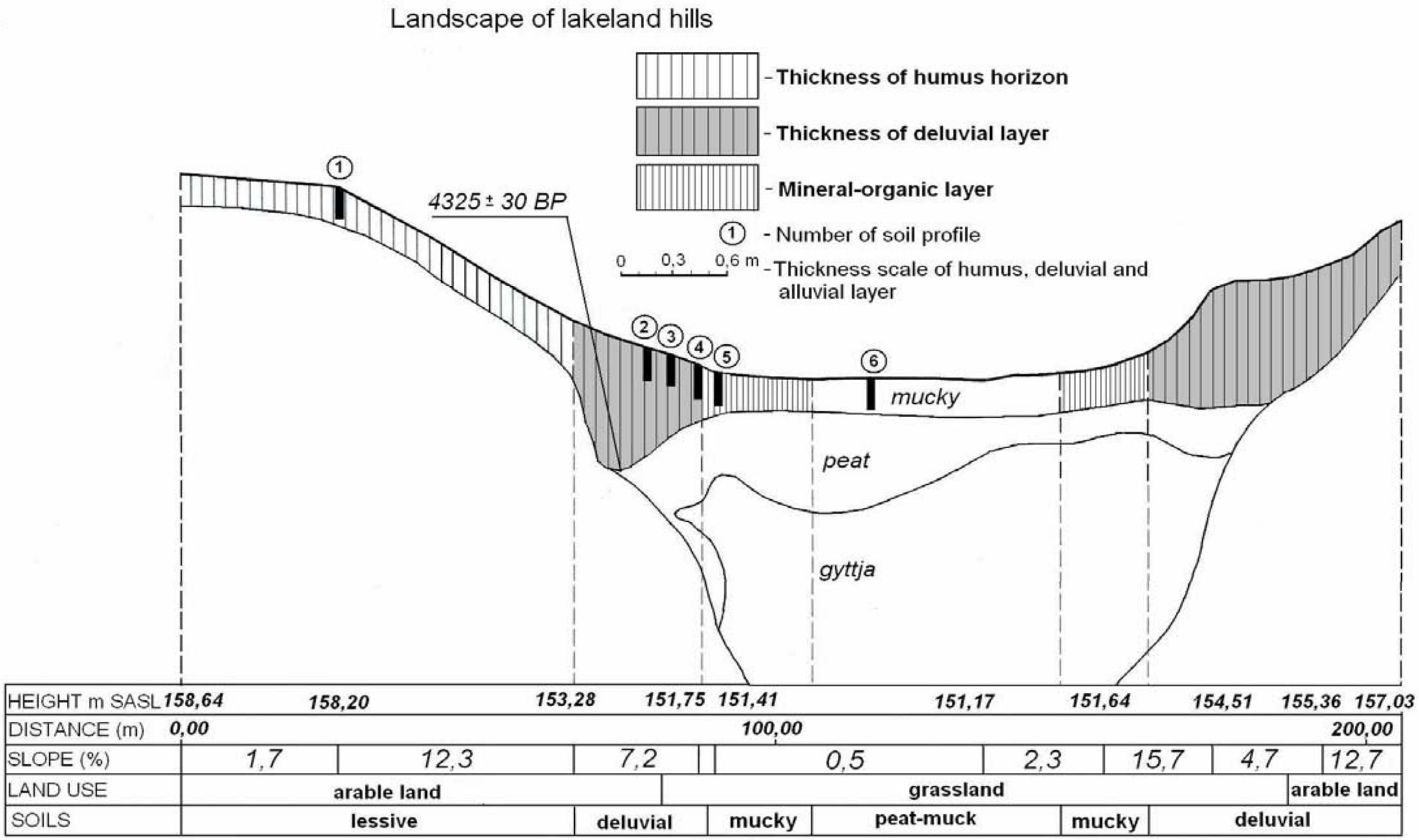
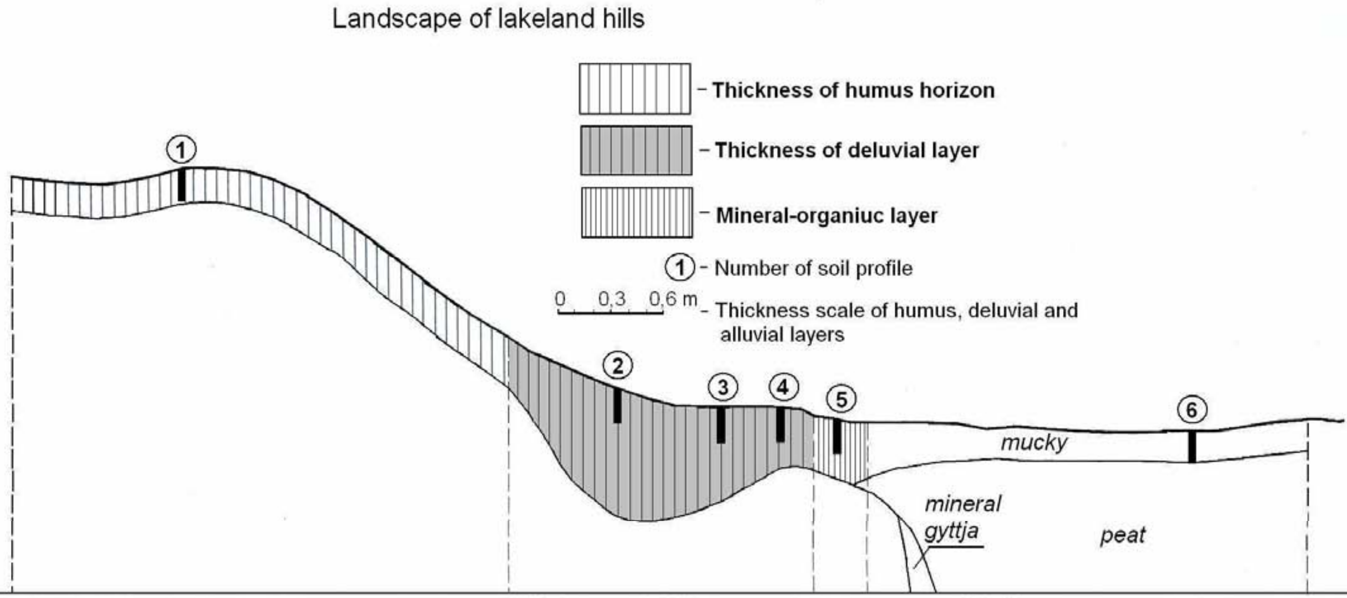


Fig. 2. Catena Lutry I



HEIGHT m ASL	152,71	152,45	153,00	152,61	146,61	144,69	144,54	143,89	143,85	144,26
DISTANCE (m)	0,00	100,00	200,00							
SLOPE (%)	1,7	3,9	2,4	13,6	7,6	0,6	2,1	0,1	2,7	
LAND USE	arable land	grassland								
SOILS	proper brown	deluvial	proper mucky	peat -mucky						

Fig. 3. Catena Linowo

In this area, Smolajny catena was chosen. The following soil sequence was found: Arenosols surrounding the valley and humous deluvial soils at the bottom of the valley. Peat-muck soils were accumulated in river valley. Near the riverbed these soils were covered with fine-grained alluvial deposits forming medium deep and deep humous alluvial soils. These soils were abundant in organic matter and were formed under gley and humus-forming process on grasslands.

On Sępopol Lowland, river valleys are well-developed, narrow and deeply incised into the surface. In the narrowness and at the edges of the valley, deluvial and alluvial deposits overlap and are mixed. Therefore, typical alluvial soils, without admixture of deluvial deposits, are formed only in wider parts of the valleys [PIAŚCIK 1986[b]].

In riverine landscape, the following sites were chosen: Równina Górna in Guber river valley and Krzeczewo in Liwna river valley at Sępopol Lowland. In river valleys, deep and medium deep humous alluvial soils occurred. On the slopes of the valley, proper and humous deluvial soils, of various depth, were developed. Black earths and lessive soils were surrounding alluvial and deluvial soils. At Równina Górna catena, located in the zone of ice-dammed lake origin (54°10′48.3″ N, 21°14′91.0″ E), toposequence consists of the following soils: proper black earths – medium deep and deep proper deluvial soils – medium deep and deep humous deluvial soils – deep humous alluvial soils (Fig. 5). Black earths, situated on the top, were formed from loam and were underlain by clay loam or heavy clay. Deluvial soils occurred on the slope and were formed from loam. Guber river valley was filled with alluvial soils formed from fine-grained deposits (silt clay loam, clay silt, silty clay, silt). Deluvial soils occupied the section of 100 m.

