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Soil Genesis

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MORPHOLOGY AND CHEMICAL PROPERTIES OF PLOUGH HORIZONS OF SOILS IN VARIOUS SLOPE POSITIONS**

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Abstract. Studies on morphological features and chemical composition of Ap horizons of soils located on gentle Narew valley-sides were carried out. The Luvisols with a texture of loamy sands and sandy loams are developed on the slope shoulder while the Mollic Gleysols of a similar texture with deposits to 110 cm thick are located on the footslope. The soil particle size distribution and total nitrogen (TN), total porosity (TP) and $K_{H_2SO_4-H_2O_2}$ content in both slope positions are similar. The mean TN, TP and $K_{H_2SO_4-H_2O_2}$ content on the slope shoulder is 0.94, 0.36 and 1.26 g kg^{-1}, respectively, while soils on the footslope are characterized with a mean content of total nitrogen, phosphorus and potassium of 1.15, 0.35, and 1.17 g kg^{-1}, respectively. Plough horizons of soils located on the footslope are more acidic with higher C_{org} content. The mean exchangeable acidity in deluvial soils (4.20 cmol(+) kg^{-1}) is higher than in soils located in upper slope positions (2.92 cmol(+) kg^{-1}). Similar texture of soils in both slope positions as well as thick deluvial deposits on the footslope is evidence of tillage erosion as the main factor of soil downslope translocation on these gentle slopes.

Agriculture is one of the main drivers of unnatural soil erosion, since many farming practices are soil-unfriendly, causing soils on arable lands more prone to erosion compared with natural undisturbed ecosystems. Soil erosion is a major cause of soil degradation in arable land, affecting soil properties and landscape processes such as nutrient redistribution, pesticide fate and greenhouse gas emission [15, 16]. In recent years, tillage erosion has been recognized as one of the most important factors in the redistribution of soils over time and in the development of morphological changes in agricultural fields and landscapes

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[5, 18, 23]. Erosion and deposition processes affect the morphological features of soils developed both in the upper position of a slope, such as the summit or shoulder, and in the lower slope position, such as the footslope and toeslope. The accumulated long-term tillage effects result in a modification of the soil profile and spatial patterns of soil variability. Moreover, soil redistribution by tillage results in a severe modification of the landscape topography as well as of the surface and subsurface hydrology (e.g., variability of infiltration and overland flow paths), causing substantial modification of geomorphic processes [5]. Tillage erosion and its impact on soil characteristics is well documented on areas covered with silty and loess soils very susceptible to erosion [17, 24], mainly on steep slopes [8, 13, 19, 25]. However, other studies reveal that despite gentle slopes of valley-sides built up of material not very prone to erosion and low phosphorus content in the topsoil, the mire in the valley margins was exposed to eutrophication resulting from erosional transport of P from arable land located on the upland [22]. Thus, the first objective of the study was the description and comparison of the morphological features of Ap horizons of soils developed from loamy sands and located in the upper and lower part of the slope, where tillage along the slope prevails. The second objective of this study was to determine differences in chemical and physicochemical properties of Ap horizons in soils located on the valley-sides, where natural and anthropogenic conditions are favourable to soil redistribution along the slope.

MATERIALS AND METHODS

The study area is located in the south-west of Białystok on the valley-sides of the Narew River within the borders of the Narew National Park (NNP) protection area. The NNP protects the swampy Narew valley and its unique anastomosing river system, rich in flora and fauna. This is one of the largest and best preserved areas of wetlands in Poland. Topography of the uplands surrounding the valley is rather moderate and the surface slope ranges between levelled plains to gentle slopes. Soils located on the valley-sides are comprised of glacial deposits, mainly sands and loamy sands and rarely loams [1]. Soils are mainly Luvisols and Arenosols. The valley is filled with organic deposits, mainly with peat. Soils in the valley are Histosols [2]. The land use on the valley-sides is dominated by agriculture. The arable fields on the valley-sides are narrow and their longer borders are parallel with the major slope, so it is common practice to conduct tillage parallel with the length of the field, which means along the slope. The major crops are rye, potato, oat and maize. The mean daily temperature ranges between -4.3°C in January and 17.3°C in July. The mean annual rainfall is 593 mm with peaks in June, July and August. Thunderstorms occur on about 25 days a year, mostly during the summer. The maximum monthly snowfall varies between 8 and 80 cm and occurs on 82-85 days a year, with midwinter thawing [7].

