Journal of Ecological Engineering
Volume 17, Issue 1, Jan. 2016, pages 69–76
DOI: 10.12911/22998993/61192

Research Article

SOIL SEQUENCES ALONG A SLOPE OF THE OPALENICA PLAIN

Michał Kozłowski[1], Jolanta Komisarek[1]

[1] Department of Soil Science and Land Reclamation. Poznan University of Life Sciences, Wojska Polskiego 28, 60-637 Poznań, Poland, e-mail: mkozl@up.poznan.pl; jolakom@up.poznan.pl

Received: 2015.11.09
Accepted: 2015.12.09
Published: 2016.01.06

ABSTRACT
The paper presents the results of a study on differentiation of the morphological structure of soil and selected physical and chemical properties of soils in toposequence of the Opalenica Plain. The study was conducted in a 1200 m long transect running through a typical soil toposequence for the Polish Lowland, and therefore the results presented in this study can be extrapolated to similar geomorphological conditions of the area. On the basis of pedological cross-section, the following soil units were distinguished: PWspgl – Albic Luvisols (Arenic) with glossic properties, PAt – Albic Glossic Retisols (Loamic), PAsp – Albic Glossic Retisols (Aric, Arenic), PAspgg – Albic Glossic Retisols (Aric, Arenic, Oxyaquic), PWsggl – Albic Luvisols (Aric, Arenic, Stagnic) with glossic properties, PWgggl – Albic Luvisols (Aric, Loamic, Stagnic) with glossic properties, CZgg – Mollic Reductigleyic Eutric Gleysols (Aric, Loamic), CFt – Fluvic Phaeozems (Aric, Arenic). Each of these units has its own specific position in toposequence but the occurrence of Fluvic Phaeozems (Aric, Arenic) are associated with geogenetic processes of Mogilnica river. In this work, using a multiple regression analysis a statistically significant relationships between the position of the soils in relief and the terrain slopes and the organic carbon content in Ap horizon, the cation exchangeable capacity, the sum of exchangeable bases and the pH were obtained. Systematic variability of most soil properties of Ap horizon have shown two distances of spatial variation. The first concerns the systematic changes in shorter distance (from 132 to 344 m) and can be associated with differences in soil properties between separate soil units. The second distance of spatial correlation ranges from 431 m to 792 m, which testify to the fact that quantitative changes in the properties of soils are realized gradually and distinctly, together with the differentiation of the slope, over several separate cartographic units.

Keywords: Luvisols, Retisols, toposequence, spatial variability.

INTRODUCTION

The hydropedologic studies of the soil distribution in relief that carried out in the Wielkopolska region in recent years have shown the existence of soil sequence along the slopes of Poznań Lakeland. This sequence is intertwined with all soil-forming processes occurring on the slopes [Głazowska 1981, Hall 1983, Marcinek and Wiślańska 1984, Marcinek et al. 1990, 1994 a, 1994 b, 1998, Marcinek and Komisarek 1991, 2000, Milne 1936, Szafrański 1993, Spychalski 1998, Komisarek 2000]. In these systems, relief determines the differentiation of soil water regime, vegetation and consequently the type of soil-forming processes that form a specific soil unit.

Detailed analysis of soil forming processes occurring along the slopes within the undulating ground moraine can be of great importance in the quantitative and qualitative characterisation of the soil covers. On the other hand, quantification of the spatial variability of soil basic properties in atoposequence allows not only a quantitative description of their pedogenesis in relation to soil-forming factors, but also the differentiation of cartographic or taxonomic units [Marcinek et al. 1998].

The aim of this study was to determine the relationship between soils morphology, basic soil properties and the soil location in a relief within the ground moraine plains of Opalenica in the Poznan Lakeland.

MATERIAL AND METHODS

The study was carried out in the municipality of Granowo on arable land in the south-central part of the Poznań Lakeland, within the Opalenica Plain. This area is located at about 38 km from Poznan city towards the south-west. Field studies were carried out in two stages. In the first stage, the soil cover variability was determined to locate representative pedons. In the second step the transect ("Granowo") in the length of 1200 m was designated (Figure 1). In 25 soil pits of the transect and 4 representative pedons, the following features characterising soil morphology were determined: genetic and diagnostic soil horizons, horizons boundary, soil colour, soil structure, soil consistency, chemical reaction with HCl and soil taxonomy were determined. From each soil horizon, monolithic disturbed soil samples were collected for laboratory analyses and undisturbed soil samples were taken for determination of the bulk density (100 cm^3) and soil water retention curve construction.

