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Chapter II

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Toposequence and Soil Properties in the Landscape of Ground Moraine of Olsztyn Lakeland

INTRODUCTION

The landscape of ground moraine of Olsztyn Lakeland has very diversified relief. Morainic culminations are accompanied by depressions of various origin, filled with Holocene deposits or lakes.

Soils of ground moraine in the area of Olsztyn Lakeland are a very interesting group due to their diversity, sequence, origin and properties [ORZECHOWSKI ET AL. 2001; PIAŚCIK et al. 2001]. They were formed as a result of overlapping soil-forming processes and are distinguished by a specific mosaic and heterogeneity. Origin and distribution of these soils is associated directly with the relief, and indirectly with the factors deriving from the relief: slope gradient, relative land level, changes of moisture. Important role in modifying soil cover of ground moraine, is played by the processes of translocation of the soil material as a result of human agricultural activity. These processes are referred to as anthropogenic denudation [SINKIEWICZ 1998; PIAŚCIK, SOWIŃSKI 2002] and affect toposequence and soil properties in diversified relief of young glacial landscapes.

The aim of the paper was to determine the toposequence and some selected soil properties at three catenas in the landscape of ground moraine of Olsztyn Lakeland.

MATERIALS AND METHODS

The research was carried out, using soil catena method, in three mid-moraine depressions located in the landscape of ground moraine in Olsztyn Lakeland: Ustnik, Żardeniki and Tomaszkowo (Fig. 1). Thirteen soil profiles were made and forty one soil samples were collected. The following soil properties were examined: texture by hydrometer method of Bouyoucos-Cassagrande modified by Prószynski with separation of sub-fractions of sand by sieving, soil reaction in H_2O and KCl potentiometrically, ash content by combustion at 550 ^{o}C, content of organic carbon in mineral formations by

Tiurin method and in organic formations by Alten method, total nitrogen by Kjeldahl method. Soil were classified according to Polish soil classification system [SYSTEMATYKA ... 1989] and World Reference Base for Soil Resources [IUSS WORKING GROUP WRB 2006].

Fig. 1. Location of investigated sites eith reference to physico-geographical regionalization of Poland

Tomaszkowo catena is located southwest of Olsztyn at the Experimental Station of University of Warmia and Mazury in Olsztyn (Fig. 1). It represents the landscape of rolling ground moraine between IV and V ridges of frontal moraines of Pomeranian phase of Vistula glaciation. Land gradients are small and amount to approximately 3°. The catena is used as ploughland.

Ustnik catena is situated in ornithological reserve "Ustnik" and surrounding area. The reserve covers an area of 30.5 ha and is located northwest of Jeziorany (Fig. 1) in the zone of rolling ground moraine between VI and VII ridges of frontal moraines of Pomeranian phase of Vistula glaciation. Land gradient amounts to 6° on average. The slopes of studied catena are used as ploughland, whereas the center is an extensive grassland.

Żardeniki catena is located west of Dobre Miasto (Fig. 1) Similarly to Ustnik catena, it is situated between VI and VII ridges of frontal moraines of Pomeranian phase of last glaciation. Land gradient amounts to 3.5 ° on average. The slopes are used as ploughland, whereas the center is an extensive grassland.

RESULTS AND DISCUSSION

Moraine landscape of Olsztyn Lakeland is particularly susceptible to the processes of translocation of soil material on the slope. These processes are called anthropogenic or agronomic denudation [SINKIEWICZ 1993, 1998] and are associated with agricultural human activity. Therefore, to determine the dynamics of young glacial agricultural landscape, it seems appropriate to use linear systems of spatial soil cover. Among these systems, DEGÓRSKI [2005] distinguishes soil toposequence, as the best for such research. This group comprises soil catenas and soil chronosequences. The concept of soil catena developed by Milne [SOMMER, SCHLICHTING 1997 referring to MILNE 1935], is the most suitable approach in the analysis of soil cover in the diversified morainic landscape.

The translocation of soil material on the slope as a result of cultivation, plays a key role in shaping and modifying land forms and soil cover of slope agricultural landscapes [DE ALBA et al. quoted in PEPENDIC, MILLER 1977, GOVERS et in. 1997; MARCINEK et in. 1998]. As a result of long-term cultivation, arable humus horizon is transported and deposited at lower parts of the slope. In the literature, this material is termed an agricultural diamicton [SINKIEWICZ 1998], anthropogenic deluvium [STOCHLAK 1996], or simply deluvium. The mentioned processes in the Masurian Lakeland were initiated approximately 4000 years BP [BIENIEK 1997].

