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Morphology and selected properties of alluvial soils in the Odra River valley, SW Poland

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Abstract

The aim of the research carried out in the middle Odra valley, SW Poland, was to demonstrate the diversification of the morphology and selected properties of alluvial soils used for agricultural purposes and to assess their changes in the conditions of river regulation. The research was carried out in the low valley of the Odra River in its middle course downstream from Wrocław. Four soil profiles were exposed on the right bank of the Odra River on the Holocene floodplain terrace. Two profiles were located in the embanked zone used as grassland, and next two profiles were located outside the embankments in the areas used as arable lands. Soils were described, sampled and analyzed using the standard procedures in soil science. The studied soils differed in the morphological features of individual genetic horizons, the location of the groundwater table, the extent and intensity of redoximorphic features, as well as the depth and stratification of the alluvial parent material. This was reflected in the classification: Eutric Fluvic Gleysol (Pantoloamic), Eutric Gleyic Fluvic Cambisol (Ochric), Eutric Fluvic Stagnic Cambisol (Ochric), Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic). In the area of this research, the effects of terrain micro-relief former meandering of the river are clearly visible, which is manifested by the heavier texture of the soils situated presently close to the river and lighter texture of soils located further away. The deep occurrence of the groundwater table in soils located in the slightly higher situated sites results in a lowering of vertical range of gleyic properties and their replacement with stagnic properties in the middle part of the soil profile. The change of the water regime contributed to the increase of biological activity, and thus the development of the *cambic* horizon. The transformation of alluvial soils used as permanent grassland into arable soils causes not only a decrease in the soil organic carbon content in the soil, but also a decrease in the unit sorption capacity of humus compounds.

1. Introduction

River systems integrate the structure, dynamics and functioning of all landscape components (Forman and Godron, 1981). River fluvial activity, the drainage of a river basin, climate and hydrological connectivity with all abiotic and biotic elements of the environment are the factors that determine the considerable dynamics of riverside habitats (Grevilliot et al., 1998; De Becker et al., 1999; Decocq, 2002; Ward et al., 2002; Langhans et al., 2006). The functional systems of plant communities, that are typically characterized by toposequence, correspond to the diversity of habitat conditions in the river valleys. They are related to the zoning and stratification of the hydrogeochemical conditions of the valleys and are subject to continuous succession processes, intensified by human activity (Czarnecka and Pelc, 2007; Cieśla, 2009).

Fluvial processes occur on all continents and in all climatic zones (Chartlon, 2008), and the high natural fertility of the deposited river sediments was recognized thousands of years ago. The river, as an independent ecosystem, affects the waterside areas in various ways (Bullinger-Weber and Gobat, 2006). As a result of its flow, various side branches, oxbow lakes and wet sites in depressions of the terrain are formed, and the riparian strip itself is a specific contact zone of the flowing waters and the land. The river influences the shaping of all habitats in the river valley (forests, meadows, wetlands), which form a highly diverse mosaic (Chojnicki, 2002; Roy-Rojewski and Banaszuk, 2004; Ligęza, 2016).

The most intense deposition of sediments takes place directly at the river bed and in the lowest sites of the floodplain, and the amount of accumulated material decreases with the distance from the main river bed (Falkowska and Falkowski, 2010; Kholodov, 2010). According to some authors, the differentiated grain size distribution in the profiles of floodplain soils depends primarily on the distance from the river bed and the valley's microrelief (Klimek, 1974; Laskowski, 1986). Hence, on the floodplain of the regulated river, sandy alluvial sediments are deposited closest to the riverbed, silty alluvial soil occur farther, while clay alluvial soils are formed farthest away from the river (Richardson and Edmonds, 1987; Leopold et al., 1995). The wider the valley, the greater the lithological diversity of alluvial soils and the greater the impact of the micro-relief of the floodplain terrace (Roj-Rojewski and Hryniewiecka, 2009). On the other hand, Banaszuk (1987), who examined alluvial soils in the Narew floodplain valley, found that their distribution and lithological-facial development showed a close relationship with the geomorphology of the area, but had little in common with the present spatial system of the river bed.

Channelization of the Odra River performed in the 19th century and the construction of flood embankments at the beginning of the 20th century initiated the large-scale regulation of the Odra valley and resulted in far-reaching changes of the natural conditions in the valley. A significant part of the riparian forests was separated from the river by hydrotechnical facilities (flood embankments), which effectively prevented their flooding and initiated the changes of vegetation known as transformation into oak-hornbeam communities. Principles of flood protection in the so-called inter-embankment zone involved the removal of trees in this zone which resulted in favoring its use firstly as meadows and then for agricultural purposes. On the other hand, the commissioning of the hydroelectric power plant in Brzeg Dolny (1958) resulted in a lowering of the Odra bottom level and caused the lowering of the groundwater table in alluvial soils in the areas downstream the dam.

Alluvial soils belong to those soils which are subject to the most intense anthropogenic transformations (Kabała et al., 2011; Labaz and Kabala, 2016; Kobierski and Banach-Szott, 2022). As a result of the regulation of the flow of rivers and limitation (or even complete elimination) of floods, the natural deposition process of the alluvial soil substrate is inhibited. Drainage of river valleys causes a series of usually (but not always) unfavorable changes in the soil, which over time are reflected in the environment and economy (Jonczak et al., 2016; Kawałko et al., 2017). Transformations of habitats and soils in the regulated river valley are highly diverse both in the cross-sections and along the river course, which results from the relationships of the soils with the groundwater level and the alluvial process (Banaszuk, 1987; Roj-Rojewski and Banaszuk, 2004; Kabała et al., 2011).