Delta landscape

This type of landscape occurs in Vistula and Pasłęka deltas and is typical for a region of Żuławy Wiślane and Staropruska Lowland (Fig. 1). This landscape is the youngest and is distinguished from other studied landscapes by plain relief, low location, high ground water level and by the origin of alluvial soils [KONDRACKI 1988, PIAŚCIK et al 2000, RYTELEWSKI 1969, WITEK 1965]. Delta landscape was shaped by accumulative river activity and technical treatments applied by man.

It is a Holocene alluvial plain which has homogenous origin, and which was shaped by flooding river waters. As a result, Pleistocene formations had been covered by Holocene riverine deposits and alluvial soils were formed. Soil conditions were associated with the origin and land hypsometry which differentiates water conditions, types of formations and their thickness.

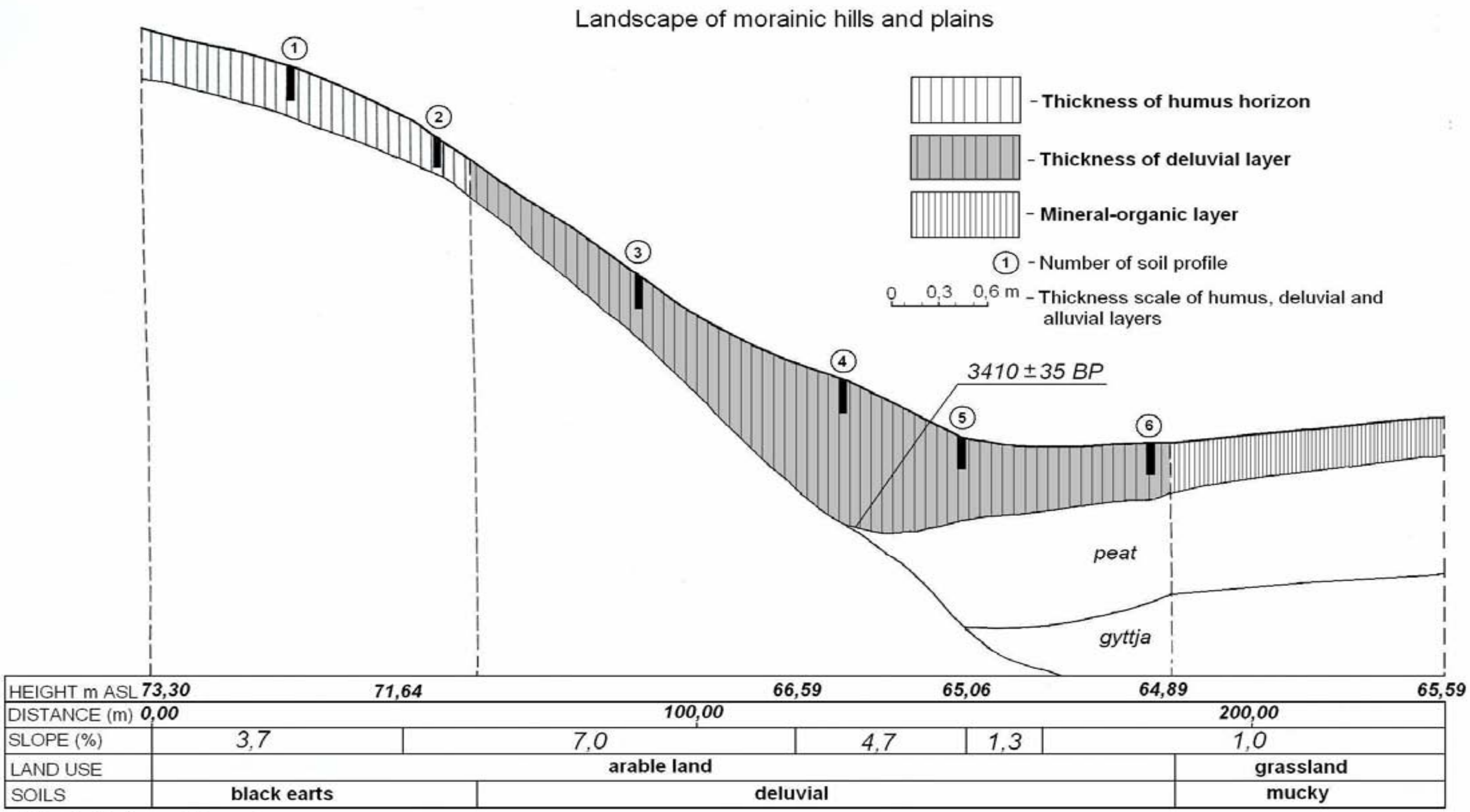


Fig. 4. Catena Reszel

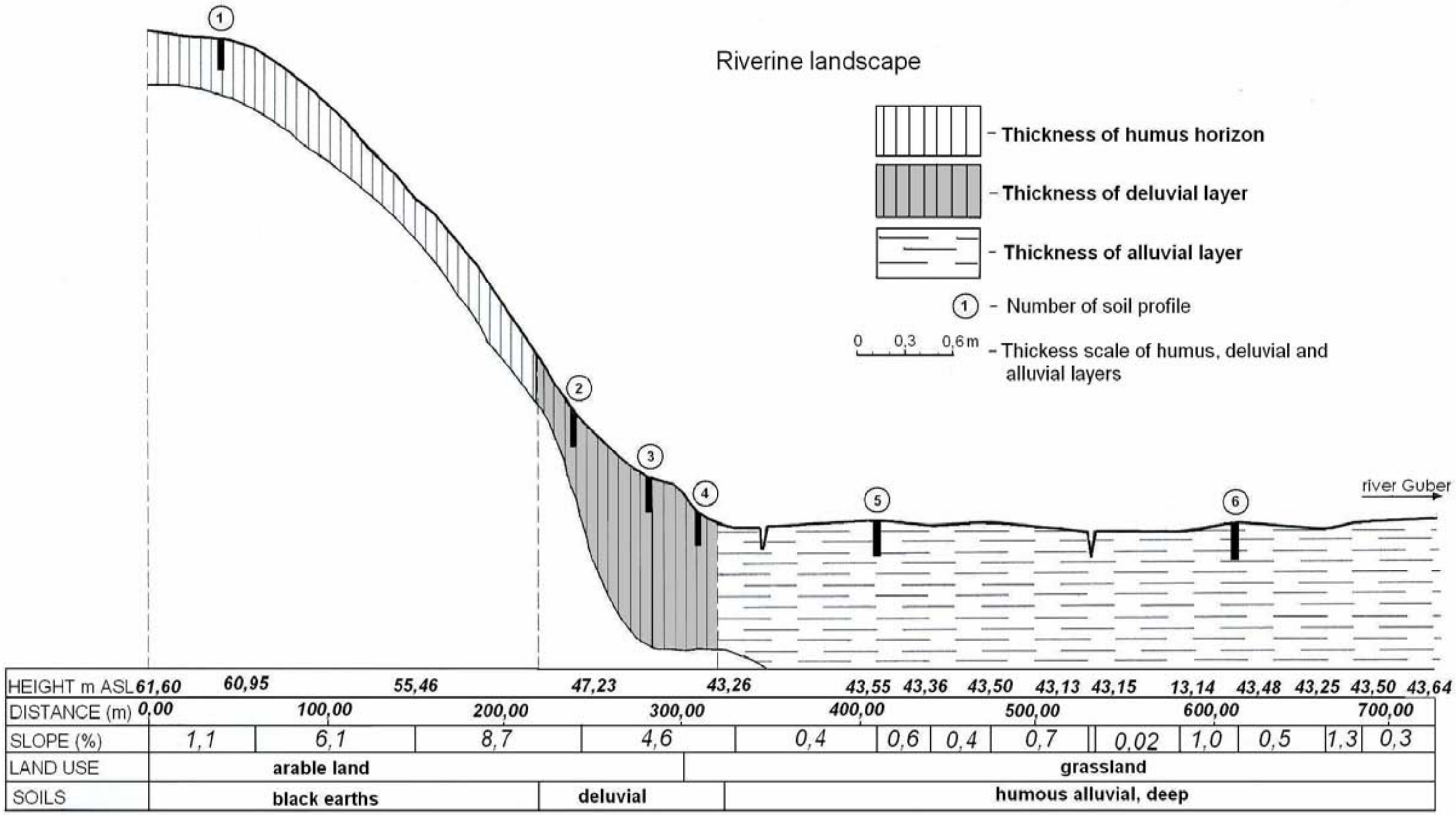


Fig. 5. Catena Równina Górna

In delta landscape, in Żuławy Wiślane, at Nowa Koscielnica site, humous alluvial soils, of various depth, were chosen.The soils were lying on alder peat and were formed from clayey silt and silt clay loam. At Jegłownik site, shallow humous alluvial soil was chosen. The soil was lying on reed peat and was formed from sandy loam. In the area of Pasłęka delta, shallow and medium deep humous alluvial soils were chosen. The soils were lying on alder peat and were formed form loamy silt and clayey silt.