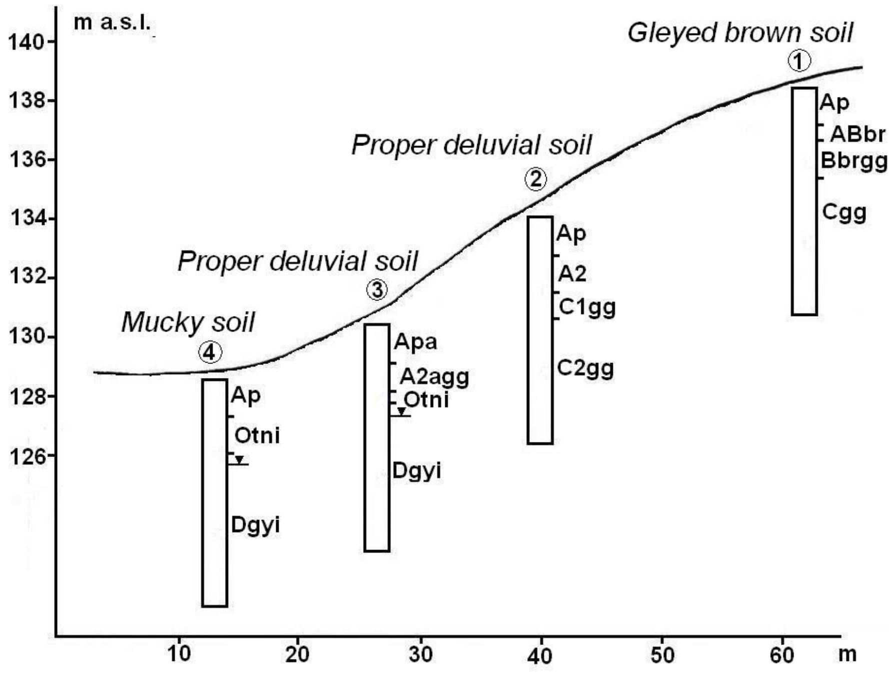

Fig. 2. Toposequence of soils in catena Tomaszkowo

Agricultural human activity transformed primary soil cover. Pedotransfer of mineral and organic material from upper slope and its accumulation in the depressions affected the variability of soil surface horizons [SMARZYŃSKA 2005]. Not cultivated initial morainic slopes represent typical eroded catenas [DE ALBA et al. 2004]. However, after taking over for cultivation, they are turned into downward-translocation catenas [SOMMER, SCHLICHTING 1997]. The elements of this typical, for agricultural morainic landscape, catena are interrelated, similarly to the relations between various soil horizons. SOMMER et al. [2008] stated that in order to analyze the dynamics of slope processes induced by human agricultural activity, the whole spectrum of geological and historical information ought to be regarded.

In the studied catenas, various geological formations were found. The slopes of analyzed forms were built from the Pleistocene post-glacial sediments, while the central parts of depressions were filled with Holocene deposits: fen peats, gyttja, mucks formed from peats and deluvial deposits.

As a result of the studies carried out in the landscape of ground moraine in Olsztyn Lakeland, three different soil toposeqences were found.
In Tomaszkowo catena (Fig. 2): brown soils – deluvial soils – mucky soils.
In Ustnik catena (Fig. 3): brown soils – deluvial soils – peat–muck soils.
In Żardeniki catena (Fig. 4): brown soils – deluvial soils – peaty soils.