Eight arable fields located on the valley-sides with slopes ranging between 2.5 and 5.3% were chosen. The field sites were chosen to be representative of the landscape type and field geometry and crop production as well as tillage methods used in the region. The length of study fields varied between 96 m and 420 m; the width was 20 m. The tillage operations on all study fields were conducted along the slope gradient. A short description of the study fields is given in Table 1.

On every study field the soil profiles were described in the upper and lower parts of the slopes, and in the case of the two longest, fields Nos 5 and 10, the soil profile was also described in the middle part of the slope. In every profile soil samples were taken from a 15-20 cm layer for texture determination, which was done using the Bouyoucos method in modification by Casagrande and Prószyński. For lower horizons the soil texture was determined at the field. On every study field soil samples for chemical properties were obtained from the Ap horizon of soils occurring on the shoulder and footslope and in addition from the midslope of the two longest study fields, in total 18 soil samples were taken. Soil was sampled from a depth of 15-20 cm. For the soil analyses, pH was measured in water and in KCl, exchangeable acidity (EA) was determined by the Kappen method, exchangeable bases were determined in 1M ammonium acetate – calcium and magnesium by flame AAS, Na and K with flame photometry. Total of exchangeable base cations (TEB), cation exchange capacity (CEC) and base saturation (BS) were calculated. Organic carbon was determined by the Tiurin method. Total nitrogen (TN) and potassium ($K_{H_2SO_4-H_2O_2}$) were determined after digestion of soil samples with sulphuric acid and hydrogen peroxide, total nitrogen was determined by the Nessler method, and potassium was measured by flame photometry. Total phosphorus was determined with ammonium metavanadate method after digestion with nitric acid and perchlorid acid mixture. The Spearman correlation analysis was done for selected soil properties, using a significance level of 5%.

RESULTS

The soils located on the slope shoulder are Luvisols, although their profiles are affected by erosion and tillage. The *luvic* horizon is eroded or incorporated into the plough horizon by tillage, while the *argic* horizon is directly beneath the plough horizon. Only soil on the slope shoulder in field 10 (profile 10a) is the Arenosol, because of the low pH and low base saturation value in the Ap horizon. Soils in the footslope are Mollic Gleysols (Colluvic) – deluvial soils, because of deep humus horizons.

On the slope shoulder Luvisols of a loamy sand texture developed. The depth of plough horizons in these soils varies from 20 to 30 cm, except the soils from field 9 (profile 9a and 9b), where the Ap horizons are 38 cm deep (Table 1). On the lower part of the slope deluvial soils of loamy sand and sandy loam occurred with humus horizon with a depth of 38 to 110 cm. The soil particle size distribution of Ap horizons in soils in both positions on the slope is similar (Table 2). The

TABLE 1. DESCRIPTION OF THE STUDIED FIELDS AND STUDIED SOILS

Study field	Slope (%)	Length (m)	Profile	Position on the slope	Horizon	Depth (cm)	Texture	Soil type
Field 12 (Łupianka Stara)	2.5	358	12a	Midslope	Ap Bt C	0-23 23-80 80-150	LS LS LS	Luvisol
			12b	Footslope	Ap A Cg G	0-30 30-47 47-70 70-150	SL SL SL SL	Mollic Gleysols (Colluvic)
Field 1 (Radule)	2.6	96	1a	Shoulder	Ap Bt BC Ck	0-20 20-45 45-74 74-150	SL SL LS LS	Luvisol
			1b	Footslope	Ap A AC C	0-20 20-40 40-50 50-150	SL SL SL SL	MollicGley sols (Colluvic)
Field 7 (Kolonia Topilec)	2.7	278	7a	Shoulder	Ap Bt C	0-30 30-49 49-150	LS LS S	Luvisol
			7b	Footslope	Ap A AC C G	0-26 26-65 65-76 76-90 90-150	LS LS LS SL S	MollicGley sols (Colluvic)
Field 10 (Jeńki Romanowo)	2.7	420	10a	Shoulder	Ap Bv C	0-25 25-60 60-150	LS LS S	Arenosol
			10b	Midslope	Ap AC C	0-50 50-60 60-150	SL LS S	MollicGley sols (Colluvic)
			10c	Footslope	Ap AC C	0-30 30-47 47-150	SL SL SL	MollicGley sols (Colluvic)
Field 9 (Kurowo)	4.1	100	9a	Shoulder	Ap Bt C	0-3838- 7474-15 0	SL LS S	Luvisol
			9b	Midslope	Ap Eet Bt C	0-38 38-53 53-89 89-150	LS LS SL LS	Luvisol