ORIGIN OF ALLUVIAL AND DELUVIAL SOILS

Formation of alluvial and deluvial soils was connected with erosive and sedimentary activity of waters. According to the Polish soil classification [1989], a criterion for distinguishing deluvial soils is: an accumulation of deluvial deposits of a thickness of more than 30 cm. In the classification of World Soil Resources (WRB), alluvial and deluvial soils are classified into one of main 30 groups of *Fluvisols* [KLASYFIKACJA ZASOBÓW GLEBOWYCH ŚWIATA 2003]. BAUŽIENIĖ et al. [2008] suggested that the terms 'deluvial soils' and 'colluvial soils' in national soil classifications of Poland and Lithuania should not be changed. The definition of deluvial deposit may be improved by diagnostic criteria: depth of more than 30 cm, more than 0.5% of organic carbon in every part of deluvial horizon of a thickness of more than 30 cm.

At Lutry I site, in landscape of lakeland hills, in the area of Pomeranian phase of Vistulianum Glaciation, the beginning of the deposition of deluvial layers covering peats was dated, using the method of radioactive carbon, at 4325 ±30 years BP. The layer of deluvial deposits has reached the thickness of 78 cm (Fig. 2). At Reszel site, located in the zone of ice-dammed lake origin, the beginning of the deposition of deluvium was dated at 3410 ±35 years BP and their thickness was smaller and amounted to 61 cm (Fig. 4). The beginning of deposition of deluvial sediments falls on sub-boreal climatic period [STARKEL 1999]. As compared to previous, subatlantic period, subboreal period was more humid and colder, with larger proportion of oak, hornbeam and beech. Therefore, due to higher moisture content in soils, particularly in sandy soils, the processes of leaching of calcium and slow acidification occurred. Together with the development of Neolithic cultures, forests occupied smaller areas and were replaced by grassland vegetation. Burning of forests increased soil fertility and enabled agricultural land use. This kind of activity activated erosion processes at a large scale. Deposits flowing from the slopes began to form deluvial soils. The scale and time shift of the beginning of deluvial deposition ought to be related to local, selective taking over of fertile land for grazing and cultivation.

In Middle Europe, anthropogenic changes of denudation and sedimentation caused by forestry-fallow management started in an early neolith, approximately 7.5-6.5 thousand years BP [STARKEL 1989]. BIENIEK [1997], using 14C method, dated the deluvial deposits in Masurian Lakeland at sub-boreal period (4 080 ±70 years BP and 3 220 ±70 years BP), the period of burning-fallow management.

In riverine landscape, at Smolajny site in Łyna river valley, the beginning of deposition of alluvial sediments which were covering the peats was dated at 5720 ±40 years BP, i. e. earlier than in morainic landscape. Alluvial deposits started accumulating during, atlantic period and have reached the thickness of 102 cm – the highest among all studied sites. In delta landscape, alluvial deposits on peats began to accumulate much later. In Vistula delta at Stara Kościelnica site, alluvial sediments began to deposit 2850 ±35 years BP. At Braniewo site in Pasłęka delta – 2190 ±30 years BP. It is the end of sub-boreal period and the beginning of sub-atlantic period. The thickness of alluvial deposits on peat at Stara Kościelnica amounted to 86 cm and at Braniewo site to 80 cm.

SOIL SORPTIVE PROPERTIES

The highest amounts of humus, silt (Ø 0.05-0.002 mm) and clay (Ø < 0.002 mm) were reported in alluvial soils in delta and riverine landscape as well as in deluvial soils in the landscape of morainic hills and plains (Tab. 1). The C:N ratio was narrow and oscillated between 8.0 in deluvial soils in the landscape of ice-dammed lake origin and 9.5 in alluvial soils in delta landscape. Soil reaction of deluvial soils in the landscape of morainic hills and plains and riverine landscape was slightly acid. At Równina Górna catena, alluvial soils in Liwna river valley had neutral soil reaction. Wide range of pH_{KCl} values, from very strongly acid (4.5) to neutral (7.1), was recorded in deluvial soils in landscape of lakeland hills (Tabs. 4-7).

Sorptive properties of alluvial and deluvial soils were strongly dependent on the content of silt (Ø 0.05-0.002 mm), clay (Ø < 0.002 mm) and humus (Tab. 1). The highest sorption capacity was reported in the soils in which the content of silt, clay and humus was the highest. In alluvial soils in delta and riverine landscapes as well as in deluvial soils in the zone of ice-dammed lake origin, mean value of cation exchange capacity exceeded 410 mmol(+) kg^{-1}. As compared to deluvial soils situated in riverine landscape and landscape of lakeland hills, the value of CEC was twice higher. Analysis of variance proved that these differences were statistically very significant (Tab. 1).

Table 1

Sorptive properties, pH, content of humus and mineral fraction in alluvial and deluvial soils

Speci-fication	Value	Alluvial soilsˆ			Deluvial soilsˆ		Statistically significant differences
		Delta landscape	Riverine landscape		Landscape of morainic hills and plains	Landscape of lakeland hills	
		A, n = 15	B, n = 22	C, n = 16	D, n = 13	E, n = 32	
% Ø in mm <0,002ˇ	x	24.3	27.1	13.4	25.9	7.6	A,B,D>C,E**
	SD	14.5	14.9	8.9	6.9	6.6	
	CV (%)	59.7	55.0	67.3	26.8	87.1	
0,05-0,002	x	51.4	53.3	27.9	44.0	33.6	A,B,D>C,E**
	SD	7.2	11.8	11.9	4.2	7.8	A,B>D*
	CV (%)	14.0	22.1	42.8	9.6	23.3	
Humus	x	40.1	48.1	34.0	65.9	31.0	D>C,E**
	SD	22.4	29.7	34.5	44.8	23.7	D>A,B*
	CV (%)	55.9	61.9	101.6	68.0	76,2	
C-org.	x	23.8	28.0	19.7	41.7	18.0	D>C,E**
	SD	13.0	17.3	20.0	26.0	13.7	D>A,B*
[$g\cdot kg^{-1}$]	CV (%)	54.8	61.9	101.6	62.3	76.2	
C:N	x	9.5:1	8.8:1	8.6:1	8.0:1	9.1:1	–
pH_{KCl}	x	5.3	6.1	5.9	6.2	5.7	B,C,D>A**
	min.	4.8	4.9	5.1	5.9	4.5	E>A*
	max.	6.8	6.7	6.4	6.6	7.1	B,D>E*
Ca^{2+}	x	297.2	423.8	191.2	392.2	150.0	B,D>A,C,E**
	SD	75.1	120.7	82.1	228.7	74.5	A>E**
	CV (%)	25.4	28.5	42.9	58.3	49.7	A>C*
Mg^{2+}	x	37.6	46.9	22.9	41.8	11.7	A,B,D>C,E**
	SD	19.0	11.2	14.6	15.9	5.1	C>E**
	CV (%)	50.4	23.9	64.0	38.1	43.7	
K^+	x	8.4	8.2	5.6	10.6	4.9	A,D>E**
	SD	2.1	7.3	3.5	2.6	1.6	D>C**
	CV (%)	25.2	89.7	61.8	24.4	33.3	A>C*, B>E*
Na^+	x	7.7	2.5	1.8	9.7	4.1	A,D>B,C,E**
	SD	2.8	0.6	1.0	2.9	1.5	E>C**, E>B*
	CV (%)	36.3	22.6	53.8	29.7	35.0	D>A**
H_h	x	60.0	17.9	13.9	25.6	23.9	A>B,C,D,E**
	SD	16.5	16.1	10.8	6.7	11.3	D>C**
	CV (%)	27.6	89.8	77.4	26.1	47.2	E>C*
SBC	x	350.9	481.4	221.5	454.3	170.7	B,D>A,C,E**
	SD	91.3	132.6	96.4	239.6	77.6	A>C,E**
	CV (%)	26.0	27.5	43.5	52.8	45.4	
CEC	x	410.9	499.3	235.4	479.9	194.6	A,B,D>C,E**
	SD	89.4	138.4	95.8	242.5	80.3	
$mmol(+)\cdot kg^{-1}$	CV (%)	21.8	27.7	40.7	50.5	41.3	

ˆ – Systematics of Polish Soils [1989]; ˇ – according to PTG 2008; H_h – hydrolytic acidity; SBC – sum of base exchangeable cations; CEC – cation exchange capasity; n – number of soil samples; x – mean; SD – standard deviation; CV – coefficient of variation; * – differences statistically significant (α = 0,05); ** – differences statistically very significant (α = 0,01)

The amount of base cations in these soils was also the highest. In alluvial soils in delta landscape, noteworthy is the decrease of sum of base cations in relation to cation exchange capacity. It is a result of acid soil reaction (pH_{KCl} 5.3) and high mean amount of exchangeable hydrogen (60.0 mmol(+)·kg^{-1}. In these soils than in other soils, mean value of hydrolytic acidity was 2-4 times higher, and mean proportion of hydrogen in soil sorption complex was the highest and amounted to 15.5% (Tabs. 1, 2). The obtained results of the analysis of variance reveaedl that these differences were statistically very significant ($\alpha = 0.01$).