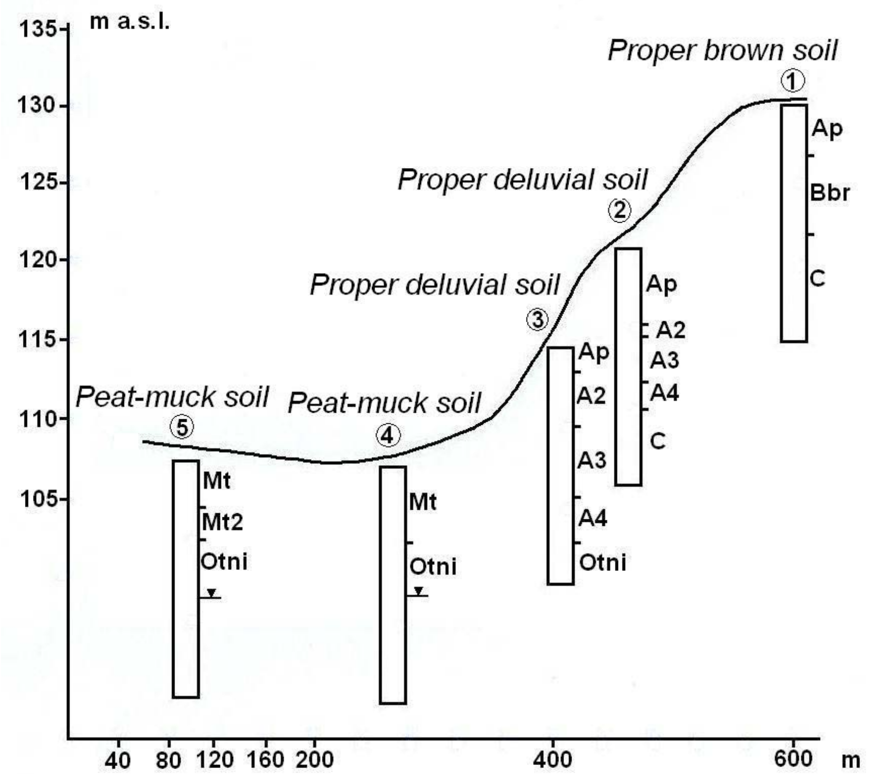

Fig. 3. Toposequence of soils in catena Ustnik

The chain connecting the three studied toposequences are deluvial soils. These soils occurred in the middle and lower parts of slopes. Basing on organic matter content they were classified as proper sub-type [SYSTEMATYKA … 1989]. Taking into account the thickness of deluvial layer, they represent shallow deluvial soils (Tomaszkowo and Żardeniki catenas), medium deep (Tomaszkowo, Ustnik and Żardenki catenas) and deep deluvial soils (Ustnik catena). The thickness of deluvial deposits was associated with the length of time and intensity of cultivation, as well as slope gradients. Interesting was the subsoil. In lower parts of the slope alder peats (Tomaszkowo and Żardeniki catenas) and sedge peats (Ustnik catena) occurred. However, in the middle of the slope, deluvial sediments were deposited on mineral soil formations.

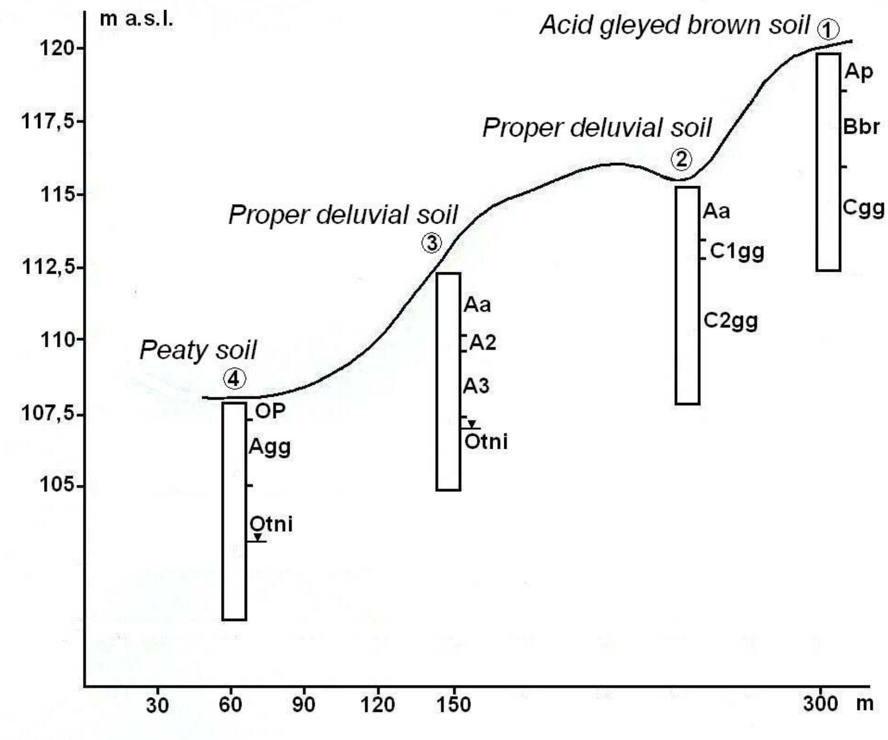

Fig. 4. Toposequence of soils in catena Żardeniki

Anthropogenic denudation processes are separating the soil cover into different links of chain, with more or less transformed, or newly formed soils [KOĆMIT et aL. 2001A; PIAŚCIK, SOWIŃSKI 2002]. On the top of the slope, in various subtypes of eroded brown soils, a mixing of A and B horizons occured as a result of plowing. In lower parts of the slope, new soils were formed – deluvial soils. However, in the depressions, the soil cover depended on land use. In Tomaszkowo catena, entirely cultivated, the last chain in soil toposequence were mucky soils. In these soils, deluvial sediments (10-30 cm thick) were deposited on peats or mucks formed from peats. Their evolution is leading toward an increase of the thickness of deluvium and transition to deluvial soils. In Ustnik and Żardeniki catenas, which depressions were used as extensive grasslands, the last chain in soil toposequence were peat-muck soil and peaty soils, respectively.

Anthropogenic denudation processes affect not only the toposequence of soils, but also their properties. These processes are impressed in soil surface horizons, which have various texture deriving from the texture of eroded land [BIENIEK 1997; KOĆMIT et al. 2001B]. CHODAK et al. [2005] and SMOLSKA [2008] stated that the material which is washed during erosion, is more fine-grained and well-sorted. MAHANEY and SANMUGADAS [1989], in late Holocene soil toposequence of west Wyoming, point to translocation of clay fraction down the slope. Similar process in the soils of the Masurian Lakeland was observed by BIENIEK [1997] and PIAŚCIK, SOWIŃSKI [2002].