TABLE 1. CONTINUATION

Study field	Slope (%)	Length (m)	Profile	Position on the slope	Horizon	Depth (cm)	Texture	Soil type
Field 3 (Bokiny)	4.8	210	3a	Shoulder	Ap Bt BC C	0-30 30-52 52-70 70-150	SL SL SL SL	Luvisol
			3b	Footslope	Ap A1 A2 Ab Cb	0-40 40-80 80-100 100-120 120-150	SL SL SL SL SL	MollicGley sols (Colluvic)
Field 5 (Łupianka Stara)	5.1	390	5a	Shoulder	Ap Bt C	0-31 31-50 50-150	LS SL LS	Luvisol
			5b	Midslope	Ap A C	0-38 38-46 46-150	SL S S	MollicGley sols (Colluvic)
			5c	Footslope	Ap A Ab Cb	0-40 40-110 110-160 160-	LS LS LS S	MollicGley sols (Colluvic)
Field 11 (Łupianka Stara)	5.3	350	11a	Shoulder	Ap Bt C	0-30 30-60 60-150	SL SL SL	Luvisol
			11b	Midslope	Ap Bt C	0-40 40-60 60-150	LS LS LS	Luvisol

differences in the morphological features are more pronounced in soils developed on the relatively steeper slopes 4.1-5.3%. On field 3 on the footslope, deluvial soil developed with 100 cm of deposits occurring on the humus horizon of the buried soil. The deposits are of a sandy loam texture and the parent material of buried soil is of a light loam texture. Even more distinctive differences in soils were found on the slope of 5.1%. Field 5 on this steep slope stretches from the summit to the footslope. On the lower part of the field deluvial soil with 110 cm of deposits occurred. The deposits are of a loamy sand texture.

The C_{org} concentration ranges from 2.50 to 9.93 g kg^{-1}, except two samples from lower parts of the slope where the concentration of organic carbon amounts 11.01 and 17.63 g kg^{-1}. In most fields the organic C content is higher in the lower part of the slope (Table 3).

Total nitrogen in plough horizon ranges from 0.47 to 1.69 g kg^{-1} (Table 3) and is not affected by the position on the slope. The TN is strongly correlated with C_{org} and exchangeable form of calcium and magnesium, as well as with the percentage

TABLE 2. PARTICLES SIZE DISTRIBUTION OF PLOUGH HORIZONS OF STUDIED SOILS

Location of fields	Profile	Percentage of fraction with particle diameter (mm)						In total		
		1-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	<0.002	1-0.05	0.05-0.002	<0.002
Field 12 (Łupianka Stara)	12a	74	9	4	4	1	8	83	9	8
	12b	56	16	8	7	4	9	72	19	9
Field 1 (Radule)	1a	52	14	7	8	4	15	66	19	15
	1b	57	17	7	5	1	13	74	13	13
Field 7 (Kol. Topilec)	7a	71	9	5	4	1	10	80	10	10
	7b	73	10	5	4	0	8	83	9	8
Field 10 (Jeńki Romanowo)	10a	74	8	3	5	1	9	82	9	9
	10b	51	16	11	8	5	9	67	24	9
	10c	54	14	7	5	2	18	68	14	18
Field 9 (Kurowo)	9a	68	11	5	5	1	10	79	11	10
	9b	67	13	6	4	1	9	80	11	9
Field 3 (Bokiny)	3a	53	18	9	5	3	12	71	17	12
	3b	48	15	12	9	3	13	63	24	13
Field 5 (Łupianka Stara)	5a	78	8	3	1	2	8	86	6	8
	5b	68	12	6	3	0	11	80	9	11
	5c	65	15	5	2	3	10	80	10	10
Field 11 (Łupianka Stara)	11a	62	9	6	7	2	14	71	15	14
	11b	75	8	4	4	1	8	83	9	8