Higher sorption capacity and sum of base cations were recorded in alluvial and deluvial soils in the zone of ice-dammed lake origin than in alluvial soils of middle Odra river [LASKOWSKI 1986, NIEDŹWIECKI 1984]. In riverine and landscape of lakeland hills, in deluvial soils, the values of cation exchange capacity and sum of base cations were similar to the amounts reported by BIENIEK [1997] in deluvial soils formed from loam.

The correlation coefficients proved that in the studied soils the values of CEC and SBC were positively correlated with clay content (Tab. 3). In deluvial soils in riverine landscape this dependence was statistically significant. In deluvial soils the values of CEC and SBC were positively correlated with the amount of silt whereas in alluvial soils the correlation was negative. Statistically significant proved to be the correlation between the amounts of humus and CEC in alluvial soils in riverine landscape (r = 0.472*) and in deluvial soils in the landscape of morainic hills and plains (r = 0.739*) and landscape of lakeland hills (r = 0.457*).

Exchangeable calcium was the dominant cation in the sorption complex of studied soils. Particularly high amounts of this cation were found in alluvial soils in riverine landscape (432.8 mmol(+)·kg^{-1}) and in deluvial soils in the landscape of morainic hills and plains (392.2 mmol(+)·kg^{-1}). Analysis of variance revealed that the differences in the content of Ca^{2+} and SBC between these soils and alluvial soils in delta landscape, deluvial soils in riverine landscape, deluvial soils in landscape of lakeland hills were very significant ($\alpha = 0.01$). Alluvial soils in riverine landscape and deluvial soils in the landscape of morainic hills and plains had the highest amounts of humus. Calcium may be retained in organic compounds therefore the losses of calcium caused by its leaching are lower than in the soils with low organic matter content [LITYŃSKI, JUROWSKA 1982]. In these soils, correlation between the amount of humus and calcium cations proved to be statistically significant (Tab. 3). In deluvial soils in riverine landscape and landscape of lakeland hills, the contents of Ca and Mg were 2-4 times lower and the content of K 1.5-2 times lower than in alluvial and deluvial soils in the zone of ice-dammed lake origin.

High soil sorption capacity and high content of base cations in alluvial and deluvial soils of the zone of ice-dammed lake origin proved that these soils can intercept and retain high amounts of mineral compounds washed with the erosive waters. These compounds may be later uptaken by plants and therefore groundwaters may be less contaminated. According to POKOJSKA [1988], the role of barriers of nutrient flow in agricultural landscape may be played by the soils of mid-field afforestations.

Table 2

Percentage of exchangeable cations in soil sorption complex and the ratio of cations

Speci-fication	Value	Alluvial soils			Deluvial solis		Statistically significant differences
		Delta land-scape	Riverine laddscape		Landscape of morainic hills and plains	Landscape of lakeland hills	
		A	B	C	D	E	
[%]	X	71.4	84.8	80.3	79.0	74.9	B,C>A,E**
Ca	SD	6.5	2.8	4.5	7.1	7.6	B>C,D*
	CV (%)	9.1	3.3	5.6	9.0	10,1	D>A*
	X	9.1	9.6	8.8	9.6	6.5	B,D>E**
Mg	SD	3.7	1.7	4.2	2.9	2,0	A,C>E*
	CV(%)	40.7	17.7	47.7	30.2	30.8	
	X	2.1	1.5	2.5	2.7	2.9	D,E>B**
K	SD	0.5	1.2	1.2	1.3	1.6	
	CV(%)	23.8	80.0	48.0	48.1	55.2	
	X	1.9	0,5	0.9	2.2	2.4	A,D,E>B,C**
Na	SD	0.4	0,2	0.8	0.7	1.0	
	CV(%)	19.2	40.0	88.9	31.8	41.7	
	X	15.5	3.6	7.5	6.5	13.3	A,E>B,C,D**
H_h	SD	6.3	2.5	7.0	3.0	5.4	C>B*
	CV(%)	40.6	69.2	93.3	46.2	40.6	
	X	84.5	96.4	92.5	93.5	86.7	B,C,D>A,E**
SBC	SD	6.3	2.5	6.9	3.0	5.4	
	CV(%)	7.4	2.6	7.5	3.2	6.2	
	x	9.1	9.1	13.5	4.4	13.5	
Ca/Mg	SD	4.1	1.7	11.7	0.5	7.2	
	CV(%)	45.1	18.7	86.7	11.4	53.3	
	X	36.4	86.7	43.5	24.8	34.1	
Ca/K	SD	9.1	64.1	31.7	0.3	20.5	
	CV(%)	25.0	73.9	72.9	1.2	60.1	
Ca+Mg/	X	21.6	54.8	30.1	21.0	18.2	
Na+K	SD	6.7	22.7	12.2	10.9	8.3	
	CV(%)	31.0	14.4	40.5	51.9	45.6	
	X	6.7	48.5	24.3	17.9	8.6	
S/H_h	SD	3.9	37.8	15.3	8.1	6.2	
	CV(%)	58.2	77.9	63.0	45.3	72.1	

Explanation as in Table 1

Table 3

Results of correlation between content of silt, clay, humus and sorptive properties of the studied soils

Speci-fication	Alluvial soils						Deluvial solis								
	Delta landscape			Riverine landscape						Landscape of morainic hills and plains			Landscape of lakeland hills		
	0,05-0,002	<0,002	Humus	0,05-0,002	<0,002	Humus	0,05-0,002	<0,002	Humus	0,05-0,002	<0,002	Humus	0,05-0,002	<0,002	Humus
Ca	0.004	0.174	-0.174	-0.559*	0.305	0.430*	0.597*	0.577	0.360	0.229	0.291	0.695*	0.560*	-0.013	0.390*
Mg	-0.388	0.519*	-0.317	-0.670*	0.599*	0.068	0.775*	0.669*	0.049	-0.454	0.441	0.895*	0.145	0.265	0.110
K	-0.272	0.450	-0.321	-0.702*	0,571*	0.179	0.686*	0.617*	-0.226	-0.221	0.223	0.086	0.094	0.249	0.139
Na	-0.042	0.367	0.175	0.508*	-0.110	-0.121	-0.369	-0.404	0.394	-0.152	0.346	0.841*	0.204	0.096	0.097
H_h	0.291	-0.030	-0.207	-0.197	-0.442*	0.710*	-0.626*	-0.660*	0.716*	0.048	-0.101	0.217	0.126	-0.334	0.603*
SBC	-0.111	0.289	-0.177	-0.603*	0.360	0.407	0.647*	0.612*	0.310	0.184	0.314	0.734*	0.512*	0.012	0.386*
CEC mmol(+)·kg^{-1}	-0.059	0.290	-0.219	-0.600*	0.293	0.472*	0.581*	0.541*	0.392	0.179	0.315	0.739*	0.512*	0.035	0.457*
C [%]	0.026	-0.131	0.094	0.191	0.105	-0.147	0.504*	0.593*	-0.065	0.173	0.306	0.448	0.377*	0.091	0.079
Mg	-0.460	0.540*	-0.262	0.014	0.310	-0.597*	0.786*	0.662*	-0.150	-0.434	-0.094	-0.195	-0.383*	0.300	-0.339
K	-0.229	0.107	-0.099	-0.599*	0.522*	0.099	0.209	0.231	-0.390	-0.017	-0.392	-0.629*	-0.359*	0.135	-0.322
Na	0.267	-0.192	0.070	0.461*	0.011	-0.427*	-0.649*	-0.576*	-0.040	-0.177	-0.176	0.484	-0.410*	0.128	-0.387*
H_h	0.265	-0.193	0.070	0.040	-0.615*	0.590*	-0.766*	-0.763*	0.206	0.026	-0.355	-0.485	-0.207	-0.303	0.181
V	-0.265	0.193	-0.070	-0.040	0.615*	-0.590*	0.766*	0.763*	-0.206	-0.026	0.355	0.485	0.207	0.303	-0.181

* - correlation significant at $p \leq 0.05$;

Quantitatively, exchangeable cations in alluvial and deluvial soils in riverine landscape and deluvial soils in the landscape of morainic hills and plains, can be arranged as follows: Ca > Mg > H > K > Na. Alluvial delta soils and, most impoverished in clay fraction, deluvial soils in landscape of lakeland hills, contained more exchangeable hydrogen than magnesium.

Correlation coefficients proved that the amount of exchangeable Mg was positively correlated with the amount of clay fraction (Tab. 3).