This area is a part of a flat ground moraine of the Leszno Phase of Baltic Glaciation [Krygowski 1953, 1961, Starkel 1987]. This plateau is split by subglacial valleys, where currently the rivers Mogilnica and Struga Kamieniecka run and escape to Warta-Oder Urstromtal.

Particle size distribution was determined according to Polish guidelines [Gleby... 1998a], soil texture according to Polish soil classification, organic carbon was determined with the dichromate wet oxidative by the Walkley-Black method [Nelson and Sommers 1982], soil carbonates were estimated bygas-volumetric Scheibler method, soil electrical conductivity was measured in suspension of H_2O (1:1), bulk density for soil horizons was measured by the core method in a cylindrical metal sampler with a volume of 100 cm^3 [Blake and Hartge 1986], particle density was determined by the picnometric [Soil survey laboratory... 1992], the soil pH was potentiometrically measured in redistilled water, 0.01M $CaCl_2$ and 1M KCl, cation exchange capacity (CEC) of soil was measured by the method of Mehlich modified by Kociałkowski and Ratajczak [1984].

Spatial variability of soil properties was assessed through the analysis of semivariograms of the selected individual variables. Experimental semivariograms were obtained from the omnidirectional semivariances $\gamma(h)$, as a set of spatial observations, $Z(x_i)$, which were calculated as [Warrick et al. 1986]:

$$\gamma_{(k)} = \frac{1}{2 \cdot n(k)} \cdot \sum_{i=1}^{n(k)} [z(x_i) - z(x_{i+k})]^2$$

where: $Z(x_i)$ and $Z(x_i+k)$ are experimental measures of any two points separated by the vector h and $N(h)$ is the number of experimental pairs separated by h.

Relations between values of semivariance and spatial correlation ranges were determined using the Variovin programme [Pannatier 1996] and Surfer 8 programme [Golden Software 2002]. The double spherical variogram model was fitted to the experimental data in order to obtain the major parameters of the spatial variability of selected soil properties:

$$\gamma_{(k)} = \begin{cases} C_o \\ C_o + C_1 \cdot \left(\frac{3}{2} \cdot \frac{k}{a1} - 0.5 \cdot \left(\frac{k}{a1} \right)^3 + C_2 \cdot \left(\frac{3}{2} \cdot \frac{k}{a2} - 0.5 \cdot \left(\frac{k}{a2} \right)^3 \right) \right) & 0 < k < a1 \\ C_o + C_1 + C_2 \cdot \left(\frac{3}{2} \cdot \frac{k}{a2} - 0.5 \cdot \left(\frac{k}{a2} \right)^3 \right) & a1 < k < a2 \\ C_o + C_1 + C_2 & a2 < k \end{cases}$$

where: C_0 – the random variable (nugget), C – the systematic variable, a – the spatial correlation range. C_0 – the random variable (nugget), C_1 and $a1$ – the systematic variable and the range of the short-range component of the spatial variation ($0<k<a1$), C_2 and $a2$ – the systematic variable and the range of the long-range component of the spatial variation ($a1<k<a2$).

In order to determine the correlation between selected soil characteristics connected with the location of the soil in the relief, multiple regression analysis was used.

RESULTS

Soils distribution

The pedological cross-section presented in Figure 1 clearly shows that the transect Granowo runs through two lowering terrains and one ground moraine terrain elevation. In this transect, we can distinguish the sequence of Luvisols/

Retisols at the slope of ESE aspect and Retisols, which in the final part of the slope with WNW aspect form associations with Fluvic Phaeozems. This last sequence of soils is unusual, because alluvial soils belong to quite a different typological unit, in which geogenic processes dominate.

The analysis of variability of these soils was carried out on the basis of homogeneous natural soil cartographic units [Systematyka Gleb Polski 2011]. In Granowo transect, the following soil units were distinguished: PWspgl – (Albic Luvisols (Arenic) with glossic properties, PAt – Albic Glossic Retisols (Loamic), PAsp – Albic Glossic Retisols (Aric, Arenic), PAspgg – Albic Glossic Retisols (Aric, Arenic, Oxyaquic), PWsggl – Albic Luvisols (Aric, Arenic, Stagnic) with glossic properties, PWgggl – Albic Luvisols (Aric, Loamic, Stagnic) with glossic properties, CZgg – Mollic Reductigleyic Eutric Gleysols (Aric, Loamic), CFt – Fluvic Phaeozems (Aric, Arenic).