Tomaszkowo catena is an example of anthropogenic denudation processes in sedimentary heavy formations. Surface horizons of eroded gleyed brown soils had clay loam texture and were underlain by silty clay loam and silty clay formations. These formations contained 34-42% of clay fraction and 36-51% of fine silt fraction (Fig. 5A). Surface horizons of investigated soil were loosened as a result of anthropogenic denudation and impoverishment in fine silt fraction by approximately 3-15%. At the bottom of the slopes, deluvial deposits had silt loam texture. These formations were enriched in fine silt fraction by approximately 20%, as compared to the surrounding soils (Fig. 5B-D). Noteworthy is heavier compaction of deluvial deposits in lower part of the slope. According to BIENIEK [1997] it is a result of evolution of deluvial material due to anthropogenic denudation and luviation of soil profile affected by infiltration soil water regime. In the analyzed catena, a translocation of silt fraction on the slope towards the depression was noted. Whereas the content of the sand fraction remained unaltered and impoverishment in clay was observed.

In Ustnik catena, humus horizon in eroded proper brown soils had loam texture and contained 23% of clay fraction, which decreased with the depth of soil profile. Similar regularity was found in the content of silt fraction (Fig. 6A). Surface horizons of deluvial soils forming at the bottom of the slope were not enriched in clay and silt (Fig. 6B and C). These soils had sandy loam texture. In spite of intensive cultivation, and fairly large land gradient (approximately 6°), anthropogenic denudation processes in these soils were weak.

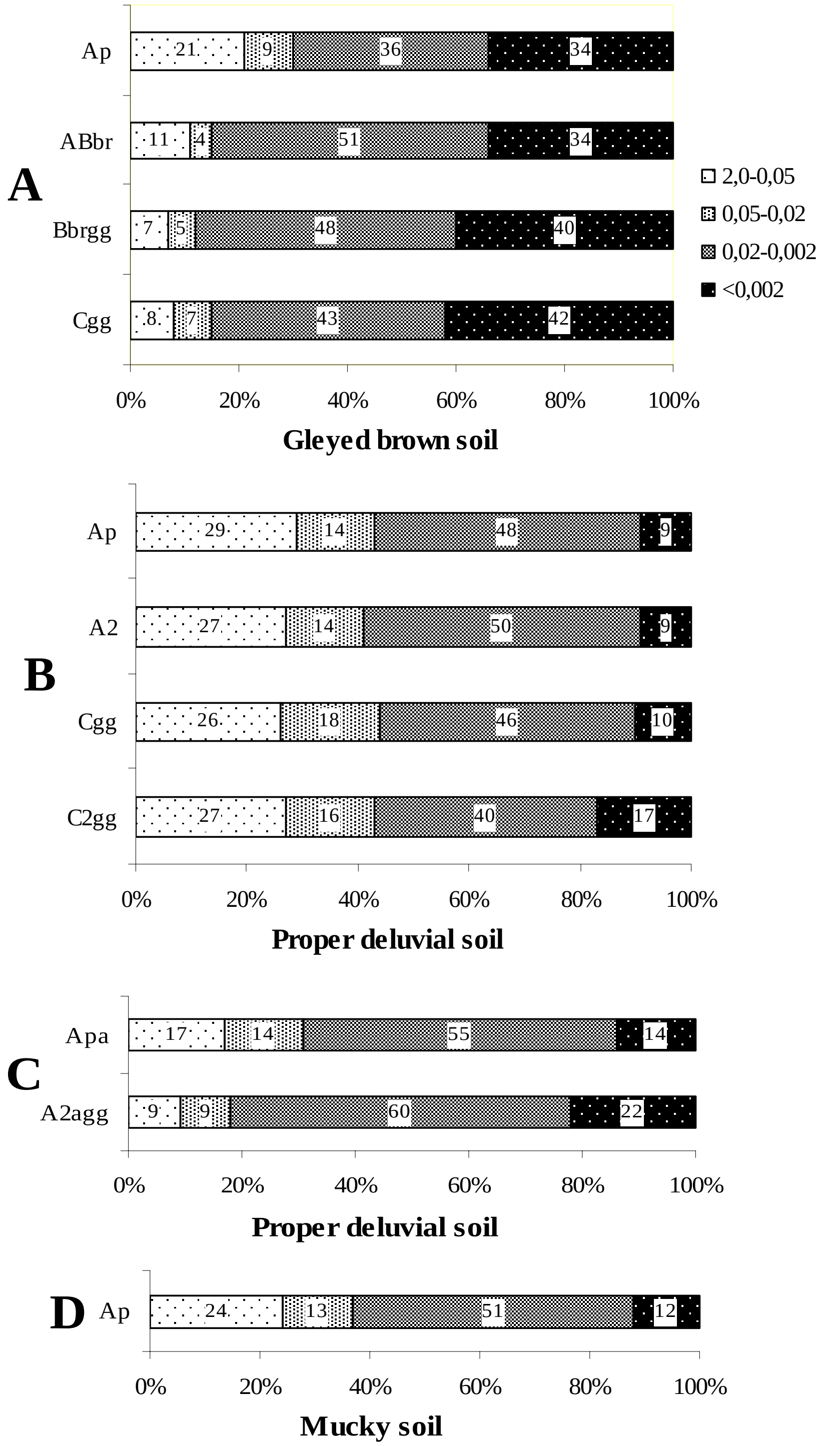

Fig. 5. Percentage content of granulometric fractions (mm) of Tomaszkowo catena soils