Studied alluvial and deluvial soils are distinguished by high trophism. According to the criteria introduced by SIUTA [1976], regarding the content of exchangeable Ca, Mg, K and Na in soil sorption complex, the studied soils are very strongly resistant to degradation. Mean values of SBC in alluvial soils in delta and riverine landscape as well as in deluvial soils in the landscape of morainic hills and plains were higher than the amounts ascribed to the highest, tenth degree of resistance to soil degradation. Deluvial soils in riverine landscape were classified into 8^{th} degree and in landscape of lakeland hills into 6^{th} degree of resistance.

Studied soils had high but differentiated proportion of base cations in soil sorption complex. Mean value of base saturation ranged from 84.5% in alluvial soils in delta landscape and 86.7% in deluvial soils in landscape of lakeland hills to more than 92.5% in alluvial and deluvial soils in other studied landscapes (Tab. 2). On the base of analysis of variance, very significant differences ($\alpha = 0.01$) in base saturation were revealed between alluvial soils in riverine landscape, deluvial soils in riverine landscape, deluvial soils in the landscape of morainic hills and plains and alluvial soils in delta landscape, deluvial soils in delta landscape, alluvial soils in landscape of lakeland hills, deluvial soils in landscape of lakeland hills. Mean proportion of hydrogen cation in soil sorption capacity of these soils ranged from 3.6% to 15.5%. Evaluating the level of soil degradation, the studied soils are slightly degraded regarding the proportion of hydrogen in soil sorption complex. The correlation coefficients proved that the base saturation is positively correlated with clay content in alluvial soils (r = 0.615*) and deluvial soils (r = 0.763*) in riverine landscape.

Slightly higher proportion of base cations and lower proportion of hydrogen in sorption complex was reported by ORZECHOWSKI [2005] in alluvial soils of Żuławy Wiślane. BIENIEK and GOTKIEWICZ [1990] also reported very high proportion of base cations in soil sorption complex of deluvial soils in the zone of morainic uplands in Mrągowo Lakeland. BIENIEK [1997] noted similar tendency in deluvial soils formed from eroded loamy brown soils.

Mean proportion of exchangeable magnesium in soil sorption capacity was low and ranged from 6.5% in deluvial soils in landscape of lakeland hills to 8.8-9.6% in alluvial and deluvial soils in other studied landscapes (Tab. 2).

Saturation of sorption complex with potassium and sodium did not exceed 3% and was the lowest in alluvial riverine soils.

In relation to optimal proportion [FILIPEK 1990], studied alluvial and deluvial soils had lower than optimal proportion of exchangeable potassium and hydrogen in the sorption complex and similar to optimal proportion of magnesium. Mean content of calcium in the soil sorption complex of studied soils was considerably higher that the value of optimal saturation, which is 65% (Tab. 2). Base saturation most similar to the optimal was found in alluvial soils in delta landscape. Mean Ca:Mg ratio showed small fluctuations and amounted to 4.4-13.5. It was most favourable in alluvial soils (9.1). High content and high proportion of exchangeable calcium and magnesium in the sorption complex of alluvial soils in riverine landscape affected wide ratio of Ca^{2+}:K^{+} (86.7) as well as the ratio of bivalent and univalent cations ($Ca^{2+}+Mg^{2+}/K^{+}+Na^{+}$), which amounted to 54.8. Such high qualitative differences and wide ratio may contribute to the inhibition of potassium uptake by plants. Calcium and magnesium cations may block the potassium uptake (LITYŃSKI, JURKOWSKA 1982].

In studied Lutry I, Reszel and Równina Górna catenas, deluvial soils located higher in the relief were more acid, by 0.3 to 0.8 value of pH, than deluvial soils situated at the bottom of the slope (Tabs. 4, 6, 7). The reaction of the soils in studied catenas depended mainly on pH value of eroded soils. At Linowo and Reszel catenas (Tabs. 5, 6) eroded proper brown soils and black earths had neutral soil reaction (6.7-7.0) in Ap horizons whereas deluvial soils had slightly acid soil reaction (5.7-6.5) in surface layers. Progressive acidification occurring simultaneously with the increasing distance from the sources of erosion was noted by BIENIEK, GOTKIEWICZ [1990], BIENIEK [1997], MARCINEK et al. [1998], ORZECHOWSKI et al. [2004], ORZECHOWSKi [2008]. At Lutry and Równina Górna catenas, eroded lessive soils and black earths had acid (5.0-5.4) soil reaction. Deluvial soils were less acidified in surface horizons and their soil reaction was from acid to slightly acid (5.1-6.4).

In investigated catenas, in surface horizons of deluvial soils the amount of organic carbon, exchangeable calcium, magnesium and sodium as well as the values of SBC and CEC were increasing towards the depression (Tabs. 4-7). Black earths at Równina Górna and proper brown soils at Linowo had higher cation exchange capacity, content of base cations, including Ca^{2+}, than proper deluvial soils located in the middle of the slope (Tabs. 5, 7). This indicates that the process of leaching of base cations, especially calcium, was most intense in this part of the slope. The washed compounds were then accumulated in the soils of depressions. Higher values of cation exchange capacity were observed in deluvial soils in closed valleys than in open valleys [UGGLA, MIROWSKI 1960].

Sorptive properties soils of Lutry I catena in the landscape of lakeland hills — Table 4

No Pro-file	Horizon	Depth cm	Soil tex-ture	% ø in mm 0,05-0,002	% ø in mm < 0,002	pH KCl	C-org. g·kg^{-1}	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H_h	SBC	CEC	SBC/CEC	Ca/CEC
								mmol(+)kg^{-1} soil							%	
							Eroded lessive soil; location: summit									
1	Ap	0-25	SL*	26	6	5.0	8.5	52.6	5.6	7.4	2.0	18.8	67.6	86.4	78.3	60.9
	Bt	25-80	SCL	25	21	5.3	–	106.1	14.7	6.8	3.6	16.9	131.2	148.1	88.6	71.7
	C	80-150	SL	24	20	5.9	–	102.8	12.3	6.1	3.2	8.6	124.4	133.0	93.5	77.3
							Proper deluvial soil, medium deep; midslope									
2	Ap	0-25	SL	38	6	5.3	13.6	54.6	5.9	6.1	2.0	24.0	68.6	92.6	74.1	59.0
	A2	25-54	SL	36	7	5.6	7.2	84.6	7.3	4.4	2.4	21.0	98.7	119.7	82.5	70.7
	A3	54-74	SL	31	8	6.7	6.4	127.5	8.1	3.2	3.7	10.5	142.5	153.0	93.1	83.3
	A4	74-95	SL	25	4	6.3	2.5	283.4	21.9	4.4	7.8	27.0	317.5	344.5	92.2	82.2
	Cgg	95-150	SL	24	14	6.3	–	93.1	10.8	5.0	3,6	5.6	112.5	118.1	95.3	78.8
							Proper deluvial soil, medium deep; lower slope									
3	Ap	0-27	SL	29	8	5.1	12.1	59.8	6.0	7.3	2.3	16.4	75.4	91.8	82.1	65.2
	A2	27-40	SL	32	7	5.9	9.4	56.6	7.5	3.7	3.0	15.0	70.8	85.8	82.5	66.0
	A3	40-72	SL	41	6	5.8	14.2	120.2	11.0	2.8	3.9	18.0	137.9	155.9	88.4	77.1
	OtniolR_3	72-116	peat	35	10	6.7	327.7	605.3	69.2	2.9	17.1	168.2	694.5	862.7	80.5	70.2
							Humous deluvial soil, shallow; foot-slope									
4	Aa	0-18	SL	32	4	5.9	30.7	99.2	10.3	3.9	4.6	28.5	118.0	146.5	80.5	67.7
	A2	18-45	SL	49	7	5.3	32.1	149.3	15.3	3.5	6.8	40.5	174.9	215.4	81.2	69.3
	OtniolR_3	45-100	peat	-	-	5.0	422.9	638.6	79.4	3.2	29.5	214.8	750.7	965.5	77.8	66.1
	OtniolR_2	110-133	peat	-	-	4.7	472.2	598.7	67.4	2.6	29,3	243.5	698.0	941.5	74.1	63.6
							Mucky soil with mineral-organic layer in top horizon; depression									
5	AO	0-15	m.-o.	35	6	6.6	102.7	654.7	61.4	5.5	9.1	216.9	730.7	947.6	77.1	69.1
	AO	15-28	m.-o.	49	8	6.3	111.4	440.9	16.3	4.6	12.3	230.7	474.1	704.8	67.3	62.6
	OtniszR_2	28-74	peat	-	-	6.1	469.0	723.8	76.2	1.9	23.1	285.4	825.0	1110.4	74.3	65.2