TABLE 3. Concentration of C_{ORG}, TN, TP, $K_{(H_2SO_4-H_2O_2)}$, AND C/N AND pH IN H_2O AND pH IN KCL IN PLOUGH HORIZONS OF STUDIED SOILS

Location of fields	Position on the slope	Profile	C_{org}	TN	TP	$K_{(H_2SO_4-H_2O_2)}$	C/N	pH	
			(g kg^{-1})					H_2O	KCl
Field 12 (Łupianka Stara)	Midslope	12a	6.06	1.37	0.38	0.89	4	6.90	6.61
	Footslope	12b	6.54	0.99	0.34	1.00	7	6.36	5.47
Field 1 (Radule)	Shoulder	1a	5.80	1.36	0.22	0.95	4	6.17	5.32
	Footslope	1b	5.75	0.60	0.31	1.17	10	5.73	4.62
Field 7 (Kol. Topilec)	Shoulder	7a	4.17	0.57	0.34	0.95	7	6.56	5.70
	Footslope	7b	17.63	1.69	0.29	0.82	10	6.86	5.98
Field 10 (Jeńki Romanowo)	Shoulder	10a	4.71	0.47	0.41	0.69	10	5.21	4.29
	Midslope	10b	9.93	1.65	0.39	1.05	6	6.11	5.21
	Footslope	10c	3.54	1.48	0.36	1.02	2	4.84	4.06
Field 9 (Kurowo)	Shoulder	9a	3.73	0.82	0.48	1.16	5	5.97	4.81
	Midslope	9b	3.76	0.82	0.55	0.98	5	5.14	4.26
Field 3 (Bokiny)	Shoulder	3a	7.33	1.21	0.38	1.82	6	7.35	6.66
	Footslope	3b	11.01	1.64	0.47	2.07	7	6.53	5.59
Field 5 (Łupianka Stara)	Shoulder	5a	2.50	0.63	0.29	0.87	4	7.88	7.60
	Midslope	5b	4.67	0.50	0.25	0.91	9	4.93	3.92
	Footslope	5c	3.33	0.52	0.34	0.93	6	5.07	3.89
Field 11 (Łupianka Stara)	Shoulder	11a	5.17	1.54	0.40	2.39	3	7.73	7.35
	Midslope	11b	5.25	1.05	0.37	0.98	5	7.23	7.09

of silt (Table 4). The total nitrogen concentration in lower slope soils is less than in soils on the slope shoulder in the case of field 12 and 1 located on gentle slopes as well as in the case of field 11 on the steepest slope. On the other hand, the TN concentration in the lower slope position is higher than on the slope shoulder in the case of a 2.7% slope (field 7 and 10) and in the case of a 4.8% slope (field 3). The TN concentration in Ap horizons of soils from field 9 and 5 located on the 4.1% and 5.1% slopes respectively is relatively uniformly distributed within the surface layer.

The amount of TP in plough horizon is from 0.22 to 0.55 g kg^{-1} (Table 3). On the gentle slopes erosion has no significant effect on the phosphorus distribution in the Ap horizon and TP concentration in soils in the lower slope is less than in the upper slope position, except the soils on field 1 located on the gentle slope (2.7%). On the other hand, on the steeper slopes, erosion has a significant effect on the TP concentration in the Ap horizon, which is higher in soils located in the lower slope position. Potassium concentration ranges from 0.82 to 2.39 g kg^{-1} (Table 3). The K concentration is higher in soils located in the lower part of the field, except field 7 and 11. The TP concentration is not correlated with any other analyzed soil features, while the potassium concentration is positively correlated with exchangeable sodium (Table 4).