Within the highest parts of area studied Luvisols, classified to PWspgl unit, have developed. In this soil unit sandy horizon reaches a depth of 59 cm, below which a small thickness (6 cm) glossichorizon has developed (Table 1). At the summit (S) and shoulder (S2) of the slope Retisols classified to PAt have developed. The PAt have ochric(Ap) andluvic(Et) horizons with sand or loamy sand texture. These horizons are mostly shallowly (average depth of 41 cm) come into sandy loam subsurface glossic horizon (E /B or/ and B /E). The *underlying* argic Bt-horizon has distinctly higher clay content than the overlying glossic horizon. The average thickness of Aphorizonis 28 cm and its organic carbon content is of 0.75%. Within the summit of the slope a soil be-

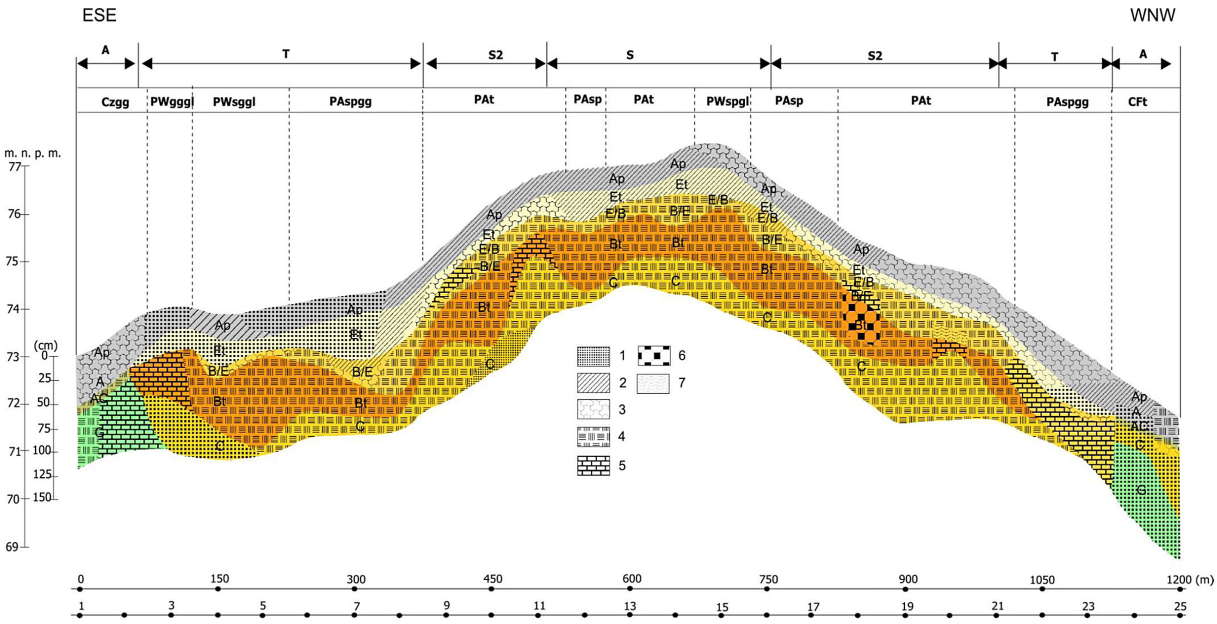

Figure 1. Pedological cross-section of Granowo transect: 1 – sand, 2 – slightly loamy sand, 3 – loamy sand, 4 – sandy loam, 5 – light loam, 6 – loam, 7 – sandy clay loam, S – summit, S2 – shoulder, T – pediment, A – footslope

Table 1. Chosen properties of soil series

Soilu nit	Thickness of sandy texture [cm]	Thickness of a horizon [cm]	Thickness of glossic horizon [cm]	C_{org} [%]	PDI [–]	pH			Exchange able cations [$cmol_{(+)}$/kg]				
						H_2O	KCl	$CaCl_2$	Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+
PAt	41	25	28	0.75	2.1	6.72	6.12	6.54	3.674	0.186	0.030	0.212	0.084
PAsp	60	27	35	0.78	2.2	6.80	6.12	6.53	3.247	0.215	0.092	0.167	0.087
PAspgg	64	34	40	0.81	3.5	6.81	6.21	6.50	3.072	0.161	0.035	0.121	0.063
PWsggl	56.5	32	10	0.81	4.4	7.31	7.04	7.12	4.900	0.113	0.048	0.124	0.038
PWgggl	48	25	5	0.78	5.9	7.11	6.65	6.87	4.270	0.111	0.037	0.095	0.013
PWspgl	59	23	6	0.73	2.3	6.89	6.55	6.86	3.650	0.153	0.001	0.131	0.090
CZgg	50	50	–	2.40	17.5	7.24	6.74	6.89	14.105	0.695	0.073	0.721	0.000
CFt	–	35	–	2.52	7.7	7.16	6.43	6.78	14.775	0.677	0.009	0.258	0.400