* – according to PTG 2008; SL – sandy loam; SCL – sandy clay loam; L – loam; CL – clay loam; SiCL – silty clay loam; SiL – silt loam; S – silt; SC – sandy clay; SiC – silty clay; C– clay; HC – heavy clay; m.-o. – mineral-organic formation; ol – alder wood peat; sz – reed peat; R_2 – medium decomposed peat; R_3 – strongly decomposed peat

Sorptive properties soils of Linowo catena in the landscape of lakeland hills

Table 5

No Pro-file	Horizon	Depth cm	Soil tex-ture	% ø in mm 0,05-0,002	% ø in mm < 0,002	PH KCl	C-org. g·kg⁻¹	Ca²⁺	Mg²⁺	K⁺	Na⁺	H_h	SBC	CEC	SBC/CEC %	Ca/CEC %
								mmol(+)kg⁻¹ soil							%	
Proper brown soil; location: summit																
1	Ap	0-25	SL	26	12	7.0	6.4	161.5	9.8	6.8	10.7	12.8	188.8	201.6	93.7	80.1
	Bbr	25-72	SL	27	15	6.9	-	152.6	4.2	4.6	3.8	11.3	165.2	176.5	93.6	86.5
	C	72-150	SL	26	14	7.4	-	221.7	2.3	4.9	8.7	7.5	237.6	245.1	96.9	90,5
Proper deluvial soil, medium deep; midslope																
2	Ap	0-25	SL	26	4	5.8	13.4	136.3	10.7	6.6	2.5	34.5	156.1	190.6	81.9	71.5
	A2	25-40	SL	29	5	5.8	12.8	136.8	9.6	5.1	3.1	31.5	154.6	186.1	83.1	73.5
	A3	40-65	SL	30	6	5.7	8.1	142.1	13.0	3.9	2.8	30.0	161.8	191.8	84.4	74.1
	A4	65-92	SiCL	45	38	5.9	1.2	201.8	26.6	8.6	5.1	28.1	242.1	270.2	89.6	74.7
Humous deluvial soil, medium deep; lower slope																
3	Ap	0-25	SL	38	2	6.0	29.7	175.9	15.2	8.5	3.7	40.5	203.3	243.8	83.4	72.1
	A2	25-55	SL	39	2	6.0	26.8	180.0	16.7	8.1	4.0	37.5	208.8	246.3	84.8	73.1
	A3	55-65	SL	32	2	6.1	23.9	151.7	14.4	3.2	3.7	35.6	173.0	208.6	82.9	72.7
	C	65-150	SL	25	17	5.6	–	62.5	1.3	4.9	2,5	15.0	71.2	86.2	82.6	72.5
Humous deluvial soil, shallow; lower slope																
4	Ap	0-25	SL	35	1	5.7	53.2	178.8	13.4	5.7	3.4	49.5	201.3	250.8	80.3	71.3
	A2	25-40	SL	33	1	5.7	54.3	183.5	11.8	5.2	4.6	46.5	205.1	251.6	91.5	72.9
	Cgg	40-150	SL	24	17	5.8	–	75.8	1.2	6.2	2.2	28.5	85.4	113.9	75.0	66.5
Proper mucky soil ; foot-slope																
5	AM	0-25	m.-o.	-	-	5.8	113.0	419.8	24.3	5.4	3,3	99.4	452.8	552.2	82.0	76.0
	AM2	25-43	m.-o.	-	-	6.2	113.8	603.2	19.8	4.2	5.1	85.0	632.3	717.3	88.2	84.1
	Cgg	43-150	SL	27	16	5.9	–	98.3	7.8	5.1	3.1	27.5	114.3	141.8	80.6	69.3
Peat-muck soil, silted; depression																
6	Mt	0-20	mucky	-	-	5.6	275.5	750.4	37.2	6.9	14.2	167.0	808.7	975,7	82.9	76.9
	Mt2	20-35	mucky	-	-	5.7	277.8	1072.0	61.7	6.9	14.4	148.0	1155.0	1303.0	90.8	85.6
	OtniszR$_3$	35-150	peat	-	-	5.9	491.2	684.9	12.9	8.1	13.0	154.0	718.9	872.9	82.4	78.5

Sorptive properties soils of Reszel catena in the landscape of morainic hills and plains Table 6

No Pro-file	Horizon	Depth cm	Soil tex-ture	% ø in mm		pH KCl	C-org.	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H_h	SBC	CEC	SBC/CEC	Ca/CEC
				0,05-0,002	< 0,002		$g \cdot kg^{-1}$	mmol(+)kg^{-1} soil							%	
							Black earths; location: summit									
1	Ap	0-25	L	46	20	6.7	25.0	201.4	26.2	10.2	9.7	18.3	247.5	265.8	92.9	75.7
	Aa	25-38	L	47	21	6.5	16.2	431.2	23.0	8.4	7.1	16.0	469.7	485.7	96.5	88.7
	C	38-150	HC	27	61	6.9	-	880.1	51.0	9.5	6.1	5.6	946.7	952.3	99.2	92.3
							Proper deluvial soil, shallow; midslope									
3	Ap	0-24	L	46	20	6.0	28.4	209.2	25.3	15.4	7.2	24.0	257.1	281.1	91.5	74.4
	Aa	24-48	L	43	25	6.2	19.8	208.3	24.7	11.3	5.6	18.0	249.9	267.9	93.3	77.7
	C	48-150	SiL	51	25	6.9	-	312.9	34.0	7.2	8.0	10.0	362.1	372.1	97.3	84.1
							Humous deluvial soil, deep; lower slope									
4	Ap	0-25	L	46	24	5.9	30.8	176.3	36.9	9.6	10.4	32.0	233,2	265.2	87,8	66.4
	A2	25-65	L	46	23	6.1	23.6	165.4	36.5	8.3	9.7	30.0	219.9	249.9	88,0	66.2
	A3	65-100	CL	40	33	6.0	20.9	263.3	33.2	9.7	7.5	22.0	313.5	335.5	93.4	78.4
	A4	100-128	CL	43	34	6.2	88.7	500.3	59.4	8.0	16.8	21.3	584.5	605.8	96.5	82.5
	C	128-150	L	48	18	6.2	–	130.5	16.4	6.2	4.5	19.5	157.6	177.1	89.0	73.6
							Humous deluvial soil medium deep; foot-slope									
5	Ap	0-26	L	49	22	6.3	56.2	849.9	42.1	9.2	10.1	32.0	911.3	943.3	96.6	90.1
	A2	25-66	CL	39	40	6.3	34.1	425.7	43.9	14.0	9.3	26.6	492.9	519.5	94.9	82.0
	OtniszR_3	66-150	peat	-	-	4.8	478.5	803.1	68.0	2.6	23.1	223.7	896.8	1120.5	80.0	71.7
							Humous deluvial soil shallow; foot-slope									
6	Ap	0-25	CL	51	28	6.5	57.4	764.7	46.4	9.8	10.8	24.8	831.7	856.5	97.1	89.3
	A2	25-46	CL	46	32	6.5	43.8	457.8	47.2	12.5	9.7	29.0	527.2	556.2	94.8	82.3
	OtniszR_3	46-125	peat	-	-	5.4	443.2	854.5	70.3	3.1	22.6	278.4	950.5	1228.9	77.3	69.5

Explanation as in Table 4

Sorptive properties soils of Równina Górna catena in the riverine landscape — Table 7

No Profile	Horizon	Depth cm	Soil texture	% ø in mm 0,05-0,002	% ø in mm < 0,002	pH KCl	C-org. g·kg^{-1}	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H_h	SBC	CEC	SBC/CEC %	Ca/CEC %
								mmol(+)kg^{-1} soil								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Black earths; location: summit																
1	Ap	0-28	L	39	14	5.4	18.6	211.4	21.4	20.0	1.1	22.1	253.9	276.0	92.0	76.6
	A2	28-38	L	40	14	5.4	77.1	194.0	21.3	17.5	1.1	19.9	233.9	253.8	92.2	76.5
	C	38-100	CL	32	38	6.1	–	198.7	36.1	11.6	1.1	12.0	247.5	259.5	95.4	76.6
	C2	100-150	SCL	47	36	6.5	–	231.0	40.5	12.2	1.3	4.1	285.0	289.1	98.6	79.9
Proper deluvial soil, medium deep; midslope																
2	Ap	0-30	L	36	19	6.0	17.2	211.8	24.2	11.0	1.2	12.0	248.2	260.2	95.4	81.4
	A2	30-55	L	34	22	5.7	13.1	194.2	19.4	10.1	1.4	11.2	225.1	236.3	95.2	82.2
	A3	55-83	CL	35	28	5.9	19.1	311.5	35.6	7.1	1.6	10.9	355.8	366.7	97.0	85.0
	C	83-150	HC	22	65	6.7	-	352.2	37.9	11.1	2.7	3.0	403.9	406.9	99.3	86.6
Proper deluvial soil, deep; lower slope																
3	Ap	0-30	L	36	14	6.1	17.6	208.3	48.1	13.4	1.4	9.7	271.2	280.9	96.5	74.2
	A2	30-50	L	35	16	6.4	7.8	204.7	27.9	4.9	2.5	6.0	240.0	246.0	97.6	83.2
	A3	50-100	L	40	21	6.3	8.3	229.8	32.6	6.0	1.2	6.0	269.6	275.6	97.8	83.4
	A4	100-135	L	42	21	6.2	10.7	238.3	31.5	6.5	1.4	8.3	277.7	286.0	97.1	83.3
	C	135-150	C	40	48	6.2	-	300.7	53.6	12.8	1.9	4.5	369.0	373.5	98.8	80.6
Humous deluvial soil medium, medium deep; foot-slope																
4	Aa	0-30	L	36	14	6.4	29.8	290.1	39.0	7.1	1.7	8.6	337.9	346.5	97.5	83.7
	A2	30-50	L	29	20	6.4	6.3	175.7	2.7	3.8	1.1	4.5	183.3	187.8	97.6	82.9
	A3	50-98	L	40	21	6.3	8.0	256.3	37.1	5.4	1.5	7.1	300.3	307.4	97.7	83.3
	C	105-150	SiCL	51	31	6.2	-	404.4	59.7	10.5	2.2	21.5	476.8	498.3	95.7	81.2