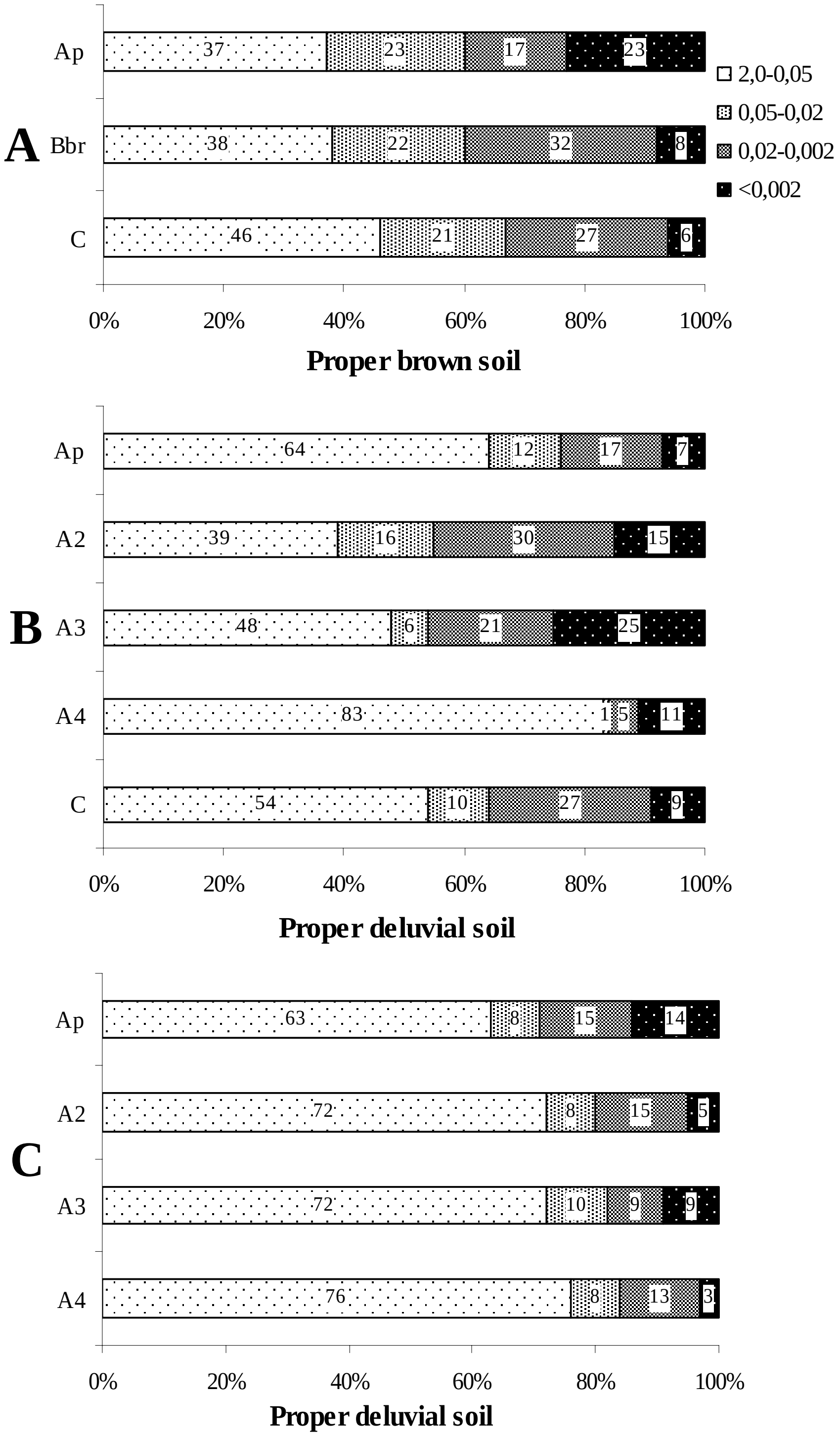

Fig. 6. Percentage content of granulometric fractions (mm) of Ustnik catena soils