longing to PAsp unit have also developed. These soils occur also below the summit of the slope, in the initial part of the shoulder of the slope with WNW aspect. The PAsp unit has sandy horizon to an average depth of 60 cm, while the average thickness of glossic horizon is 35 cm and is much higher in comparison to that in PAt unit soils (28 cm). The average content of organic carbon in A horizon of this unit is 0.78%. Within the pediments of the slopes PAspgg soils have formed. In terms of taxonomy they belong to a sub type of Albic Retisols (Arenic), like the PAsp soils, but in the former soil unit reduct imorphic colour increases with depth. Sandy texture occurs to an average depth of 64 cm, an average thickness of Aphorizon is 34 cm but glossic horizon thickness is 40 cm. The Ap surface horizon of PAspgg unit contains 0.81% of organic carbon on average. Within the pediment of the slope, with ESE aspect, the Albic Luvisols (Aric, Arenic, Stagnic) with glossic properties have been formed. The thickness of glossic horizon is 10 cm, which does not allow the classification of the pedons to Retisols, while sandy material reaches a depth of 57 cm. In the final part of this slope element, the Albic Luvisols (Aric, Loamic, Stagnic) with glossic properties unit (PWgggl) has been distinguished. The soils of this unit have a sandy material to a depth of 48cm and a small thickness of glossic horizon, which does not allow their classification to PWsggl unit. Like for the soils of PWsggl unit, reduct imorphic colour increased with depth. The pediment of the slope with ESE aspects moothly transforms in the foot slope where the soils classified to the Mollic Reductigleyic Eutric Gleysols (Aric, Loamic) unit (CZgg) are formed. The average content of organic carbon in 50 cm thickness of Mollic horizonis 2.3%.The *underlying* horizons have greyish olive colour. A characteristic feature of this sol unit is the absence of free carbonates in 100 cm thickness, which would suggest that this these should be classified to another subtype of Gleysols or Phaeozems. But the alkalinity of the whole solum, high organic carbon content, high thickness of Mollic horizon and underlying horizons with reduct imorphic colours have argued the classification of these soils to the Mollic Reductigleyic Eutric Gleysols subtype. The pediment of the slope with WNW aspect is represented by Fluvic Phaeozems (Aric, Arenic) (CFT). The occurrence of these soils in association with Retisols is associated with sedimentary processes of the Mogilnica river-bed materials (mainly fluvioglacial sands). In Ap horizon the average organic content is 2.32% and this horizon has 35 cm thickness. The underlying horizons have sand texture with a clear evidence of stratification.

The thickness of Ap horizon and organic carbon content

The pedological cross-section presented in Figure 1 clearly shows that the thickness of the *Ap* horizon in this toposequence is a function of soil position on the slopes. In the soils classified as belonging to PWspgl, PAt and PAsp units, the thickness of *Ap* horizon is about 25 cm, while in Retisols and Luvisols with a clear evidence of reduct imorphic colours (PAspgg, PWsggl, PWggglunits) from 25 to 34 cm (Table 1). Clearly greater thickness of *A* horizon occurs in soils at the foot slope (CZggand CFt units). Also, the organic carbon content (C_{org}) is related to the location of soils on the slopes. In Luvisols and Retisols of upper slope parts (PWspgl, PAt and PAsp) it is of about 0.76%, while in the soils at the foot slope sits content is about 2.45%. In addition to the relief (Δh – m, the height difference between the point being under consideration and the lowest point in the analysed toposequence) the organic carbon content also depends on the soil pH (pH_{KCl}), the cation exchange capacity (CEC – cmol(+)/kg) and the terrain slopes (SP – %), which can be described by the equation:

$$C_{org} = -0.17 \cdot pH_{KCl} - 0.01 \cdot \Delta h + 0.158 \cdot CEC - 0.02 \cdot SP + 1.287 \ (R^2 = 0.963)$$

The pH and cation exchange capacity

The pH of *Ap* horizon is determined by the organic carbon content (C_{org}), the clay content (fi – %) and cation exchange capacity, as shown by the equation:

$$pH_{H_2O} = 6.96 - 1.45 \cdot C_{org} - 0.11 \cdot fi + 0.28 \cdot CEC \ (R^2 = 0.83)$$