The aim of the research carried out in the middle Odra valley was to demonstrate the diversification of the morphology and selected properties of alluvial soils used for agricultural purposes and to assess their changes after river regulation.

2. Materials and methods

2.1. Study area

The research was carried out in the low valley of the Odra River in its middle course downstream from Wrocław (Fig. 1). The Pleistocene terraces of the Odra river, shaped by fluvioglacial water of Weichselian glaciation are mainly built of sands and gravels, while the Holocene terraces often contain fine-textured interbeddings. The surface layers of floodplains are typically built of loamy or silty soil materials (Pawlak et al., 2008; Marks, 2011; Kabała, 2015; Kawałko et al., 2021). Channelization of the river in the 19th century, the construction of embankments at the beginning of the 20th century and the large-scale regulation of the Odra valley was effective in protecting the zones out of embankment from floods and generally led to lowering of the groundwater table (Głuchowska and Pływaczyk, 2008; Ciszewski and Czajka, 2015). These changes created favorable conditions for the agricultural use of soils and replacement of riparian forests by farmlands, and pastures by plowed fields (Kabała et al., 2011). The inter-embankment areas are also mostly used as grasslands and arable land.

2.2. Soil sampling and analysis

This research is based on the analysis of soil materials collected from 4 soil profiles situated on the right bank of the Odra along the transect running north-east from the river. Profiles 1 and 2 were located in the embanked zone used as grassland, while profiles 3 and 4 were located outside the embankments in the areas used as arable lands (Fig. 1).

Soil morphology was described following the Annex to the Polish Soil Classification (Kabała et al., 2019). In particular, attention was paid to the type, form, and intensity of soil gleying and redox precipitations, as well as soil structure and colour in the surface and subsurface horizons. Soils were classified using the WRB system (IUSS Working Group WRB, 2015), and the Polish Soil Classification (Kabała et al., 2019). Soil colour was determined using the Munsell Color Charts. Bulk soil samples were collected from all distinguished horizons. Soil samples were dried, crushed and sieved, and the basic properties were determined in the fine earths (<2 mm). Particle-size distribution was determined using sieves (for sand fraction) and a hydrometer method (for silt and clay fraction) (Papuga et al., 2018). Soil pH was measured potentiometrically in distilled water and 1 M KCl, at a soil: liquid ratio of 1:2.5 (v/v) (van Reeuwijk, 1992). Soil organic carbon (SOC) was measured by dry combustion using a Ströhlein CS-mat 5500 analyzer (samples did not contain carbonates; thus, no pretreatment was applied). The total nitrogen content (TN) was measured by the Kjeldahl method using a Büchi semi-automated analyzer (K439+K350). The hydrolytic acidity (Ha) was determined by extraction with 0.5M $Ca(OAc)_2$ (soil:solution 1:10) and potentiometrical titration up to pH 7.8 (Kabała and Karczewska, 2017). Exchangeable base cations (EBC, i.e. the sum of Ca^{2+}, K^+, Mg^{2+}, Na^+) were extracted using buffered 1 M NH_4OAc at pH 7 and analyzed by atomic absorption (Mg) and emission (Ca, K, Na) spectrophotometry. The cation exchange capacity (CEC) and base saturation (BS) were calculated using the sum of exchangeable base cations (EBC) and the hydrolytic acidity (Ha).

For both groups of soils, used as grassland and as arable lands, the relationships between the exchangeable base cations (EBC) and the cation exchange capacity (CEC) on the one hand, and the content of clay fraction and soil organic carbon (SOC) were analyzed. For this purpose, a multiple correlation analysis was performed. Since it was found that the single correlation coefficients calculated for SOC were higher for logarithmic values than for the original SOC values, therefore, for the calculation of the multiple correlation it was assumed that the independent