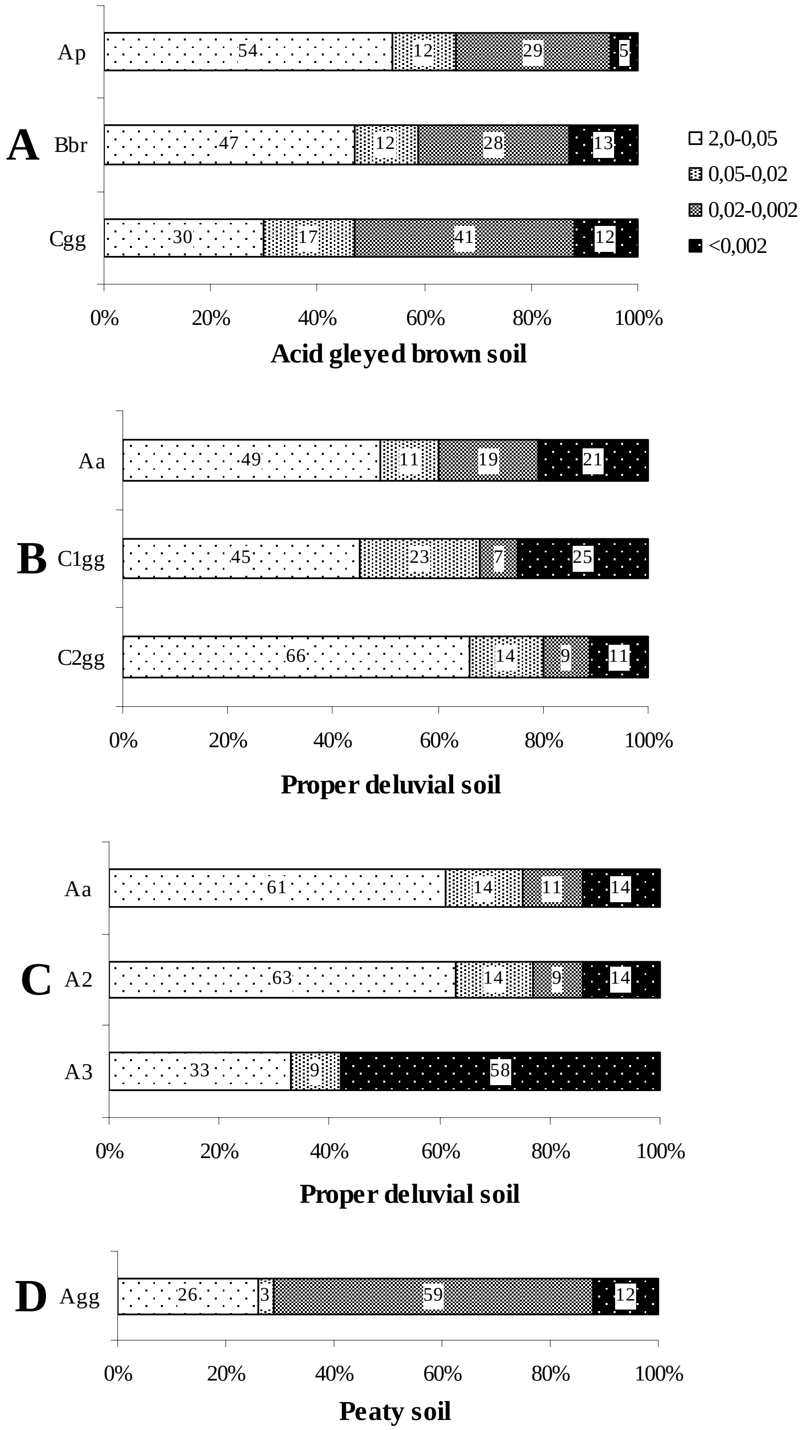

Fig. 7. Percentage content of granulometric fractions (mm) of Żardeniki catena soil

In Żardeniki catena, acid, eroded gleyed brown soils, occurring at the top of the slope, had sandy loam texture in surface horizon, and illuviation horizon as well as parent material had loam and silt loam texture, respectively (Fig. 7A). Eroded material was accumulated in the middle and lower parts of the slope. It modified the texture of proper deluvial soil formed in the middle of the slope (Fig. 7B), which in surface horizon showed loam texture turning into sandy loam in C2gg horizon. The surface horizon of studied soil contained 16% more of clay than eroded soil. Similarly, deluvial soil located in lower part of the slope, contained more clay fraction (by 9%) than eroded soils (Fig. 7C). It had sandy loam texture which deeper turned into clay. Surface Agg horizon in peaty soil had silt loam texture with the highest amount of fine silt fraction (Fig. 7D).

Translocation of mineral and organic material in catenal systems affects physical and chemical properties of soils. In eroded soils, shallowly lying subsoil has an influence on the decrease of aggregate stability, higher pH values, lower content of organic carbon and total nitrogen. Concentration of biogenic compounds is associated with the translocation of labile fractions of organic matter downward the slope [SMARZYŃSKA 2005 referring to GREGORICH et al. 1998].

Soil reaction analyzed in water and potassium chloride, in the three catenas of Olsztyn Lakeland was very diverse and ranged from very acid to neutral (Tabs. 1, 2, 3).

Surface horizons of deluvial soil had very diverse pH_{KCl} values which ranged from 3.8 in Tomaszkwo (Tab. 1) to 6.9 in Ustnik (Tab. 2) and slightly increased with the depth of the soil profile. In surface horizon of mucky soil, pH_{KCl} values amounted to 4.3 (Tab. 1) and showed no considerable changes with increasing depth. In muck horizons of peat-muck soils, pH_{KCl} values ranged from 6.3 to 6.8 (Tab. 2). In underlying peats pH_{KCl} did not show variations and amounted to 6.1-6.3.

In surface horizons of eroded brown soils, pH_{KCl} values amounted to 4.5-7.1. In Ustnik and Żardeniki catenas, soil reaction was unaltered throughout the soil profile (Tabs. 2 and 3). However, in Tomaszkowo catena, pH values were considerably decreasing with increasing depth (Tab. 1).