While the TN concentration is low in the soils in lower parts of the fields it results in a higher C/N ratio in these soils. The studied soils have a wide range of pH in KCl values, ranging from 4.29 to 7.60 and this parameter is lower (3.89-7.09) in the lower part of the field (Table 3). The pH is strongly correlated with percentage of silt, as well as with exchangeable calcium and magnesium, base saturation.

The cations exchange capacity of plough horizons ranges from 4.28 to 19.60 cmol(+) kg^{-1} (Table 5). Exchangeable calcium is the dominant cation in the sum of base cations. The soil content of Ca^{2+} ranges from 0.29 to 17.90 cmol(+) kg^{-1}. Exchangeable magnesium and potassium are next in the sequence of cations abundance in the sum of base cations, and their contents range from 0.05 to 0.99 cmol(+) kg^{-1} and from 0.03 to 0.31 cmol(+) kg^{-1} respectively. The lowest in the plough horizon is the content of exchangeable sodium ranging from 0.01 to 0.04 cmol(+) kg^{-1}. Higher exchangeable acidity corresponds with a low amount of Ca^{2+}. High variability of all exchangeable cations in the soil results in a wide range of base saturation, ranging from 4.8 to 97.7% (Table 5). The exchangeable forms of sodium and magnesium are positively correlated with the percentage of silt, while the Na^+ content is correlated with the percentage of clay. The K^+ content is correlated with exchangeable sodium content (Table 4). The content of Ca^{2+} and Mg^{2+} in the Ap horizons from upper parts of the slope is lower comparing with the lower parts of the slope, which results in higher exchangeable acidity in the soils from slope shoulder. The content of K^+ is less pronounced and only few soils in the lower field position are enriched with this cation. The amount of Na^+ is similar in soils from both positions on the field. Base saturation is higher in soils located on the slope shoulder.

TABLE 4. CORRELATION COEFFICIENT BETWEEN CHEMICAL AND PHYSICOCHEMICAL FEATURES AND TEXTURE

Parameter	Sand 0.1-0.05	Silt 0.05-0.002	Clay <0.002	C_{org}	TN	TP	$K(H_2SO_4-H_2O_2)$	pH in KCl	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	EA	CEC	BS
Sand 0.1-0.05	1.00															
Silt 0.05-0.002	0.03	1.00														
Clay <0.002	-0.31	0.01	1.00													
C_{org}	0.41	0.45	-0.19	1.00												
TN	-0.25	**0.53***	-0.11	0.63	1.00											
TP	-0.27	0.04	0.24	0.02	0.16	1.00										
$K(H_2SO_4-H_2O_2)$	-0.21	0.23	0.41	0.23	0.38	0.43	1.00									
pH in KCl	0.04	**0.94**	-0.06	0.33	0.42	-0.01	0.10	1.00								
Ca^{2+}	0.02	**0.99**	-0.01	0.45	**0.54**	0.07	0.27	**0.92**	1.00							
Mg^{2+}	0.10	**0.78**	0.15	**0.62**	**0.57**	-0.13	0.18	0.75	0.75	1.00						
K^+	-0.31	0.01	1.00	-0.19	-0.11	0.24	0.41	-0.06	-0.01	0.15	1.00					
Na^+	0.01	0.23	**0.49**	-0.01	0.14	-0.29	0.02	0.14	0.23	0.38	**0.49**	1.00				
TEB	0.02	**0.99**	0.03	0.45	0.55	0.01	0.27	**0.90**	**0.99**	**0.79**	0.03	0.30	1.00			
EA	-0.05	**-0.74**	-0.15	-0.09	-0.06	0.40	-0.01	**-0.76**	**-0.70**	**-0.59**	-0.15	-0.33	**-0.72**	1.00		
CEC	-0.23	**0.55**	-0.21	0.21	**0.62**	0.42	0.27	0.46	**0.59**	0.29	-0.21	0.02	**0.57**	0.03	1.00	
BS	-0.03	**0.94**	0.14	0.36	0.40	-0.18	0.20	**0.90**	**0.91**	**0.81**	0.13	0.33	**0.93**	**-0.89**	0.30	1.00