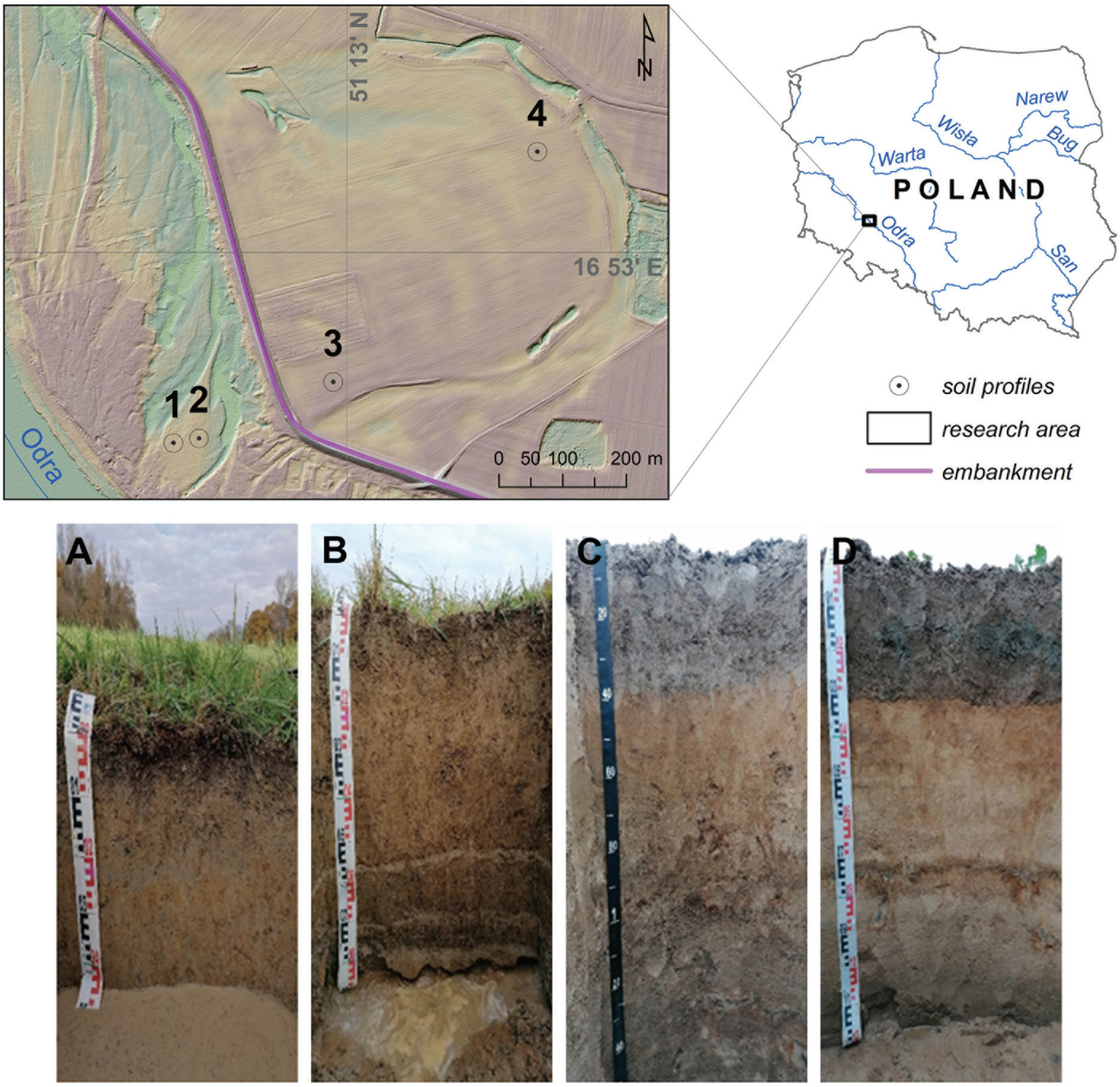

Fig. 1. Location and morphology of the studied soils: A – Profile No 1: Eutric Fluvic Gleysol (Pantoloamic), B – Profile No 2: Eutric Gleyic Fluvic Cambisol (Ochric), C – Profile No 3: Eutric Fluvic Stagnic Cambisol (Ochric), D – Profile No 4: Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic)

variable should have the form X = clay% + a * ln (SOC%), where "a" is the factor that determines the relative effect of ln (SOC%) on the exchangeable base cations (EBC) and the cation exchange capacity (CEC), in relation to the effect of the clay fraction content. The values of the coefficients "a" were selected in such a way as to obtain the maximum correlation coefficients r between the independent variable X and the dependent variables.

3. Results and discussion

The studied soils differed in the morphological features of individual genetic horizons, the location of the groundwater table, the extent and intensity of redoximorphic features, as well as the depth and stratification of the alluvial parent material (Fig. 1). According to the WRB Classification (2015), the soils represented the following types: Eutric Fluvic Gleysol (Pantoloamic) – profile 1, Eutric Gleyic Fluvic Cambisol (Ochric) – profile 2, Eutric Fluvic Stagnic Cambisol (Ochric) – profile 3 and Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic) – profile 4 (Table 1). Gleba gruntowo-glejowa typowa (GGt), Mada brunatna gruntowo-glejowa (BFgg), Mada brunatna próchniczna opadowo-glejowa (BFhog) and Mada rdzawa (BFrd), respectively. Below, there is a more detailed description of soil morphological features.

Profile 1 – Eutric Fluvic Gleysol (Pantoloamic) was situated in the inter-embankment, in the depression of the terrain forming the former oxbow lake (on recent meander deposits) (108.7 m a.s.l.) (Fig. 1). A groundwater level was as shallow as at a depth of 45 cm. The 10 cm thick horizon A with a dark color (2.5Y 3/1 very dark gray color) showed a granular structure, and the features of gleyic properties were visible (Table 1). In the horizon G with an angular structure, the gleyic features occupied more than 50% of the surface. The distinguished soil horizons had a silty-clay texture, and differed in color and structure.