Table 7. continued.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Humus alluvial very strongly, deep; river valley																
5	Aa	0-20	L	49	23	6.6	51.9	331.3	34.5	6.0	1.9	8.3	373.7	382.0	97.8	86.7
	A2	20-40	SiC	45	44	6.7	36.2	395.6	47.2	12.2	2.6	4.9	457.6	462.5	98.9	85.5
	A3	40-78	SiC	42	51	6.6	12.4	435.5	49.1	14.6	2.2	5,3	501.4	506.7	98.9	85.9
	A4	78-150	HC	39	51	6.7	2.7	387.5	55.5	12.2	2.0	4.5	457.2	461.7	99.0	83.9
Humus alluvial very strongly, deep; river valley																
6	Aa	0-28	SiCL	54	29	6.7	44.3	643.7	54.4	9.3	2,4	5,6	709.8	715.4	99.2	90.0
	A2	28-47	SiCL	55	38	6.6	15,8	505.8	53.6	6.5	2,5	4.9	568.4	573.3	99.1	88.2
	A3	47-87	C	39	49	6.3	28.1	588.6	70.6	12.2	2,7	9.0	674.1	683.1	98.7	86.2
	A4	87-150	SiC	44	45	6,2	9.3	583.9	68,9	8,8	2,3	7,9	663.9	671.8	98.8	87.0

Explanation as in Table 4

In surface horizons of deluvial soils in landscape of lakeland hills, the amounts of organic carbon and silt were increasing towards the depression whereas clay content did not increase (Tabs. 4, 5). The content of exchangeable calcium increased considerably whereas saturation of sorption complex with calcium hardly increased. In mucky and peat-muck soils, located in the lowest part of the catena, a considerable accumulation of exchangeable Ca, Mg, Na and H was recorded. Potassium was not washed into organic soils of depressions. The highest content of potassium was found in deluvial soils situated at the bottom of the slope. Surface Ap and Aa horizons of deluvial soils contained less exchangeable calcium and lower saturation of sorption complex with Ca than underlying horizons. The amounts of hydrogen cation were contrary to the content of calcium cation. Lower proportion of exchangeable calcium in surface layers of deluvial soils than in underlying horizons proves that the process of decalcification occurs [BIENIEK 1997, ORZECHOWSKI et al. 2001, WÓJCIAK 1976].

At Reszel catena in the landscape of morainic hills and plains, sorptive properties of deluvial soils varied (Tab. 6). The lowest content of exchangeable calcium, the lowest value of CEC and SBC were recorded at the bottom of the slope. The reason of this is that glacio-limnic clay deposits abundant in calcium carbonate were the soil parent materials of black earths. Black earths have heavy texture, high proportion of mixed-pocket swelling minerals, illite/smectite type, with high content of smectite packets and therefore calcium is washed to the bottom of the slope, where its content is 4 times higher than in the soils situated higher in the relief. The content of silt and clay in the soils of this catena increased towards the depression.

At Równina Górna catena in riverine landscape, the content of Ca^{2+}, Na^{+}, Mg^{2+}, values of SBC and CEC in deluvial soils and alluvial soils situated in a wide Guber river valley (Fig. 5) increased towards the depression (Tab. 7). The distribution of hydrogen cation is contrary to the distribution found in other analysed catenas of mid-moraine depressions with closed valleys. In a catena sequence, the content of exchangeable hydrogen and saturation of sorption complex with hydrogen decreased towards the depression. The content of clay, silt and organic carbon was twice higher in alluvial valley soils than in deluvial soils, which resulted in very high soil sorption capacity.

CONCLUSIONS

1. Sorptive properties of alluvial and deluvial soils in delta, riverine, landscape of lakeland hillss and landscape of lakeland hills and plains varied in a catena sequence and in a soil profile. The value of sorption capacity and cation composition of sorption complex depended mainly on soil texture, amount of humus and location in a relief.

2. Alluvial soils in delta and riverine landscapes as well as deluvial soils in the landscape of morainic hills and plains were distinguished by the highest mean content of silt, clay and humus. In these soils, mean values of cation exchange capacity, sum of base cations and amounts of exchangeable calcium, magnesium and potassium were considerably higher than in deluvial soils in riverine and landscape of lakeland hillss. These differences were statistically very significant for the value of CEC and amounts of exchangeable Mg.

3. Regarding the amount of base cations, the studied soils are classified as very strongly resistant to degradation. The highest degree of resistance was stated for alluvial soils in delta and riverine landscapes, and deluvial soils in the landscape of morainic hills and plains. The trophism of soils was high. Regarding proportion of hydrogen in soil sorption complex, the soils are classified as very little degraded.

4. The catenas in riverine landscape, landscape of morainic hills and plains and landscape of lakeland hills had a characteristic toposequence of soils. In surface horizons of deluvial soils, the amount of organic carbon, exchangeable calcium and magnesium, values of CEC and SBC were increasing towards the depression. The highest sorption capacity was noted in humous deluvial soils located at the bottom of the slope.

5. The origin of deluvial soils in young glacial landscape of north-eastern Poland falls on sub-boreal period and the origin of alluvial soils in delta landscape is dated at late sub-boreal and early sub-atlantic period.

REFERENCES

BAUŽIENĖ I., ŚWITONIAK M., CHARZYŃSKI P. 2008. *Properties of deluwial soils in Poland and Lithuania and propositons for their classification*. Žemės Ûkio Mokslai, 15/3: 29-35.

BIAŁOUSZ S. 1978. *Wpływ morfogenezy Pojezierza Mazurskiego na kształtowanie się gleb.* Rocz. Nauk. Rol. D 166: 87-126.

BIENIEK B., GOTKIEWICZ J. 1990. *Badania nad właściwościami i troficznością gleb deluwialnych terenów młodoglacjalnych Pojezierza Mrągowskiego*. Acta Acad. Agricult. Tech. Olst., Geodesia et Ruris Regulatio 20: 109-119.

BIENIEK B. 1997. *Właściwości i rozwój gleb deluwialnych Pojezierza Mazurskiego*. Acta Acad. Tech. Agricul. Tech. Olst. Agricultura, 64 Suppl. B: ss. 80.

DŁUGOSZ J., ORZECHOWSKI M., KOBIERSKI M., SMÓLCZYŃSKI S., ZAMORSKI R. 2009. *Clay minerals from Weichselian glaciolimnic sediments of the Sępopolska Plain (NE Poland).* Geologica Carpahtica 60/3: 263-267.

FILIPEK T. 1990. *Kształtowanie się równowagi jonowej w życie w zależności od wysycenia gleb kationami*. Rocz. Glebzn. 41/1-2: 133-143.

FRIELINGHAUS M., SCHMIDT R.1991. *Heterogeneity in the soil cover and soil erosion in the young moraine region.* Mitteilungen des Deutschen Bodenkundlichen Gesellschaft., 66/2: 939-942.

GOTKIEWICZ J., SMOŁUCHA J. 1996. *Charakterystyka krajobrazów młodoglacjalnych Pojezierza Mazurskiego i Równiny Sępopolskiej.* Zesz. Probl. Post. Nauk Roln., 431: 119-136.

JÓZEFACIUK A., JÓZEFACIUK C. 1992. *Struktura zagrożenia erozją wodną fizjograficznych krain Polski.* Pam. Puł., Suplement, 101: 23-49.

Klasyfikacja Zasobów Glebowych Świata (World Reference Base for Soil Resources – WRB). 2003. Tłumaczenie i Redakcja BEDNAREK R., CHARZYŃSKI P., POKOJSKA U., Toruń: ss. 106.