TABLE 5. Sorption features of plough horizons of studied soils

Location of fields	Position on the slope	Profile	Base cations							BS^3
			Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB^1	EA^2	CEC	
			cmol(+) kg^{-1}							
Field 12 (Łupianka Stara)	Midslope	12a	4.43	0.53	0.15	0.02	5.13	2.33	7.45	68.8
	Footslope	12b	3.73	0.69	0.12	0.02	4.57	3.86	8.43	54.2
Field 1 (Radule)	Shoulder	1a	4.17	0.86	0.17	0.03	5.23	2.21	7.44	70.3
	Footslope	1b	2.33	0.30	0.11	0.02	2.76	2.72	5.48	50.4
Field 7 (Kol. Topilec)	Shoulder	7a	2.34	0.35	0.15	0.02	2.85	3.04	5.89	48.4
	Footslope	7b	4.93	0.99	0.06	0.03	6.01	3.15	9.16	65.6
Field 10 (Jeńki Romanowo)	Shoulder	10a	0.74	0.10	0.06	0.01	0.91	7.35	8.26	11.0
	Midslope	10b	5.43	0.16	0.03	0.02	5.64	6.79	12.43	45.4
	Footslope	10c	0.29	0.05	0.09	0.01	0.45	8.63	9.07	4.8
Field 9 (Kurowo)	Shoulder	9a	1.74	0.23	0.23	0.03	2.22	5.40	7.62	29.2
	Midslope	9b	1.14	0.15	0.19	0.01	1.49	8.55	10.04	14.8
Field 3 (Bokiny)	Shoulder	3a	5.93	0.46	0.16	0.01	6.55	1.61	8.17	80.3
	Footslope	3b	5.93	0.79	0.21	0.03	6.95	3.53	10.47	66.3
Field 5 (Łupianka Stara)	Shoulder	5a	9.78	0.31	0.10	0.03	10.22	0.36	10.58	96.6
	Midslope	5b	0.60	0.07	0.20	0.03	0.90	3.47	4.37	20.6
	Footslope	5c	0.65	0.12	0.20	0.03	1.00	3.28	4.28	23.4
Field 11 (Łupianka Stara)	Shoulder	11a	17.90	0.91	0.31	0.04	19.15	0.45	19.60	97.7
	Midslope	11b	6.93	0.58	0.11	0.01	7.62	0.86	8.48	89.8

TEB^1 – total exchangeable bases, EA^2 – exchangable acidity, BS^3 – base saturation.

The mean values of selected properties and particle size distribution were compared for the plough horizons of soils from slope shoulders (profiles 1a, 3a, 5a, 7a, 9a, 10a, 11a) and deluvial soils from the footslope (profiles 1b, 3b, 5c,7b, 10c, 12b). Mean C_{org} concentration for plough horizons of soils on the slope shoulder is 4.77 g kg^{-1}, while in the plough horizons of deluvial soils in the footslope the organic carbon content is higher and amounts to 7.97 g kg^{-1} (Table 6). The mean value for TN in Ap horizons sampled from the slope shoulder is equal to 0.94 g kg^{-1} and increases on the footslope position to 1.15 g kg^{-1}. However, a comparison of soils from the same slope revealed that the amount of TN is not correlated with the slope position. The mean values of TP and $K_{H_2SO_4-H_2O_2}$ are similar in soils from both studied positions on the slope. The median of pH (in H_2O and KCl) calculated for deluvial soils is lower than that calculated for soils on the slope shoulder. The

TABLE 6. COMPARISON OF TEXTURE, CHEMICAL AND PHYSICOCHEMICAL FEATURES OF PLOUGH HORIZONS IN SOIL LOCATED ON SHOULDER AND FOOTSLOPE