Table 1
Selected morfological properties and texture of studied soils

Profile No.	Soil horizon	Depth [cm]	Munsell-Color Charts	Reductomorphic colour	Oxymorphic colour	Structure	Percentage content of [mm]			Texture class
							2.0–0.05	0.05–0.002	<0.002	
Eutric Fluvic Gleysol (Pantoloamic) / Gleba gruntowo-glejowa typowa										
1	Adgg	0–10	2.5Y 3/1	–	10% 5YR 4/6	granular	14	55	31	gpyi / SiCL
	G1	10–25	2.5Y 5/1	80% 2.5Y 5/1	20% 2.5YR 4/6	angular	13	54	33	gpyi / SiCL
	G2	25–45	10YR 5/2	60% 10YR 5/2	40% 2.5Y 4/7	angular	10	61	29	gpyi / SiCL
Eutric Gleyic Fluvic Cambisol (Ochric) / Mada brunatna gruntowo-glejowa										
2	Ad	0–10	10YR 3/3	–	–	granular	17	59	24	pyi / SiL
	ABg	10–20	7.5YR 4/3	5% 2.5Y 5/2	10% 7.5YR 3/4	angular	16	62	22	pyi / SiL
	Bwg	20–45	10YR 4/3	20% 2.5Y 5/2	20% 7.5YR 3/4	angular	13	57	30	gpyi / SiCL
	BCg	45–55	10YR 6/2	50% 2.5Y 5/2	50% 7.5YR 4/6	angular	12	66	22	pyi / SiL
	IIG	55–58	10YR 5/2	–	10% 7.5YR 4/6	loose	81	13	6	pg / LS
	IIIG1	58–75	2.5Y 5/2	80% 2.5Y 5/2	10% 7.5YR 4/4	angular	16	63	21	pyi / SiL
	IIIG2	75–85	2.5Y 5/2	80% 2.5Y 5/2	10% 7.5YR 4/4	angular	24	53	23	pyi / SiL
	IVG1	85–100	10YR 6/3	–	–	loose	98	1	1	pl / S
	IVG2	100–150	10YR 5/2	–	–	loose	98	1	1	pl / S
Eutric Fluvic Stagnic Cambisol (Ochric) / Mada brunatna próchniczna opadowo-glejowa										
3	Ap	0–30	10YR 4/2	–	–	granular	61	26	13	gl / SL
	A2g	30–38	10YR 4/2	20% 10YR 5/4	20% 7.5YR 3/4	subangular	61	24	15	gl / SL
	IIBwg	38–70	10YR 4/4	20% 10YR 5/4	15% 7.5YR 4/6	subangular	76	15	9	gp / SL
	IIICrg	70–100	7.5YR 3/4	30% 10YR 5/4	25% 7.5YR 4/6	loose	87	8	5	pg / LS
	IIIC	100–130	10YR 5/4	5% 10YR 5/4	5% 7.5YR 4/6	loose	99	0	1	pl / S
	IIICgg	130–150	10YR 5/4	25% 10YR 5/4	15% 7.5YR 4/6	loose	98	0	2	pl / S
Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic) / Mada rdzawa										
4	Ap	0–30	10YR 4/2	–	–	granular	57	25	18	gl / SL
	IIBvg	30–45	10YR 4/4	–	–	loose	94	2	4	pl / S
	IIBCg	45–60	10YR 5/4	5% 10YR 4/1	5% 7.5YR 3/4	loose	95	2	3	pl / S
	IICg1	60–72	10YR 5/3	–	15% 7.5YR 3/4	loose	98	0	2	pl / S
	IICg2	72–78	10YR 4/3	10% 10YR 4/1	5% 7.5YR 3/4	loose	81	13	6	pg / LS
	IICg3	78–110	10YR 6/3	10% 10YR 4/1	<5% 7.5YR 3/4	loose	99	0	1	pl / S
	IICgg	110–150	10YR 5/2	–	–	loose	98	0	2	pl / S

Explanation: Texture class according to PTG 2008 and USDA:
gpyi – glina pylasto-ilasta; pyi – pył ilasty; pg – piasek glinasty; pl – piasek luźny; gl – glina lekka; gp – glina piaszczysta; SiCL – silty clay loam; SiL – silt loam; SL – sandy loam; LS – loamy sand; S – sand;

Profile 2 – Eutric Gleyic Fluvic Cambisol (Ochric), was located (108.7 m a.s.l.), at a distance of 15 m from the profile 1 (Fig. 1). The groundwater table was at the depth of 85 cm. There was a clear stratification in the profile. The humus horizon, with a granular structure and a thickness of 10 cm, was dark in color (10YR 3/3 dark brown color) and did not show redoximorphic features (Table 1). Redoximorphic spots were only observed in a well-developed Bwg horizon (25 cm) with a brown color (10YR 4/3) and the angular structure. The profile also included ABg and BCg transitional horizons, which are indicative of an intensive development of cambic horizon. Beginning from a depth of 55 cm, downward, the color and structure of soil varied due to its different texture, and the features of the gleyic properties that covered approx 80% of the surface. There were numerous small plant roots present in the soil to the depth of 75 cm, and numerous earthworms were found in the 0–45 cm layer.

Profile 3 – Eutric Fluvic Stagnic Cambisol (Ochric), was situated in the part of the floodplain (109.4 m a.s.l.) thas was cut off from the river bed by a flood embankment, inside the old meandering bend (near the edge of the oxbow lake channel), on a slightly elevated strip of land. Groundwater occured at a depth of 170 cm (Fig. 1). There was a clear stratification in the profile. A well-developed Ap horizon (10YR 4/2 dark grayish brown color), with a thickness of 38 cm, was bipartial because of different plowing depths that was applied in that area, and the duality of the horizon was highlighted by the presence of stagnic properties and a different structure (Table 1). In the profile 3, the 42 cm Bwg horizon with dark yellowish brown color (10YR 4/4) and subangular structure was distinguished. The stagnic