KLOSS M., KRUK M., WILPISZEWSKA I. 1987. *Geneza charakterystyka przyrodnicza i przekształcenia antropogeniczne zagłębień bezodpływowych we współczesnym krajobrazie Pojezierza Mazurskiego.* Kosmos 36/4: 621-641.

KOC J. 1991. *Produktywność agrocenoz w odwodnionych zagłębieniach bezodpływowych.* Acta Acad. Agricult. Tech. Olst., Agricult., 52: 3-16.

KOĆMIT A., RACZKOWSKI B., PODLASIŃSKI M. 2001. *Typologiczna przynależność erodowanych gleb wytworzonych z glin morenowych wybranego obiektu na Pomorzu Zachodnim.* Folia Universitatis Agriculturae Stetinensis, 217 Agricultura (87): 103-108.

KONDRACKI J. 1972. *Polska północno-wschodnia.* PWN, Warszawa: ss. 271.

KONDRACKI J. 1988. *Gografia fizyczna Polski*. PWN, Warszawa: ss 463.

KRUK M. 1987. *Typy zagłębień bezodpływowych i czynniki kształtujące w nich obieg wody w współczesnym krajobrazie Pojezierza Mazurskiego.* Ekol. Pol., 35/3-4: 655-678.

LASKOWSKI S. 1986: *Powstawanie i rozwój oraz właściwości gleb aluwialnych doliny środkowej Odry.* Zesz. Nauk. AR Wrocław, Rozprawy 56: ss. 68.

LITYŃSKI T., JURKOWSKA H. 1982. *Żyzność gleby i odżywianie się roślin*. PWN Warszawa: ss. 642.

MARCINEK J., KAŹIMIEROWSKI C., KOMISAREK J. 1998. *Rozmieszczenie gleb i zróżnicowanie ich właściwości w katenie falistej moreny dennej Pojezierza Poznańskiego.* Zesz. Probl. Post. Nauk Rol., 460: 53-73.

NIEDŹWIECKI E. 1984: *Zmiany cech morfologicznych i właściwości gleb uprawnych na tle odpowiadających im gleb leśnych na Pomorzu Szczecińskim*. AR w Szczecinie, Rozprawy 92: 5-154.

ORZECHOWSKI M., SMÓLCZYŃSKI S., SOWIŃSKI P. 2001. *Właściwości gleb obniżeń sródmorenowych Pojezierza Mazurskiego.* Zesz. Probl. Post. Nauk Rol., 467: 229-235.

ORZECHOWSKI M., SMÓLCZYŃSKI S., SOWIŃSKI P. 2004. *Przekształcenia antropogeniczne gleb obniżeń śródmorenowych Pojezierza Mazurskiego.* Rocz. Glebozn. 40/2: 311-320.

ORZECHOWSKI M., SMÓLCZYŃSKI S., SOWIŃSKI P. 2005. *Właściwości sorpcyjne gleb aluwialnych Żuław Wiślanych.* Rocz. Glebozn. 41/1-2: 119-127.

ORZECHOWSKI M. 2008. *Właściwości gleb erodowanych i deluwialnych na Pojezierzu Mazurskim i Nizinie Sępopolskiej.* Rocz. Glebozn. 59/3,4: 236-242.

PIAŚCIK H. 1986[a]. *Gleby siedlisk hydrogenicznych doliny Łyny.* I. Basen pojeziorowy. Acta Acad. Agricult. Tech. Olst., Geodaesia et Ruris Regulatio, 16: 77-88.

PIAŚCIK H. 1986[b]. *Gleby siedlisk hydrogenicznych doliny Łyny*. II. Basen utworów zastoiskowych, namułowych oraz namułowo-mułowych. Acta Acad. Agricult. Tech. Olst., Geodaesia et Ruris Regulatio, 16: 89-101.

PIAŚCIK H., GOTKIEWICZ J., SMOŁUCHA J., MORZE A. 1996. *Gleby mineralne w krajobrazach młodoglacjalnych Pojezierza Mazurskiego i Równiny Sępopolskiej*. Zesz. Probl. Post. Nauk Roln., 431: 137-155.

PIAŚCIK H., ORZECHOWSKI M., SMÓLCZYŃSKI S. 2000. *Siedliska glebowe delty Wisły*. Rocz. AR Poznań CCCXVII, Roln. 56: 115-124.

POKOJSKA U. 1988. *Potencjalne możliwości zatrzymywania składników pokarmowych przez gleby zadrzewień śródpolnych i łąk w krajobrazie rolniczym*. Rocz. Glebozn. 39/1: 51-61.
RENIGER A. 1950. *Próba oceny nasilenia i zasięgów potencjalnej erozji gleb w Polsce*. Puławy, Rocz. Nauk Rol. 54.
RYTELEWSKI J. 1969. *Właściwości fizyczne i chemiczne mad przy ujściu rzeki Pasłęki.* Zesz. Nauk. WSR Olsztyn 25/3: 6523-670.
SINKIEWICZ M. 1998. *Rozwój denudacji antropogenicznej w środkowej części Polski Północnej.* UMK Toruń: ss. 103.
SIUTA J. 1976. *Znaczenie odporności gleb (na degradację) w gospodarce zasobami środowiska przyrodniczego.* Instytut Kształtowania Środowiska, Warszawa: ss. 15.
SMOLSKA E. 2005. *Znaczenie spłukiwania w modelowaniu stoków młodoglacjalnych (na przykładzie Pojezierza Suwalskiego).* Wydz. Geografii i Studiów Regionalnych UW, Warszawa: ss. 146.
SOLARSKI H., NOWICKI J. 1990. *Możliwości retencyjne oczek wodnych i mokradeł na Pojezierzu Mazurskim*. Acta Acad. Agricult. Tech. Olst., Geodaesia et Ruris Regulatio, 20: 173-183.
SOMMER M., SCHLICHTING E. 1997. *Archetypes of catenas in respect to matter-a concept for structuring and grouping catenas*. Geoderma, 76: 1-33.
Systematyka gleb Polski. Rocz. Glebozn. 1989, 40(3/4), : ss. 150.
STARKEL L. 1989. *Antropogeniczne zmiany denudacji i sedymentacji w holocenie na obszarach Europy Środkowej.* Prz. Geogr., 61/1-2: 33-49.
STARKEL L. 1999. *Geografia Polski, środowiska przyrodnicze.* Wydawnictwo Naukowe PWN, Warszawa: ss. 593.
STASIAK J. 1971. *Holocen Polski Północno-Wschodniej.* PWN, Warszawa: ss. 109.
STATSOFT, Inc.: 2007, STATISTICA, version 8.
STOCHLAK J. 1996. *Osady deluwialne nieodłączny efekt procesu spłukiwania i propozycja ich podziału.* Ogólnopolskie Sympozjum Nauk. Ochrona agrosystemów zagrożonych erozja. Puławy-Lublin-Zwierzyniec: 111-132.
UGGLA H. 1956. *Ogólna charakterystyka gleb Pojezierza Mazurskiego*. Zesz. Nauk WSR Olszt., 1: 15-54.
UGGLA H., WITEK T. 1958. *Czarne ziemie kętrzyńskie.* Zesz. Nauk. WSR Olszt. 3: 69-108.
UGGLA H., MIROWSKI Z. 1960. *Wpływ erozji wodnej na morfologię i niektóre właściwości chemiczne gleb na kilku wzgórzach morenowych Pojezierza Mazurskiego*. Rocz. Nauk Roln., 74-F-2: 219-242.
UGGLA H., MIROWSKI Z., GRABARCZYK S., NOŻYŃSKI A., RYTELEWSKI J., SOLARSKI H. 1967. *Strefy zagrożenia erozją wodną gleb północno-wschodniego regionu Polski.* Zesz. Nauk. WSR Olsztyn 23/565: 225-243.
UGGLA H., MIROWSKI Z., GRABARCZYK S., NOŻYŃSKI A., RYTELEWSKI J., SOLARSKI H. 1968. *Procesy erozji wodnej w terenach pagórkowatych północno-wschodniej części Polski*. Rocz. Glebozn. 13/2: 415-447.
WITEK T. 1965. *Gleby Żuław Wiślanych*. Pam. Puławski. 18: 157-266.
WÓJCIAK H. 1976. *Właściwości gleb deluwialnych okolic Olsztyna o różnych typach stosunków wodnych.* Zesz. Nauk. ART Olszt., Geodezja I Urządzenia Rolne, 5: 169-191.
Acknowledgement: In the years 2007-2009, the research was financially supported by the Ministry of Science and Higher Education, research project No N N305 2776 33.

Mirosław Orzechowski
Department of Soil Science and Soil Protection, University of Warmia and Mazury
10-727 Olsztyn, Plac Łódzki 3