Features		Soils located on slope shoulder[1]	Soils located on footslope[2]
		n=7 mean	n=6 mean
Texture	sand 1.0-0.05 (%)	76±7	73±7
	silt 0.05-0.002 (%)	12±5	15±6
	clay <0.002 (%)	11±3	12±4
C_{org} (g kg^{-1})		4.77±1.55	7.97±5.49
TN (g kg^{-1})		0.94±0.47	1.15±0.52
TP (g kg^{-1})		0.36±0.22	0.35±0.08
$K_{(H_2SO_4-H_2O_2)}$ (g kg^{-1})		1.26±0.69	1.17±0.45
C/N		5±3	7±2
pH[3]	in H_2O	6.56	6.05
	in KCl	5.70	5.05
Base cation	Ca^{2+} (cmol(+) kg^{-1})	6.09±6.03	2.98±2.28
	Mg^{2+} (cmol(+) kg^{-1})	0.46±0.31	0.49±0.39
	K^+ (cmol(+) kg^{-1})	0.17±0.08	0.13±0.06
	Na^+ (cmol(+) kg^{-1})	0.02±0.01	0.02±0.01
	TEB (cmol(+) kg^{-1})	6.73±6.30	3.62±2.43
	EA (cmol(+) kg^{-1})	2.92±2.41	4.20±2.66
	CEC (cmol(+) kg^{-1})	9.65±4.60	7.82±2.39
BS (%)		61.9±33.51	44.1±24.78

[1]Profiles 1a, 3a, 5a, 7a, 9a, 10a, 11a; [2]profiles 1b, 3b, 5c, 7b, 10c, 12b; [3]median.

mean concentration of Ca^{2+} in deluvial soils is 2.98 cmol(+) kg^{-1}, while the average exchangeable calcium concentration in soils from upper parts of slope is equal to 6.09 cmol(+) kg^{-1}. This results in higher mean exchangeable acidity in deluvial soils (4.20 cmol(+) kg^{-1}) than in soils located in upper slope positions (2.92 cmol(+) kg^{-1}). The mean concentration of Mg^{2+} is similar for Ap horizons of soils in the upper and lower part of the slope and is equal to 0.46 cmol(+) kg^{-1} and 0.49 cmol(+) kg^{-1}, respectively (Table 6). The mean concentration of K^+ in soils from the slope shoulder is 0.17 cmol(+) kg^{-1}, while the average K^+ concentration for deluvial soils is 0.13 K^+cmol(+) kg^{-1}. The mean base saturation in soils from the upper slope position (61.93%) is higher than the mean BS value for deluvial soils (44.12%).

DISSCUSION

The studies revealed that soils on the Narew River valley slopes ranging from 2.5 to 5.3% are eroded. The truncated profile with plough horizon underlain directly with the *argic* horizon is characteristic for eroded Luvisols [10, 14, 20]. On such gentle slopes tillage erosion prevails [10]. Deluvial deposits accumulated on the lower part of the fields suggest water and tillage erosion as factors affecting soil development. On such gentle slopes tillage erosion has a dominant impact over a larger portion of the field compared to water erosion [18]. Similar texture of soils in the upper and lower parts of the slope is one piece of evidence for tillage erosion as the main factor for soil downslope translocation on the gentle slopes. Water erosion is limited to rills created during ploughing. Similar erosion patterns have been observed in other undulating landscapes [9]. The behaviour of the water erosion process at a field boundary is complex and characterized by a high spatial and temporal variability. The fraction of the overland flow infiltrate near the field boundary and sediment is likely to be deposited here, especially in the rows tilled parallel to the field lower boundary, perpendicular to the slope [21]. Partial runoff overflows the boundary and the material is deposited on the meadows located on the toeslope next to arable land. These kinds of sediment depositional areas outside the field were observed in several places during the study period. It should be emphasized that the shallow groundwater level in the lower part of the slope also has an effect on the development and morphological features of soils located on the footslope. Features of gleyic process were found in several soils on the footslope. It should be also mentioned that in dry years, farmers tend to take to ploughing parts of their meadows located in the lower position of the slope adjacent to the lower border of the arable field. These soils were mainly affected by turf growing and shallow groundwater level and only partly by the sedimentation of eroded material.

The morphological features of plough horizons in various positions on the slope are affected by tillage erosion [9, 10] and water erosion has smaller impact [14]. The deluvial deposits thick to 110 cm on the footslopes are the main evidence for soil translocation along the slope. The chemical properties of soils located in various positions on the slope are less modified, mainly by tillage erosion. Studies of Kaźmierowski [11] revealed a small impact of tillage erosion on modification of chemical and physicochemical properties of Ap horizons. On steeper slopes the material transported downslope enriches the depositional areas in the footslope with phosphorus. The erosional soil enrichment in potassium and organic carbon in lower parts of the fields is small. The enrichment of soils in depositional areas in organic carbon was also observed by Szrejder [20] and Bieniek and Wójciak [4]. However, the differences in soils from upper slope and lower slope positions are not very pronounced due to the fact that they are mainly affected by tillage erosion. This type of erosion is important in sediment transport on gentle slopes [8]. The variability of TN, TP and $K_{H_2SO_4-H_2O_2}$ along the slope may be the effect of the differences in soil texture. This is suggested by the positive correlation between TN and percentage of silt.