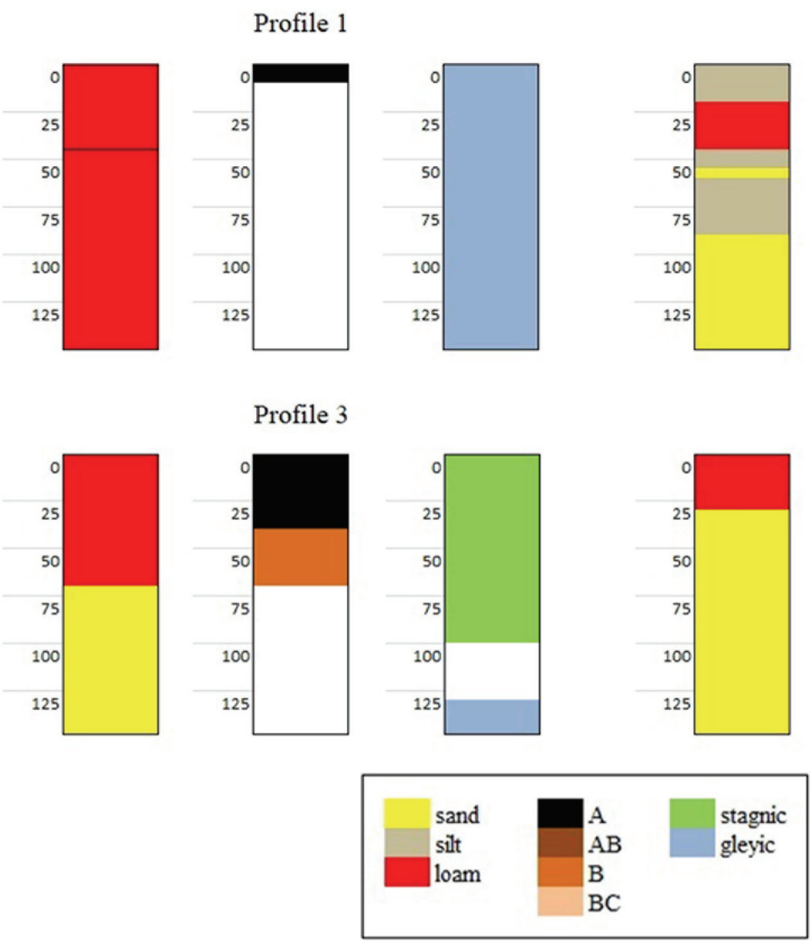

Fig. 2. Selected morphological features of studied soils: texture layering in the soil profiles, thickness of A, AB, B and BC horizons (in centimeters), the presence and depth of stagnic and gleyic properties

properties (a mosaic of colors – reddish-brown interiors of aggregates and grey surroundings) were visible down to a depth of 100 cm. In the lower part of the profile, despite the sandy texture, gleyic features were apparent (the colors tended to change concentrically around the root canals or along them with black spots in former rootlets, grey interiors and rusty surroundings). There were numerous earthworms present in the soil down to a depth of 70 cm.

Profile 4 – Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic), was located on a higher floodplain terrace (109 m a.s.l.), at the distance of 100 m further north of the profile 3 (Fig. 1). The Ap horizon with 10YR 4/2 dark grayish brown color had a thickness of 30 cm and a granular structure (Table 1). In some places, in the central part of this horizon, the spots with very dark gray color (5Y 3/1) were present, which was created by plowing up manure and related higher soil moisture. Under the Ap horizon, a 15 cm horizon Bvg with a subangular structure was distinguished. At a depth of 60–110 cm, the stagnic features were visible, while the gleyic features were visible deeper, which was caused by the presence of groundwater at a depth of 130 cm. An a few centimeter-deep brown layer (IIBCg) was an apparent symptom of soil stratification, as were the slightly thicker layers underneath. Numerous earthworms were present in the 0–45 cm layer of soil.

The soil texture in individual layers of the profiles examined was noticeably differentiated, and varied from sand to silty-clay, which is typical for alluvial soils of Central Europe. The exception was the profile 1, in which the texture of silty-clay loam occurred in the entire shallow soil profile (Table 1, Fig. 2). The greatest differentiation of texture was observed in the profile 2, with its upper and middle parts formed of material with relatively heavy texture (loam and silty-clay loam), while the sand occurred below a depth of 85 cm (except for a thin sandy interlayer at a depth of 55–58 cm). The profiles 3 and 4, located in the bend of the old oxbow lake, were characterized by a much lighter, loamy-sand texture.

The pH values of the studied soils, measured in suspension in H_2O, ranged from 4.96 (Profile 1, Adgg) to 6.54 (Profile 3, IIICgg) and apparently tended to increase with the depth (Profile 1 and 3), or showed some differentiation in individual horizons (the profiles 2 and 4) (Table 2). The pH values were higher in soils used as arable lands compared to grasslands.

The content of soil organic carbon (SOC) in the surface soil horizons (operationally defined taking into account the weighted averages for the 30 cm soil layer) was clearly higher in grassland soils and had the values of 26.7 $g \cdot kg^{-1}$ (Profile 1) and 17.8 $g \cdot kg^{-1}$, respectively. In the Ap horizons of arable soils, the related values were similar in both soil profiles, and did not exceed 11.5 $g \cdot kg^{-1}$.