The data presented in Figure 2 show that the cationic exchange capacity (CEC) significantly increases in the lower part of the slope and takes the highest values in the soils from CZggand CFt units, in which it is mainly demined by the organic carbon content:

$$CEC = 5.95 \cdot C_{org} + 0.155 \cdot pH_{H_2O} - 11.03 \ (R^2 = 0.971)$$

The CEC in *Ap* horizon is also affected by soil pH, but not statistically significant correlation

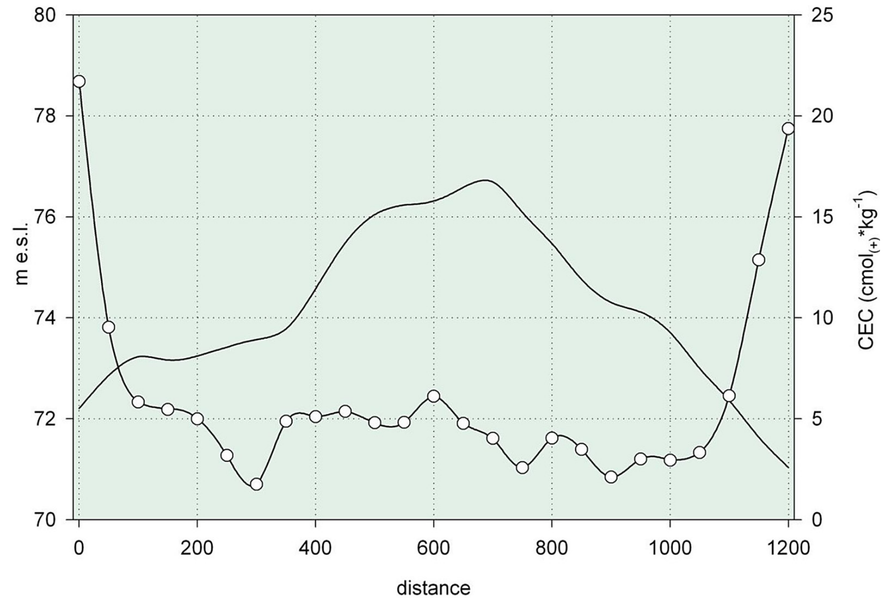

Figure 2. Cation exchangeable capacity (CEC) in plough layer

was obtained between the CEC and the content of clay fraction. It could be related to the small spatial diversity of the content of this separate in the analysed horizon.

The processes occurring in the analysed toposequence, in which the Retisols and the Luvisols developed, are manifested by the relationship between the terrain slopes and the thickness of glossic horizon. Many of soil properties depend on the position in relief, in particular on the soil water regime, which directly determines the leaching of calcium and other cations and a clay separate from eluvial horizon, as well as the degradation of argic horizon and development of a subsurface glossic horizon. Hence, Figure 3 presents the relationship between the terrain slopes, that occur 100 m above a considered pedon, and the thickness of glossic horizon. It clearly shows that the thickness of glossic horizon is determined by terrain slopes, which occur above the analysed soil and may be related to the amount of water that has flown into the pedon from upper parts of the slope.

Spatial variability ofselectedsoil properties

Distribution of soils in the sequence analysed shows great spatial diversity, which is an

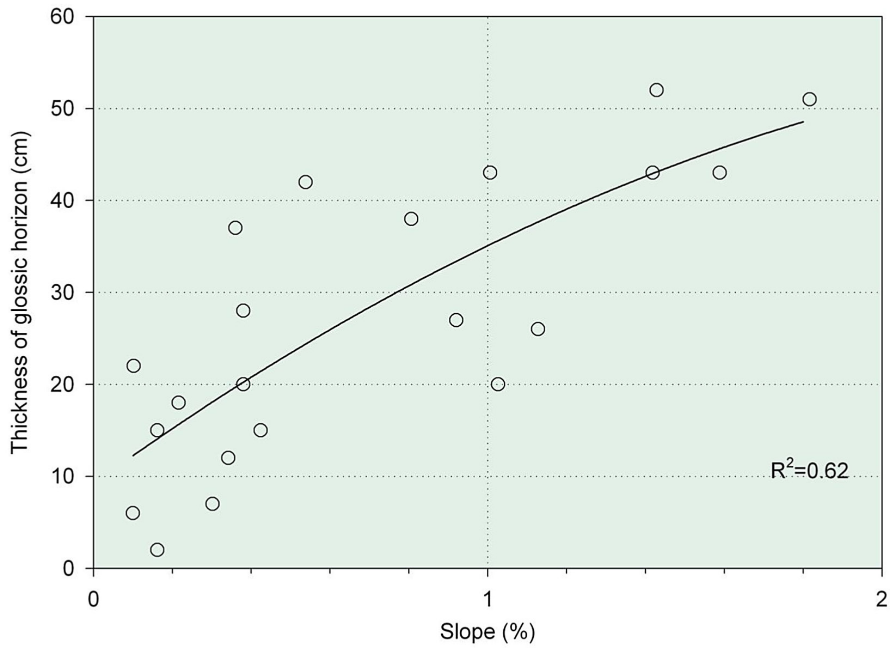

Figure 3. The relationship between the terrain slope and thickness of glossic horizon