Decreasing of pH values, together with increasing distance from the source of erosion, noted by UGGLA et al. [1968] and BIENIEK [1997], was observed only in Tomaszkowo catena. In other catenas – Ustnik and Żardeniki, soil reaction showed no relation to the location of the soil in relief.

In analyzed toposequences, the content of organic carbon was increasing with decreasing land level (Tabs. 1, 2, 3). Eroded brown soils contained the lowest amounts of organic carbon (3.80-18.00 $g \cdot kg^{-1}$). The content of organic carbon in surface horizons of deluvial soils ranged from 12.0 to 25.5 $g \cdot kg^{-1}$.

Table 1

Properties of soils in catena Tomaszkowo

Profile No	Horizon	Depth (cm)	Soil formation	Ash content (%)	pH		OC	$N_{tot.}$	C:N
					H_2O	KCl	$g \cdot kg^{-1}$		
Gleyed brows soil; Gleyic-Eutric Cambisol									
1	Ap	0-24	CL	98,2	7,8	7,1	10,50	1,38	7,6
	ABbr	24-45	SiCL	99,4	7,1	5,6	3,80	0,59	6,4
	Bbrgg	45-65	SiCL		7,2	5,3			
	Cgg	65-150	SiCL		5,5	3,8			
Proper deluvial soil; Eutric Fluvisol									
2	Ap	0-24	SiL	97,9	6,9	6,2	12,00	1,47	8,2
	A2	24-51	SiL	98,9	6,3	4,1	6,40	0,88	7,3
	Cgg	51-68	SiL		7,2	5,6			
	C2gg	68-150	SiL		6,6	5,0			
Proper deluvial soil; Eutric Fluvisol									
3	Apa	0-25	SiL	96,1	5,0	4,1	22,50	2,99	7,5
	A2agg	25-44	SiL	97,6	4,9	3,8	13,90	1,70	8,2
	Otni	44-50	$tniolR_3$	38,1	5,3	4,5	360,10	12,70	28,4
Mucky soil; Eutri Haplic Histosol									
4	Ap	0-28	SiL	94,1	5,0	4,3	34,10	2,98	11,4
	Otni	28-59	$tniolR_3$	53,7	5,5	4,8	204,50	7,81	26,2

Explanations: CL – clay loam; SiCL – silty clay loam; SiC – silty clay; SiL – silt loam; $tniolR_3$ – strongly decomposed alder wood peat

Table 2

Properties of soils in catena Ustnik

Profile No	Horizon	Depth (cm)	Soil formation	Ash content (%)	pH		OC	$N_{tot.}$	C:N
					H_2O	KCl	$g \cdot kg^{-1}$		
Proper brown soil; Eutric Cambisol									
1	Ap	0-28	L	95,9	7,5	6,7	18,00	0,64	28,1
	Bbr	28-80	SiL		8,0	7,0			
	C	80-150	SL		8,1	7,1			
Proper deluvial soil; Eutric Fluvisol									
2	Ap	0-49	SL	96,0	6,9	6,0	28,00	1,22	23,0
	A2	49-58	SL	98,2	6,9	5,8	16,00	2,48	6,5
	A3	58-80	SCL	97,6	7,3	6,3	19,00	2,10	9,1
	A4	80-100	LS	98,5	8,0	7,2	1,00	0,14	7,1
	C	100-150	SL		8,0	7,0			
Proper deluvial soil; Eutric Fluvisol									
3	Ap	0-17	SL	94,6	7,5	6,9	16,00	1,90	8,4
	A2	17-53	SL	96,9	7,8	7,1	7,00	0,94	7,5
	A3	53-89	SL	97,7	7,6	6,9	4,00	0,88	4,6
	A4	89-126	SL	98,0	7,1	6,7	4,00	0,64	6,3
	Otni	126-150	$tnituR_2$	27,9	6,5	6,0	500,00	25,12	19,9
Peat-muk soil; Eutri Haplic Histosol									
4	Mt	0-48	mt	62,7	6,8	6,3	214,00	12,43	17,2
	Otnitu	48-81	$tnituR_2$	49,2	6,7	6,1	316,00	13,84	22,8
Peat-muck soil; Eutri Haplic Histosol									
5	Mt1	0-28	mt	64,9	7,4	6,8	132,00	9,34	14,1
	Mt2	28-51	mt	35,2	7,1	6,6	306,00	19,63	15,5
	Otnitu	51-84	$tnituR_2$	21,7	6,8	6,3	553,00	30,15	18,3

Explanations: L – loam; SiL – silt loam; SL – sandy loam; SCL – sandy clay loam; LS – loamy sand; $tnituR_2$ – medium decomposed sedgereed peat; mt – peat muck