Table 2
Selected physico-chemical properties of studied soils

Profile No.	Soil horizon	Depth [cm]	pH		SOC	TN	C:N	Ha	EBC	CEC	BS
			H_2O	1 M KCl	[g·kg^{-1}]			cmol(+)kg^{-1}			[%]
Eutric Fluvic Gleysol (Pantoloamic) / Gleba gruntowo-glejowa typowa											
1	Adgg	0–10	4.96	3.91	48.6	2.8	17,3	9.87	15.57	25.44	61.19
	G1	10–25	5.25	3.70	18.6	1.2	15,6	6.02	16.76	22.77	73.58
	G2	25–45	5.28	3.68	7.7	0.4	18,8	4.19	13.10	17.29	75.77
Eutric Gleyic Fluvic Cambisol (Ochric) / Mada brunatna gruntowo-glejowa											
2	Ad	0–10	5.02	3.75	28.8	1.9	15,6	7.51	13.53	21.04	64.31
	ABg	10–20	5.29	3.73	15.3	1.0	15,0	5.09	13.68	18.77	72.89
	Bwg	20–45	5.36	3.66	9.2	0.5	19,4	4.32	12.18	16.50	73.85
	BCg	45–55	5.59	3.80	7.0	0.3	20,6	3.25	10.65	13.90	76.61
	IIG	55–58	5.29	4.12	2.3	n.d.	n.d.	0.83	2.93	3.76	77.91
	IIIG1	58–75	5.23	4.02	6.1	0.4	17,2	2.91	11.83	14.74	80.26
	IIIG2	75–85	5.26	4.06	5.8	0.3	20,4	2.86	11.16	14.02	79.60
	IVG1	85–100	5.53	4.65	1.1	n.d.	n.d.	0.03	0.76	0.78	96.80
	IVG2	100–150	5.53	4.49	9.0	n.d.	n.d.	0.09	0.71	0.80	88.73
Eutric Fluvic Stagnic Cambisol (Ochric) / Mada brunatna próchniczna opadowo-glejowa											
3	Ap	0–30	5.67	4.62	11.4	1.0	11,5	1.99	7.19	9.17	78.36
	A2g	30–38	5.80	4.67	9.9	0.8	12,3	1.83	7.61	9.44	80.61
	IIBwg	38–70	6.17	4.74	3.4	0.3	13,3	0.67	5.13	5.79	88.52
	IIICrg	70–100	6.34	4.98	2.2	n.d.	n.d.	0.30	2.92	3.22	90.67
	IIIC	100–130	6.48	5.54	7.0	n.d.	n.d.	0.02	0.77	0.79	97.46
	IIICgg	130–150	6.54	5.75	7.0	n.d.	n.d.	0.01	0.91	0.92	98.92
Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic) / Mada rdzawa											
4	Ap	0–30	6.42	5.41	11.5	1.0	11,7	1.39	11.53	12.92	89.24
	IIBvg	30–45	6.14	5.11	2.5	n.d.	n.d.	0.39	3.01	3.40	88.53
	IIBCg	45–60	6.28	5.23	2.3	n.d.	n.d.	0.25	2.41	2.66	90.59
	IICg1	60–72	6.28	5.21	6.0	n.d.	n.d.	0.09	0.92	1.00	91.53
	IICg2	72–78	6.15	4.93	2.0	n.d.	n.d.	0.49	3.16	3.65	86.56
	IICg3	78–110	6.40	5.28	0.6	n.d.	n.d.	0.05	0.61	0.66	93.16
	IICgg	110–150	6.40	5.48	0.7	n.d.	n.d.	0.05	1.14	1.19	95.79

Explanation: SOC – soil organic carbon; TN – total nitrogen; Ha – hydrolytic acidity; EBC – exchangeable base cations; CEC – cation exchange capacity; BS – base saturation; n.d. – not detected;

The content of total nitrogen (TN) in grassland soils was 2.8 g·kg^{-1} (Profile 1) and 1.9 g·kg^{-1} (Profile 2), respectively, while in arable soils, TN was much lower, at the level of 1 g·kg^{-1}. Such values of the above parameters determined the values of C:N ratio, which was much higher, i.e. at the level of 17.3:1 and 15.6:1, in grassland soils compared to arable soils, where it was assessed as 11.6:1 (Table 2).

The hydrolytic acidity (Ha) of the analyzed soils generally tended to decrease with increasing depth, except for the thin layers with a texture strongly different from that of the adjacent horizons, which disturbed this tendency (Table 2). The values of Ha were in grassland soils higher than those in arable soils, and ranges from 0.03 cmol(+)kg^{-1} (Profile 2, IVG1) to 9.87 cmol(+)kg^{-1} (Profile 1, Adgg). In the arable soils, the Ha ranged from 1.99 cmol(+)kg^{-1} (Profile 3, Ap) to 0.01 cmol(+)kg^{-1} (Profile 3, IIICgg).

The cation exchange capacity (CEC) of the studied soils varied both within the individual genetic horizons and between the profiles (Table 2). The highest values were typical for the surface soil horizons, rich in organic matter, and ranged from 9.17 cmol(+)kg^{-1} (Profile 3) to 25.44 cmol(+)kg^{-1} (Profile 1). The subsurface horizons were characterized generally by lower CEC values that represented a wide range of values, related mainly to soil content of clay fraction. The grassland soils had a higher CEC compared to arable soils. All examined soils showed a relatively high level of base saturation (BS) (Table 2). There were some differences between the genetic horizons within a given soil profile. The lowest saturation of the sorption complex with base cations (slightly above 60%) occured in the most acidic Ad horizons of grassland soils (Profiles 1 and 2), while the BS values of arable soils in the Ap horizons was over 78% (Profile 3) and over 89% (Profile 4). In all the profiles, the highest values of BS were found in the deepest soil layers.

The relationships between the EBC and CEC, on the one hand, and the independent variable that involved soil SOC and clay, constructed as previously described, on the other, were characterized by very high values of the correlation coefficients (Fig. 3a-d). If calculated separately for each soil profile, it was r = 0.9836 and r = 0.9943, respectively, for the grassland soils, and r = 0.9823 and r = 0.9943, respectively, for arable soils. Such high r values confirm the known fact that the cation exchange capacity of alluvial soils is shaped practically entirely by the content of clay fraction (called formerly in Polish soil science a "colloidal clay") and organic carbon (Laskowski, 1986; Chojnicki, 2002; Kawałko et al., 2011; Ligęza, 2016).