inevitable and natural property. Despite the clear differences between separate soil units, changes in soil properties are realized gradually. The geostatistic analysis has shown that changes in soils properties occur progressively (systematically), demonstrating high systematic variability and small random variability (Table 2). Participation of random variation (C_0) in the sill of glossic horizon thickness was 28% (8.8 cm), while the random variability of exchangeable magnesium and potassium was 20% and 14%, respectively. The other examined soil properties were characterized by a small random variability of around 5%. The random variability of Ap horizon thickness was 5.5%. This means that the change in Ap horizon thickness of 2 cm may occur over space less than the distance between the measuring points, i.e. <50m. The random variability of organic carbon contents was 0.15% and its change can occur over space less than 50m. The PDI (profiles darkness index) showed less random variability (2%), while random change in pH of *Ap* horizon accounted for only about 1% of the total spatial variability of the characteristics of the transect analysed.

In the structure of predictable variability (systematic) most of the analysed soil properties show two correlated distances in the spatial variation. The first concerns the systematic changes taking place over short-range distances (from 87 m to 344 m), which may result from the variation of soil properties between separate soil units. The second characterizes long-range changes in soil properties (from 431 m to 792 m), which testify to the fact that quantitative changes in the soil properties are realized gradually and distinctly together with differentiation of the slope, over several separate soil cartographic units. These changes may result from the dynamic equilibrium which is established between the weathering processes and translocation of the weathering products, as well as their solubility and precipitation. Specific identification of spatial variability of soil properties together with the range of spatial correlation is the basis for the assessment of regional variability of soil characteristics, interpolation of point results to areas not measured, as well as spatial modelling of processes in soils and quantitative modelling and description of soil cover [Marcinek et al. 1998].

DISCUSSION

The processes of soil genesis and evolution are closely dependent on the conditions of the natural environment and the relationship between its elements, which resulted in a dynamic equilibrium creating a given soil. Spatial and temporal variability of soil-forming factors and the relationship between them, are the major

Table 2. Parameters of semivariograms

Properties	Specification	Parameters of semivariograms					
		C_o	C_1	C_2	a_1 [m]	a_2 [m]	C_0/sill [%]
Thickness of A horizon	[cm]	3	16	42	132	500	5.5
Thickness of glossic horizon	[cm]	78	113	89	87	313	28.0
C_{org}	[%]	0.024	0.278	0.267	274	792	4.2
PDI	[–]	0.34	4.99	10.98	344	700	2.1
pH_{H2O}	[pH]	0.0040	–	0.3227	–	559	1.2
pH_{KCL}		0.0070	–	0.6921	–	640	1.0
pH_{CaCl2}		0.0150	0.0306	0.2388	255	634	5.3
Ca	[cmol$_{(+)}$/kg]	0.4200	4.9840	13.4827	195	431	2.2
Mg		0.0098	0.0158	0.0238	231	607	19.8
K		0.0055	0.0184	0.0145	156	494	14.3
Na		0.0015	0.0017	–	208	–	47.1
TEB		0.480	7.895	13.415	224	444	2.2
CEC		0.450	5.765	6.661	220	434	3.5

C_{org} – organic carbon content, PDI – profile darkness index, Ca – exchangeable calcium, Mg – exchangeable magnesium, K – exchangeable potassium, Na – exchangeable sodium, TEB – sum of exchangeable bases, CEC – cation exchangeable capacity.

cause of soil cover diversity [Hall 1983, Wilding and Drees 1983, Soil Survey Manual 1993, Buolet al. 1997].

This study confirmed the existence of soil sequences of Retisols/Luvisols and Gleysols along the slopes in the Polish Lowlands [Marcinek et al. 1994 b, 1995 a, 1998, Marcinek and Komisarek 1991, Marcinek and Wiślańska 1984, Komisarek 2000]. They were formed from a glacial till of Leszno Phase of Baltic Glaciation. In the analysed transect Retisols of different subtypes with well-developed glossic horizon dominate. Within the summit and shoulder of the slope, the soils do not show gleyic properties, but with decreasing soil position in relief, within slope pediments, they have gleyic properties. The soils of the transect usually have a sandy texture from surface up to 50 cm.