The variability of pH both in upper and lower part of the slope may be related to soil texture and $CaCO_3$ content and to different calcium fertilizers rates. The correlation between pH and content of exchangeable calcium and magnesium as well as with the percentage of silt suggests big role of soil texture in pH level. Higher exchangeable acidity, lower pH values and CEC of soil in lower parts of fields is affected by the shallow groundwater level and faster movement of cations along the profile. Similar content of easily migrating elements in deluvial soils compared to soils in an upperslope position was found in the young glacial landscape [10]. Also, Gołębiowska *et al*. [6] confirmed the acidification of soils in the footslope position. The deluvial soils from the Mazurian Lake District have higher CEC in comparison to eroded soils on the slope, but their Ap horizons have lower pH values and higher exchangeable acidity which is affected by blocking the ion exchange of slightly acidic binding of carboxylic groups in sorption complex by hardly exchangeable hydrogen [3].

CONCLUSIONS

1. Soils on the gentle slopes of the Narew River valley are modified by the processes of tillage and water erosion. The dominant Luvisols in the upper part of the slope are truncated and their *luvic* horizon is incorporated into the plough horizon. On the footslopes, Mollic Gleysols soils developed with thick deluvial deposits (up to 110 cm).

2. Similar texture of soils and TN, TP and $K_{H_2SO_4-H_2O_2}$ content in both slope positions are evidence of tillage erosion as the main factor of soil downslope translocation on these gentle slopes.

3. The differences in physicochemical properties of soils located in various positions on the slope are more distinct. Higher exchangeable acidity, lower pH values and CEC of soil in lower parts of fields is affected by the shallow groundwater level and faster movement of cations along the profile.

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CECHY MORFOLOGICZNE I WŁAŚCIWOŚCI CHEMICZNE POZIOMÓW ORNOPRÓCHNICZNYCH GLEB W RÓŻNYCH POŁOŻENIACH NA ZBOCZU

Badania cech morfologicznych i chemizmu poziomów Ap gleb przeprowadzono na łagodnych zboczach doliny Narwi. W górnych częściach zboczy wykształciły się przede wszystkim gleby płowe o składzie granulometrycznym, piasków gliniastych lub glin piaszczystych, natomiast u podnóży zboczy występują gleby deluwialne czarnoziemne o podobnym składzie granulometrycznym i miąższości osadów deluwialnych do 110 cm. Skład granulometryczny poziomów ornopróchnicznych oraz ich zasobność w ogólne formy azotu, fosforu i potasu są podobne. Średnia zawartość ogólnych form azotu, fosforu i potasu wynosi w glebach położonych w górnej części zboczy odpowiednio 0,94, 0,36 i 1,26 g kg^{-1}, natomiast zawartość omawianych pierwiastków w glebach u podnóży zboczy wynosi 1,15, 0,35 i 1,17 g kg^{-1}. Poziomy ornopróchniczne gleb położonych u podnóży zboczy charakteryzują się kwaśniejszym odczynem. Gleby te są bardziej zasobne w węgiel organiczny. Średnia kwasowość hydrolityczna gleb położonych w górnej części zboczy wynosi 2,92 cmol(+) kg^{-1}, podczas gdy gleby podnóży zboczy charakteryzują się wyższą średnią wartością H_h równą 4,20 cmol(+) kg^{-1}. Duża miąższość osadów deluwialnych, podobny skład granulometryczny gleb w obu położeniach oraz niewielkie wzbogacenie poziomów Ap gleb zlokalizowanych u podnóży zboczy wskazuje na erozję uprawową jako główny czynnik przemieszczania materiału glebowego wzdłuż stoku.