When analyzing the variability range of the EBC and the values of the coefficients "a" for alluvial soils used as grassland and arable lands, it can be seen that the SOC content had a greater impact on the EBC value in grassland soils than in arable soils (the 'a' values were assessed as a = 4.88 and a = 2.64 for meadow soils and arable soils, respectively). A similar effect, i.e. the differentiation between grassland and arable soil, was even more pronounced if considering the CEC parameter. In this case, the values of the parameter a were: 15.56 for grassland soils, and only 0.90 for arable soils (Fig. 3a-d).

The observed system of dependencies indicates that the transformation of alluvial soils used as permanent grassland

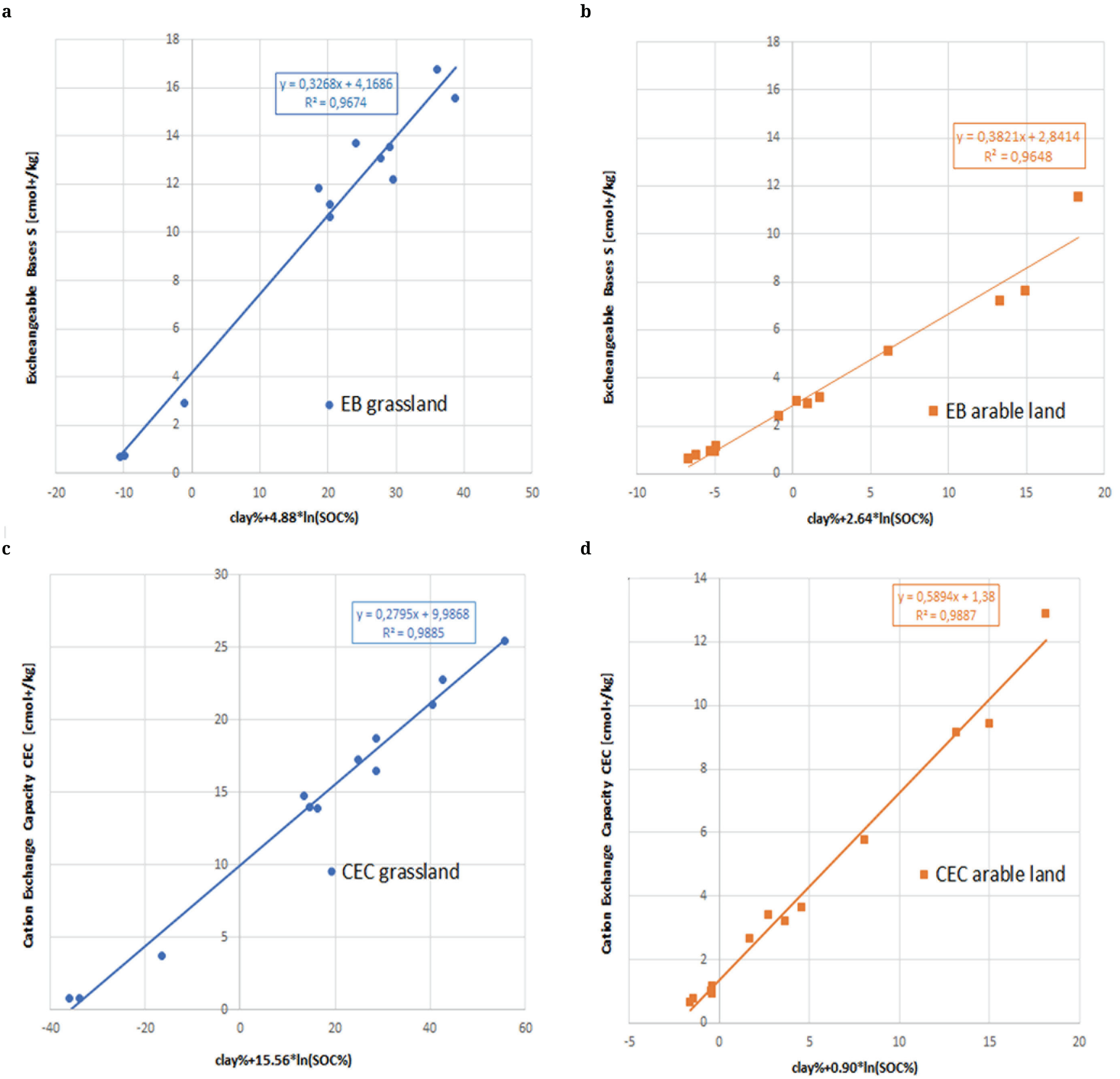

Fig. 3. Relationship between the exchangeable base cations (EBC) and the total cation exchange capacity (CEC) and the independent variable calculated on the basis of the content of clay and SOC in the soil for alluvial grassland and arable soils

into arable soils causes not only a decrease in the SOC content in the soil but also a decrease in the unit sorption capacity of humus compounds, both in relation to acidic and alkaline cations.

Lowering of the groundwater level and changing the soil moisture regime can often be observed in regulated river valleys, in soils with various types of use (Laskowski, 1986; Šimanský, 2018; Dezső et al., 2019; Kawałko et al., 2021). The changes are particularly well pronounced in the upper parts of the soil profiles.