The analysis of the variability of soils cover was carried out on the basis of homogeneous natural soil units. In addition to the Retisols, Luvisols were identified in the transect and they represented 3 units (PWspgl, PWsggl, PWgggl). They accounted for about 20% of soils of the transect analysed. A characteristic feature of these soils is the thickness of glossic horizon. On the one hand, the thickness was smaller than 15 cm which did not allow their classification to the Retisols, on the other hand, this thickness was over 5 cm, which was the argument deciding about inclusion of this horizon into cartographic units. It has been established that the development of glossic horizon depends on the quantity of water in flowing to the argic horizon, which significantly affects the leaching of clay separate and free iron oxides.

The relationship between the terrain slopes, that occur over a distance of 100 m above the considered pedon of Retisols/Luvisols, and the thickness of glossic horizon clearly indicate that the greater the terrain slopes above the soil considered, the greater the thickness of the glossic horizon. This could be related to the amount of water inflow from the surface and subsurface to the soil. It is a relationship that explains about 60% of the variance of the thickness of a well-developed glossic horizon. Therefore, the above relationship should be approached with caution, because it may be a characteristic only of the soil cover of the transect analysed. Despite the clear differences between the separate soil units, the changes in soil properties are realized gradually. Changes in the soils properties of *Ap* horizon occur gradually (systematically), demonstrating high systematic variability and small random variability.

The structure of systematic variability of most analysed soil properties of *Ap* horizon shows two distances of spatial variation that not been noted in previous studies [Marcineket al. 1998]. The first one is realized at a distance from 87 m to 344 m, and can be associated with differences in soil properties between separate soil units. The second distance of spatial correlation ranges from 431 m to 792 m, which testify to the fact that quantitative changes in the properties of soils are realized gradually and distinctly, together with the differentiation of the slope, over several separate cartographic units.

CONCLUSIONS

Evaluation of soil distribution and determination of the relationship between the soil morphology and basic soil properties, and the soil location in a relief within the ground moraine plains of Opalenica Lakeland Poznan permits drawing the following conclusions:

1. The analysis of soil toposequence of Opalenica Plain showed that Retisols dominate over Luvisols.
2. High correlation between the location of the soil in a relief or terrain slopes and the thickness of *Ap* horizon and the organic carbon content indicates a link between these characteristics with the toposequential system.
3. Differentiation of inorganic carbon content in the transect analysed is significantly correlated with pH, cation exchange capacity, terrain slopes and location of the soil in the relief. The cation exchange capacity of *Ap* horizon mainly depends on the organic carbon content and pH.
4. Soil properties of toposequence are characterized by small random variability and high systematic variability in which two ranges of spatial correlation can be distinguished. The first one is realized at a distance from 87 m to 344 m, whereas the second at a distance from 431 m to 792 m.
5. The glossic horizon thickness of Retisols of Opalenica Plain depends on the amount of surface and subsurface water inflow to the soil from upper parts of the slope.