Table 3

Properties of soils in catena Żardeniki

Profile No	Horizon	Depth (cm)	Soil formation	Ash content (%)	pH		OC	$N_{tot.}$	C:N
					H_2O	KCl	$g \cdot kg^{-1}$		
Acid, gleyed brown soil; Gleyic Dystric Cambisol									
1	Ap	0-25	SL	93,6	6,7	5,5	15,90	1,55	10,3
	Bbr	25-80	L		6,9	5,4			
	Cgg	80-150	SiL		6,9	5,3			
Proper deluvial soil; Eutric Fluvisol									
2	Aa	0-36	L	81,4	5,5	4,0	14,48	1,11	12,8
	C1gg	36-50	L		6,4	4,2			
	C2gg	50-150	SL		6,3	4,2			
Proper deluvial soil; Eutric Fluvisol									
3	Aa	0-45	SL	94,5	6,7	6,0	15,10	1,61	9,4
	A2	45-52	SL	90,4	6,8	6,6	29,90	3,15	9,5
	A3	52-97	C	90,9	7,1	6,1	14,90	1,51	9,9
	Otni	97-150	$tniolR_3$		6,4	5,7	235,4	9,31	25,3
Peaty soil; Histic Mollic Gleysol									
4	OP	0-9	min.-org.	80,8	6,6	5,9	111,50	5,73	19,5
	Agg	9-59	SiL	88,2	7,0	5,7	22,90	2,19	10,5
	$OtniolR_3$	59-150	$tniolR_3$		6,5	5,7	254,70	8,99	28,4

Explanations: SL – sandy loam; l – loam; SiL – silt loam; C – clay; $tniolR_3$ – strongly decomposed alder wood peat

The content of OC was generally decreasing with increasing depth in the soil profile. However, towards the depression the amounts of organic carbon were higher. The highest amount of analyzed element were recorded in the soils situated in the center of depression in Ustnik and Żardeniki catenas. In peat-muck soils in Ustnik catena, the content of organic carbon amounted to 132.00-306.00 $g \cdot kg^{-1}$in mucks formed from peat and increased with the depth in the soil profile amounting to 553.00 $g \cdot kg^{-1}$ in sedge peats. In surface horizon of peaty soil in Żardeniki catena, the content of organic carbon amounted to 111.50 $g \cdot kg^{-1}$. Such considerable differences in organic carbon content between eroded brown soils, and soil of depressions should be first associated with anthropogenic denudation processes. As a result of denudation, organic matter complexed with clay particles is translocated down the slope. Secondly, in the depressions an accumulation of organic matter under semihydrogenic and hydrogenic conditions occurs.

Total nitrogen content is associated with the typical, for a particular habitat, vegetation cover. The concentration of this compound can be modified by topographic conditions and human activity. In the soils of studied toposeqences in Olsztyn Lakeland, total nitrogen content was dependent on the type of accumulated formations. In mineral formations of eroded and deluvial soils total nitrogen content amounted to 0.14-3.15 $g \cdot kg^{-1}$ and was increasing with decreasing land level. In surface horizons of mucky soil, the amount of total nitrogen amounted to 2.98 $g \cdot kg^{-1}$. In relation to mineral-organic deposits, total organic nitrogen content in organic formations was several times higher. In mucks formed from peat total nitrogen content amounted to 12.43-19.63 $g \cdot kg^{-1}$, whereas in peats it amounted to 7.81-30.15 $g \cdot kg^{-1}$.

In studied soils, C:N ratio was variable. In Toamszkowo and Żardeniki catenas it widened as land level decreased, contrary to Ustnik catena. Mineral formations of deluvial and eroded brown forest soils in Tomaszkowo and Żardeniki catenas had narrow C:N ratio which hardly exceeded 10, which was also reported in the literature [BIENIEK 1997; ORZECHOWSKI et al. 2001]. In mineral-organic formations of mucky soils, the C:N ratio slightly increased and amounted to 11.4. The widest C:N ratios were noted in organic formations of mucky soils and peat-muck soils (20-25). Soils in Ustnik catena differed. Eroded proper brown soils and surface horizon of proper deluvial soil (Tab. 2) were characterized by a wide C: N ratio – 23-28. In mineral deposits of deluvial soils the ratio amounted to 10. Slightly lower values of this parameter were noted in peat-muck soils of Ustnik catena (14.1-22.8).

CONCLUSIONS

1. Studied soils in the landscape of ground moraine in Olsztyn Lakeland were characterized by a specific toposeqence. On the top and in upper parts of the slope different subtypes of brown soil occurred. In the middle and lower parts of the slope they turned into proper deluvial soils. The last link in the toposequence of the studied three catenas were mucky soils (Tomaszkowo catena), peat-muck soils (Ustnik catena) or peaty soils (Żardeniki catena).

2. Translocation of soil material led to the enrichment in silt (Tomaszkowo catena) and clay (Żardeniki catena) of newly formed soils. In the soils of Ustnik catena an enrichment in finest fraction was observed.

3. InTomaszkowo catena, a decrease of pH values simultaneously with the increasing distance from the sources of erosion, was reported. In Ustnik and Toamszkowo catenas, soil reaction did not show catenal variations.

4. In the studied catenas, organic carbon and total nitrogen was increasing towards the depressions.

5. In Toaszkowo and Żardeniki catenas, the C:N ratio was widening with decreasing land level. Inverse relationship was noted in the soils of Ustnik catena.

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