When analyzing the morphology and classification of studied grassland soils that were located closer to the river bed, and arable soils, located slightly higher and separated by the embankment from the Odra river, the following factors were taken into account: texture, development of A and B horizons and oxidoreductive properties (stagnic or gleyic features). The grassland soils located on the recent meander deposits were characterized by a more compact texture compared to the arable soils located further away from the river. In all soils, the humus horizons had a well-developed (strong) granular structure. In grassland soils the thickness of the humus horizon was smaller (10 cm), the color was darker, and the SOC content was much higher than in arable soils.

Due to the thickness, texture, color and structure development, as well as biological activity, in three out of the four analyzed soil profiles, diagnostic *cambic* horizons were identified. The average thickness of the "proper" Bw (Bv) horizons was about 24 cm (15–32 cm). The average depth of the lower border of these horizons ranged from 45 to 70 cm. The transient BC horizons were additionally distinguished in two profiles (profiles 2 and 4), and the total thickness of B and transient BC horizons was 35 cm and 30 cm, respectively. The depths of the lower border of these horizons were 55 cm and 60 cm. The B horizons had an angular or subangular structure. The development of B horizons seems to be a natural result of biological activation of subsoil layers under aerobic conditions. Similar changes towards the development of Bw horizons were found in most drained alluvial soils (Chojnicki, 2002; Šimanský, 2018; Kawałko et al., 2021).

It should be stressed that all the soil profiles examined were located within the Holocene floodplain, where a strong influence of groundwater on soil properties can be expected. In fact, the gleyic properties, defined according to the Polish Soil Classification (Kabała et al., 2019), were identified in all the examined soils. In grassland soils the gleyic features were present in the whole soil profile or beginning from a depth of 45 cm, while in arable soils they appeared only at a depth of over 110 cm. Gleyic properties were not related to any specific class of soil texture, and were identified both in loams, silts and sands.

Stagnic properties were identified in three of four tested soils, which proves the phenomenon of lowering the groundwater table. The stagnic features occurred in the horizons with various texture, and were found either in the humus horizon or in the layers lying directly below it. In the arable soils, the stagnic properties occurred down to the depth of 100–110 cm and were also maintained in sandy soil layers. In two soils, with different uses, the layers with stagnic properties were in direct contact with those with gleyic properties lying underneath.

4. Conclusions

1. In the area of this research, the effects of terrain microrelief former meandering of the river are clearly visible, which is manifested by the heavier texture of the soils situated presently close to the river and lighter texture of soils located further away.
2. The deep occurrence of the groundwater table in soils located in the slightly higher situated sites results in a lowering of vertical range of gleyic properties and their replacement with stagnic properties in the middle part of the soil profile.
3. The change of the water regime contributed to the increase of biological activity, and thus the development of the *cambic* horizon.
4. The transformation of alluvial soils used as permanent grassland into arable soils causes not only a decrease in the soil organic carbon content in the soil, but also a decrease in the unit sorption capacity of humus compounds.
5. The physicochemical properties of the alluvial soils in the Odra Valley depend mainly on the microrelief and land use of soils.

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Morfologia i wybrane właściwości gleb aluwialnych w dolinie Odry

Słowa kluczowe

Terasa zalewowa
Osady aluwialne
Dolina Odry
Poziom wód gruntowych
Właściwości gleb

Streszczenie

Celem pracy było wykazanie zróżnicowania morfologii i wybranych właściwości gleb aluwialnych użytkowanych rolniczo oraz ocena ich przemian w warunkach regulacji rzeki. Badania prowadzono w nizinnej dolinie Odry w jej środkowym biegu poniżej Wrocławia. Wykonano 4 odkrywki glebowe na prawym brzegu Odry na holoceńskiej terasie zalewowej. Dwa profile znajdowały się w strefie międzywala i były użytkowane jako łąki, a dwa profile zlokalizowane poza obwałowaniami były użytkowane jako pola uprawne. Gleby zostały opisane, opróbowane i przeanalizowane stosując standardowe metody dla badań gleboznawczych. Badane gleby różniły się cechami morfologicznymi poszczególnych poziomów genetycznych, położeniem zwierciadła wody gruntowej, zasiegiem i intensywnością cech redoksymorficznych, a także głębokością i zachowaniem stratyfikacji aluwialnego materiału macierzystego. Znalazło to odzwierciedlenie w klasyfikacji: Eutric Fluvic Gleysol (Pantoloamic), Eutric Gleyic Fluvic Cambisol (Ochric), Eutric Fluvic Stagnic Cambisol (Ochric), Eutric Stagnic Fluvisol (Katoarenic, Ochric, Brunic). W rejonie prowadzonych badań wyraźnie widoczny jest wpływ mikrorzeźby terenu i zmian położenia osadów aluwialnych podczas meandrowania rzeki, co przejawia się zwięzłym uziarnieniem gleb znajdujących się obecnie blisko rzeki i lżejszym gleb położonych w dalszej odległości. Głębokie występowanie zwierciadła wody w glebach położonych na nieco wyższych elementach mikroreliefu spowodowało obniżenie pionowego zasięgu oglejenia gruntowego oraz zastępowanie go oglejeniem opadowym w środkowej części profilu glebowego. Zmiana reżimu wodnego przyczyniła się do wzrostu aktywności biologicznej, a tym samym rozwoju poziomu *cambic*. Przekształcenie gleb aluwialnych użytkowanych jako trwałe użytki zielone w gleby uprawne powoduje nie tylko spadek zawartości SOC w glebie, ale także obniżenie jednostkowej zdolności sorpcyjnej związków próchnicznych.