REFERENCES

1. Blake G.R., Hartge K.H. 1986. Bulk density. In: R.A. Klute (Ed.) Method of soil analysis. P. 1. Physical and mineralogical methods. Agronomy Monograph 9. ASA-SSSA, Madison, 363–375.
2. Buol S.W., Hole F.D., McCracken R.J., Southard R.J. 1997. Soil genesis and classification. Inowa State Univ. Press, Ames.
3. Głazowska M.A. 1981. Gleby kuli ziemskiej. PWN, Warszawa.
4. Golden Software 2002. Surfer version 8.01. Surface Mapping System. Colorado.
5. Hall G.F. 1983. Pedology and geomorphology. In: L.P. Wilding, N.E. Smeck, G.F. (Eds.) Pedogenesis and Soil Taxonomy. I. concept and interaction. Hall. Developments in Soil Science 11 A. Elsevier. Amsterdam, 117–140.
6. Kociałkowski W.Z., Ratajczak M. 1984. Uproszczona metoda oznaczania kationów wymiennych i kationowej pojemności wymiennej gleby według Meliha. Rocz. AR Pozn. 146, Roln. 27, 105–116.
7. Komisarek J. 2000. Kształtowanie się właściwości gleb płowych i czarnych ziem oraz chemizmu wód gruntowych w katenie falistej Pojezierza Poznańskiego. Rocz. AR Pozn. Rozp. Nauk. 307.
8. Krygowski B. 1953. Mapa geomorfologiczna Niziny Wielkopolskiej. Red. B. Krygowski.
9. Krygowski B. 1961. Geografia fizyczna Niziny Wielkopolskiej. Cz. 1. Geomorfologia. Kom. Fizjogr. PTPN, Poznań.
10. Marcinek J. Kaźmierowski C. Komisarek J. 1998. Rozmieszczenie gleb i zróżnicowanie ich właściwości w katenie falistej moreny dennej Pojezierza Poznańskiego. Zesz. Prob. Post. Nauk Roln. 460, 53–73.
11. Marcinek J., Komisarek J. 1991. Rozmieszczenie materii organicznej w układach katenalnych gleb Wielkopolski. Rocz. AR Pozn. 224, Mel. 5, 65–81.
12. Marcinek J., Komisarek J. 2000. Wpływ naturalnych warunków drenażu gleb na ich reżim wodny. Rocz. AR Pozn. 317, Roln. 56, 79–88.
13. Marcinek J., Komisarek J., Kaźmierowski C. 1994a. Dynamika składników rozpuszczonych w wodach gruntowych uprawnych gleb płowych i czarnych ziem. Rocz. AR Pozn. 268, Melior. Inż. Środ. 15, cz. 1, 69–82.
14. Marcinek J., Komisarek J., Spychalski M. 1990. Gleby środkowej Wielkopolski. W: L. Ryszkowski., J. Marcinek, A. Kędziora (Red.) Obieg wody i bariery biogeochemiczne w krajobrazie rolniczym. Wyd. UAM, Poznań 141–147.
15. Marcinek J., Spychalski M., Komisarek J. 1994b. Dynamika wody glebowej w glebach autogenicznych i semihydrogenicznych w układzie toposekwencyjnym moreny dennej Pojezierza Poznańskiego. Rocz. AR Pozn. 268, Mel. Inż. Środ. 15, cz. I, 131–145.
16. Marcinek J., Wiślańska A. 1984. Asocjacje czarnych ziem i gleb płowych falistej moreny dennej Równiny Kościańskiej. Rocz. AR Pozn. 149, 65–81.
17. Milne G. 1936. Normal erosion as a factor in soil profile development. Nature, 138, 548–549.
18. Nelson D. W., Sommes L.E. 1982. Total carbon, and organic matter. In: A.L. Page (Ed.) Methods of soil analysis. P. 2. Chemical and microbiological properties. Red. Agronomy Monograph 9. ASA-SSSA, Madison, 539–580.
19. Pannatier Y. 1996. VARIOWIN: Software for Spatial Data Analysis in 2D. Springer Verlag, 91 p.
20. PN-R-04032. 1998. Gleby i utwory mineralne. Pobierania próbek i oznaczanie składu granulometrycznego. Polski Komitet Normalizacyjny, Warszawa.
21. Soil survey laboratory methods manual. 1992. Soil Survey Laboratory Staff. Soil Survey Investigation Report 42. v. 2,0. USDA.
22. Soil survey laboratory methods manual. 1996. Soil Survey Laboratory Staff. Soil Survey Investigation Report 42. v. 3,0. USDA.
23. Soil survey manual. 1993. Soil Survey Staff. U.S. Dep. Agric. Handb. 19.U.S Govt. Print. Off. Washington, DC.
24. Spychalski M. 1998. Gospodarka wodna wybranych gleb uprawnych Pojezierzy Poznańskiego i Leszczyńskiego. Rocz. AR Pozn. Rozpr. Nauk. 284.
25. Starkel L. 1987. Przeglądowa mapa geomorfologiczna Polski (1:500 000). Inst. Geogr. Przest. Zagosp. PAN. Warszawa.
26. Systematyka Gleb Polski, 2011. Roczniki Gleboznawcze – Soil Science Annual, 62(3), 1–193.
27. Szafrański Cz. 1993. Gospodarka wodna gleb terenów bogato urzeźbionych i potrzeby ich melioracji. Rocz. AR Pozn. Rozpr. Nauk. 244.
28. Warrick A.W., Myers D.E., Nielsen D.R. 1986. Geostatistical methods applied to soil science. In: R.A. Klute (Ed.) Method of soil analysis. P. 1. Physical and mineralogical methods. Agronomy Monograph 9. ASA-SSSA, Madison, 53–82.
29. Wilding L.P., Drees L.R. 1983. Spatial variability and pedology. In: L.P. Wilding, N.E. Smeck, G.F. Hall (Eds.) Pedogenesis and soil taxomomy. I. Concept and interaction. Development in Soil Science 11 A. Elsevier, Amsterdam: 83–116.